PHOTOGRAMMETRIC MAPPING WITH TOTAL STATION

Ph.D. THESIS

by

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A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY
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ROORKEE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"PHOTOGRAMMETRIC MAPPING WITH TOTAL STATION"**, in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy and submitted in the Department of Civil Engineering of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from January, 2010 to October, 2015 under the supervision of Dr. Kamal Jain, Professor, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

(SUSHIL KUMAR)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Kamal Jain)
Supervisor

Dated:

The Ph.D. Viva-Voce Examination of **Mr. Sushil Kumar**, Research Scholar, has been held on _ _ _ _ _ _ _ _ _ _

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ABSTRACT

"Photogrammetric Mapping with Total Station (PMTS)" is a research work carried out for the purpose of integrating a powerful processing component with robotic total station and a photogrammetric system. Primary objective of PMTS is to provide a cost effective solution for precise measurement of 3D point cloud.

The era of merging photogrammetry with angle measurement technology began with development of photo-theodolite (Porro, 1865). Up to till date all research works carried out in the area of PMTS are following the principle founded by developer of photo-theodolite. At present, photo-theodolite is replaced with advance robotic total station (IATS, 2005). Concept of scanning fuction was introduced by motorizing the total station (IASTS, 2007).

Present trends in Photogrammetry are shifting from satellite Photogrammetry towards Close Range Photogrammetry (CRP). TS technologies are trending towards more and more automation, long range measurement, speed, precision, miniaturization, energy efficient and intelligent behavior, etc. Parallel to this, people throughout the world are working to bring both the technologies more close to each other for providing cost effective solutions with high quality results.

Scanning Total Stations and Laser Scanning Devices have gained their popularity in providing solutions for 3D point cloud. The market is still dominated by photogrammetric systems for providing timely and cost effective solution of 3D point generation. All big manufacturer of the world had launched their high end products in the market. Laser scanner devices launched by them are Leica Scan Station C5, Trimble TX5, Topcon IP-S3, Topcon GLS 1500, Nikon insight L100, Leica Scan Station C10, Trimble TX8, FARO Focus 3DX 130, Topcon GLS 2000, Nikon XC65Dx, etc. Scanning Total Stations launched by them are Leica Viva TS 16, Trimble S7, Trimble S8, Trimble S9 and Topcon IS-3, etc. An integrated version of the two technologies is also available in the market e.g. Trimble XV comes with more advanced technologies. It is an example of Laser Scan Device integrated with Total Station.

Besides high end technology is available in the market, but these devices come to be black boxes for their users. No one knows the real technology used by them in these devices.

Moreover they are very costly (more than Rs. 40 lakhs). For realization of the concept of "Make in India" and to develop an indigenous technology, the concept of PMTS is introduced in the research work presented here.

In the first phase of development, reverse engineering was carried out for the purpose of understanding the existing technologies. After extracting internal architecture and instruction set of the robotic base, its overall control was transferred to computer system. For this purpose an interface and its library of subroutines were developed. It provides a service of communication channel between the robotic base and computer system. The interface also provides a facility to develop programs in high level language like C and Visual Basic, etc. for robotic applications of total station. This programming environment facilitates the users with a customizable environment for robotic applications at their own end. No more dependencies will be there on the manufacturer to fulfill day to day requirement after customized automation for the system.

The controller which comes with robotic base was not capable in fulfilling all the requirements of the PMTS. Thus a powerful controller was developed in C language followed by its revised version developed in Visual Basic language. In the revised version of controller, a better GUI environment was provided to the users of PMTS.

On successful implementation of first phase, its integration with photogrammetric system was carried out. The work was divided into two parts a) Mounting the camera on total station b) Optical orientation of camera system with telescope of total station. Major problem which is being faced throughout the world is to design the distortion model of the lens assembly. A new approach for modeling lens distortions was suggested for preparing distortion free model of camera used in PMTS. It was successfully completed and deployed. The concept of "WYSIWYG" (What you see is what you get) was used for modeling the distortions in lens assembly. In this phase of development, mapping of photo-coordinates to telescope coordinates were completed with precise results.

On successful integration of camera system with total station, a sub system responsible for image assisted total station movement was developed. An approach for precise object targeting was successfully developed and was deployed in PMTS. This subsystem helped in replacing the functions of telescope in total station. Problem of narrow view of telescope was completely solved. Camera plays a dual role in PMTS. In its first role, it captures high resolution images of the field for photogrammetric use. Secondly, it provides a wider live view of the field for setting the targets to be measured.

One problem was observed with scanning function. Total station was taking large amount of time for capturing field profile by using its scan function. Total stations are calibrated by the manufacturer for predefined values of environmental parameters like temperature, pressure and humidity, etc. There exists a provision of adjustment in measured values of target against change in value of environmental parameters. For it, current values of these parameters are to be entered in the total station for precise measurement of the target. During execution of scan function manual update of parameters is not feasible. A separate approach is proposed for online automatic updating environmental parameters into the total station.

At the time of testing phase of PMTS, the system stopped responding, during its execution, twice or thrice in a week. To overcome this, a deep behavioral study of the system was done to find out sources or cause of errors. It was found that certain time critical operations during parallel communication with multiple devices, absurd targets, communication with slower devices, HD camera, complex real time expressions, etc. were responsible for system failure. A further solution was suggested for removal of these problems. In the end, after deployment of solutions for system failure, PMTS became a reliable system and no further system failure was observed. As a byproduct of the research work, a new finding for fixing the factual precedence of brackets in BODMAS was successfully registered in the copyright office of India.

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LIST OF ABBREVIATIONS USED

1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional
APA	Average Pixel Angle
AR	Augmented Reality
ASCII	American Standard Codes for Information Interexchange
ASL	Auto Synchronized Laser
BPS	Bits Per Second
BS	Black Sheet
CAP	Computer Assisted Photogrammetry
CCD	Charge Coupled Device
CCS	Cartesian Coordinate System
CMOS	Complementary Metal Oxide Semiconductor
CRP	Close Range Photogrammetry
CTD	Circle of Threshold Distance
DC	Digital Camera
DGPS	Differential Global Positioning System
E	Easting
EBCDIC	Extended Binary Coded Interchange Codes
EDM	Electroic Distance Meter
ET	Extra Time
GB	Giga Byte
GCU	Geodimeter Control Unit
GCUO	Geodimeter Control Unit Output
GCP	Ground Control Points
GPS	Global Positioning System
GSD	Ground Sample Distance
G-XYZ	Ground coordinate system XYZ
H	Height
HA	Horizontal Angle
HD	High Density

HLL	High Level Language
IASTS	Image Assisted Scanning Total Station
IATS	Image Assisted Total Station
ICP	Image Control Point
ICSM	Image Controlled Station Movement
ID	Identification
IFC	Interface Circuit
IH	Instrument Height
IU	Interface Unit
LASER	Light Amplification by Stimulated Emission of Radiation
LSD	Laser Scanning Device
m	meter
MLS	Mobile LASER Scanning
mm	millimeter
MMS	Mobile Mapping System
MRTS	Manual Reflector-less Total Station
N	Northing
OATPA	Offset Adjusted Tangential Pixel Angle
PE	Projector Equation
PMTS	Photogrammetric Mapping with Total Station
PP	Principle Point
PP3D	Polygon Plane in 3D
ppm	parts per million
PTS	Photo Total Station
PTSS	Photo Total Station System
PU	Processing Unit
RB	Robotic Base
RBI	Robotic Base Input
RBO	Robotic Base Output
RCS	Rectangular Coordinate System
RE	Reverse Engineering
RRTS	Robotic Reflectorless Total Station
RS232	Recommended Standard no. 232

RTS	Robotic Total Station
SCS	Spherical Coordinate System
SD	Slope Distance
SfM	Structure from Motion
SLR	Single Lens Reflex
SP	Station Position
STS	Scanning Total Station
S-XYZ	image Space coordinate system XYZ
TCS	Total Station Coordinate System
TD	Threshold Distance
THA	Target Horizontal Angle
TPA	Tangential Pixel Angle
TS	Total Station
TT	Time Taken
TVA	Target Vertical Angle
T-XYZ	Total station coordinate system XYZ
UAV	Unmanned Aerial Vehicle
USB	Universal Serial Bus
VA	Vertical Angle
VGA	Video Graphics Array
VR	Virtual Reality
WB	White Board
WLAN	Wireless Local Area Network
WT	Wait Time
µm	Micrometer

Chapter 1

INTRODUCTION

1.1 Introduction

Dissatisfaction with inefficiencies of existing technologies is sufficient reason for improving them. In the past, surveying equipments have undergone a tremendous amount of enhancements and improvements. Total Station (TS) technology is also one of them. They have travelled a long path of improvements from conventional TS, 1977 to Robotic Reflector less TS (RRTS), 1995 (Table 2.1). Robotic TS (RTS) had provided sufficient automation for ease to use. Their controller came with most common inbuilt programs for robotic applications. But they failed to gain popularity as was to be expected. The reasons for it may be requirement of more expertise from the surveyor's end. Regardless of automatic features, targeting the object to a narrow view of the telescope remains a laborious task. Nowadays there is an increasing demand for full three dimensional data for planning, architecture, environmental analysis, tourism etc. (Shashi, M. et al., 2007). This increasing demand of precise 3D point cloud attracted attention towards alternate technologies. Photogrammetric systems are capable of performing a total field survey (3D point cloud) within a short period of time. On the other hand the task of measuring 3D point cloud with TS is an impossible task. Existing TS technology has one advantage over photogrammetric systems that they can perform precise measurement. Thus the integration of both the technologies can be a good alternative.

This search diverted the route back to era of photo-theodolite introduced by Porro in1865 (Scherer, M. et al., 2009) in it, a photogrammetric system was integrated with a theodolite. First mention of this hybrid instrument was observed in Italy. Porro in year 1865 and Pagnini in year 1884 of Italy have successfully developed this device (Luhmann, T. et al., 2006). In 1984, another old example of phototheodolite which became popular is Bridges-Lee phototheodolite, 1894. In those days analogue theodolites were in use for measuring angles, distances were measured by means of tape, chain, etc. All types of measurements were recorded manually in books of the survey. Now comes the era of digitization in instrumentations. First tacheometer capable of recording angles and distances along with their feature ID in digital form came into picture in 1968. This instrument was bulky in size and weight, but laid the foundation for modern TS. The first instance of TS came in 1977, in which distances were measured with reflectors. Later on, the problem of physically inaccessible targets gave rise to a new technology called reflector less TS in 1982. This reflector less technology became quite useful in providing freedom to measure accessible targets also. Image analysis method was another technology which dealt with the problem of fixing prism on inaccessible targets. This method of replacing prism was described by (Gottwald, R., 1987; Huep, W., 1988). Mixing of image data with theodolite information require optical alignment of theodolite optics with sensor optics as described by (Brandstätter, G., 1989; Huang, Y.D., 1992; Uffenkamp, V., 1993; Anai, T. et al., 2000; Zhang, Z. et al., 2003). Such arrangement creates parallactic errors and will create problems for objects in near range. One of the major drawbacks with photo theodolite was that it was manually driven. Motorizing it had provided a facility of automatic online measurement. Roic, M. (1996) designed an algorithm to register unremarkable 3D objects for visual observations. Mischke, A. (2000) measured unremarkable points on simple 3D objects by applying image processing methods. The work of (Fabiankowitsch, J., 1990; Wieser, A., 1995) encouraged these developments. They all took help of motorized Leica videotheodolite TM3000V. Seatovic, D. (2000) developed a control software for this instrument. This software was responsible for steering theodolite and capturing images followed by processing for automatic measurement. This research work of Wasmeier, P. (2002) on the Leica TCA2003 theodolite made use of internal CCD camera for ranges beyond close-range optics. Riechmann, W. (1992) had done a comparative study between a photogrammetric scanning system of resolution of 4200×6250 pixels and a video-theodolite system.

The concept of motorized TS was introduced in 1995 (Buchmann, P., 1996). It brought a revolution in TS reflector less technology. Concepts like intelligent tacheometry became possible with them; these were steered by programs of controllers; one man survey was an important feature in it. First TS (2005) with the integrated photogrammetric system was manually driven. It was named as IATS (Image Assisted TS) and was capable of extracting features from images. Motorized IATS came with added feature of scanning in 2007 and was given a name IASTS. It is still partially completed and lots of add on features are yet to be searched and added.

3D LASER scanners have gained popularity in present era. It is an active technology for capturing 3D point data. This technology completely reveals the merits of the laser, like strong coherence, good directivity and small divergence angle. They have good precision, high speed, simple in handling, strong ability against interference and convenient data processing. They can measure big sized, complex, irregular and non-standard entity in real-time. Multi-aspect and Omni-bearing perspectives on these data and analysis can be carried out easily. Laser scanning systems commonly use a line source or point source of light. Distance and angle made by a point on the surface of target are basic parameters of measurement in it.

Its comparison was carried out with passive systems (Photogrammetry) by (El-Hakim, S. F. et al., 1995). Their results show that its accuracy is poor for well defined targets against photogrammetric system (1: 3000 - 1:7500 for the ASL scanner compared to 1:20000 or better). In case of edges, again photogrammetric systems still provide better accuracy than active systems (1:15,000 or better compared to 1:7500 for the ASL scanner). Edge detection technique used by (Katiyar, S.K. et al., 2011) can be helpful in this case. A passive system like Photogrammetry has one disadvantage as compared with it is that they get affected significantly by the ambient light and may require several camera positions to extract 3-D coordinates on all edges. On smoothly structured and un-textured surfaces, it can provide a complete 3-D map with about 1:3500 accuracy while passive systems may not be able to acquire any measurements. It is because photogrammetric systems are not capable of measuring objects without distinguishing features. Therefore, the comparison is invalid in this case.

A study carried out by (Zhang, L**.,** 2009), on Forestry Resources Inventory, shows that applications of LASER scanned data suffers from problem of missing objects during automatic object detection from scanned data. Their study was based on automatic feature detection from data acquired with laser scanner. Their results show a relatively poor rate of 22% trees detected in a single scan and 52% detection rate by using multiple scans. In their study stem position was determined with high precision; breast height diameters had a standard deviation of 3.5cm and Standard deviation of tree height measurement was 5.6 meters. Thus, their study concluded with un-satisfactory results with this technology.

In LASER scanners quality and quantity of the reflected signal get influenced by multiple parameters like surface reflectivity, steepness angle of the surface, standoff distance, ambient lighting condition and incidence angle. For estimating amount of influence, a study of these parameters was carried out (Manorathna, P. et al., 2014).

Laser Scanning Device (LSD) when compared with Scanning Total Station (STS), both has same working principle, i.e. measurement of angles and distance using laser technology to find polar coordinates of target. Speed of LSD is fast as compared with STS. One day work of STS can be done within a time period of one to two hours with LSD (Haddad, N. et al., 2007). Accuracy of LSD is poor; measurement error will be in the range 0.2 to 2 cm (Haddad, N. et al., 2007). Cultural heritages are the most suitable places for LSD, but not for STS due to environmental disturbances. Merge of data, scanned from LSD and STS to increase accuracy in not possible (Haddad, N. et al., 2007). Processing of the huge amount of data obtained from LSD is not possible because of non availability of software for handling such amount of data. Therefore, for processing it some reduction in data size will be required.

(Pflipsen, B., 2006) carried out a study to compare LSD and STS to answer following questions: (a) Which one is more accurate and efficient? (b) Do different software products produce the same results? (c) What will be the maximum level of reduction? She concluded that it is necessary to reduce the size of data, otherwise processing is not possible even with powerful tools. Software with different capability will produce different results. This variation in results is due to the different amount of size reduction. Maximum level of reduction is bounded by affordable results. Good parameter for size reduction is the density of the point cloud. He found no difference in accuracy for both. In case of speed, LSD is faster in scanning the data of the field. But in post processing maximum time STS data get processed with faster speed.

(Scherer, M., 2004) proposed an approach to optimize geometrical and image data used in architectural surveying. An image of field contains infinite attributes of the field. Online registration of geometrical data with image data makes possibilities of offline surveying. Selection of geometrical data is dependent on shape and size of objects in the field i.e. in the image.

1.2 Present Scenario

Present trends in Photogrammetry are shifting from satellite Photogrammetry towards Close Range Photogrammetry (CRP). On the other hand Theodolites are not in practical use these days and are replaced by advance tools called TS. TS technologies are trending towards more and more automation, long range measurement, speed, precision, miniaturization, energy efficient and intelligent behavior, etc. Parallel to this, people throughout the world are working to bring both the technologies more close to each other for providing cost effective solutions with high quality results (Scherer, M., 2002; Murai, S. et al., 2004; Zhang, A.Z. et al., 2004; Jeong, J.H. et al., 2007). Precision in photogrammetric systems is delimited mainly by sensor resolution and lens distortions. Introduction of super resolution sensors in future may overcome this drawback and may be a better alternate solution alone. At present, a solution for precise 3D point cloud relies on merging of both the technologies together (Scherer, M., 2002; Murai, S. et al., 2004; Zhang, A.Z. et al., 2004; Jeong, J.H. et al., 2007).

Lack of skilled staff is demanding more automation in the instruments. Present automatic solutions, excluding Photogrammetry, for 3D point cloud are provided by Scanning TS (STS) and Laser Scanning Devices (LSD). All big manufacturers of TS have started manufacturing of STS, LSD and LSD with TS. For better coverage of the market, two high end versions of LSD product are available in the market. Entry level version is for beginners and is a cheap solution, e.g. Leica Scan Station C5, Trimble TX5, Topcon IP-S3, Topcon GLS 1500, Nikon insight L100 etc. Another version comes with advance technology and features, for example Leica Scan Station C10, Trimble TX8, FARO Focus 3DX 130, Topcon GLS 2000 and Nikon XC65Dx etc. Storage capacity has gone beyond 80 GB. Multiple user interfaces include on-board control, notebook, tablet PC or remote controller. They are integrated with high resolution zoom video camera for color overlapping on 3D data. Scan rate is quite high (50000 points/second). Field of view is same as of TS (horizontal – 360^0, vertical - 270^0). Scan resolution is in terms of spot size (7mm gaussian based) and point spacing (below 1mm) for a distance below 50m. Scan range of LSD is up to 500m. Provisions for communication are ethernet, wlan or USB. The input method is via touch screens. Multiple parameters are used to specify accuracy e.g. position (6mm), distance (4mm), angle (12") and surface (2mm) etc.

STS and LSD are comparable technology. In certain application both of them produces the same results. In accuracy, STS are much better than LSD, but work at slower speed. STS comes with multiple options for measuring angles (0.5', 1", 2", 3" or 5"). User can select one out of them as per requirement. Distance measurement range for prismatic mode is up to 3500m and for the non prismatic mode is less than 300m or 500m depending on the power of LASER used. Accuracy of distance measurement is 1mm + 1.5ppm for reflector mode and 2mm + 2ppm for reflectorless mode. The imaging device camera is of high resolution (5 Mega pixels). Data storage capacity is up to 2 GB internal and 8 GB external. Communication ways with them are RS232, USB, Bluetooth and WLAN. Measuring time is within 1.2 seconds for standard, 0.4 seconds for tracking in prism mode. Measuring time for prism less mode is 1 to 5 seconds for standard and 0.4 for tracking mode. Automatic target search and power search are important features with them.

Examples are Leica Viva TS 16, Trimble S7, Trimble S8, Trimble S9 and Topcon IS-3 etc. Trimble XV comes with more advanced technologies. It is an example of LSD integrated with TS.

Temporal scan data using scan functions of STS can also be used in monitoring Natural hazards like landslides (Kumar, K. et al., 2014). Landslides are among the most frequently occurring hazards in the hilly terrain of Himalaya (Kumar, K. et al., 1998).

1.3 Research Gaps

Literature review on the integration of photogrammetric systems with TS revealed multiple research gaps. All advance forms of photo-theodolites sold by various big manufacturers of the world have made use of advance technologies for automation of manual work, high speed, more storage, enhanced wide range, more accuracy, additional attributes of data captured, multiple communication ways, easy to use and are simple. But all the advance instruments launched by them are black boxes. No one, except the manufacturer, knows technological concepts inside them. That is why they are offering these instruments at very high cost (above Rs. 40 lakhs). Even these instruments are still under development stage and require further improvement. For the concept of 'Make in India' there is requirement of indigenous technology. Higher end developments in TS technologies are still not easy and simple to use as they demand specialized expertise. RTS with scan function takes a larger amount of time for 3D point cloud generation. Scan function is not time and energy efficient. During long running of scanning function, change in environmental parameters' value is not considered till date. Precise measurement with close range photogrammetry is under development stage. The complete solution is not available with stand alone TS or stand alone photogrammetric systems. Present Robotics Applications are not customizable at user level. It is difficult to place Optical Control Points / control bars at unreachable elevations. Integration of computer system, RTS and photogrammetric Image assisted controls is still under development stage.

1.4 Need of Study

The primary need of the study is to provide an indigenous cost effective solution for 3D point cloud generation with higher accuracy. For it there will be a need of combining computer system, photogrammetric system and an RTS to make a single system. For the purpose of integrating RTS with computer system, engineering level technical details of RTS are required. Its internal architecture, instruction set, application programs are needed. No manufacturers offer to share their interest in sharing their technical details and codes. Option of designing an own RTS by applying servo motors on encoders is not technically feasible under available knowledge in India. Thus, reverse engineering on the existing RTS for extending the usability, is the option left with us. It is need of the study. Moreover RTS are calibrated with particular environmental parameters with a temperature may be of 20^0C. For changed environmental conditions mathematical corrections are done on measurements to maintain the accuracy. It is important, but no option is given to apply correction during time consuming scan function in which the device will work for multiple hours continuously. Even a day will be required to scan data of a monument or building with RTS. Therefore a separate study has to be carried out for it. Optical integration of an RTS with a digital camera will require online orientation for mapping photo-coordinates to TS coordinate system and vice versa. Disassembling of RTS and mount the camera at its optical centre for removal of all types of parallactic problems can disturb its calibration. There is a need to study how a single camera will perform the task of image capturing and live video. Integration of multiple independent devices may create a problem of its synchronization and control. Solution for this has to be found out. For the purpose of customizable robotic application environment as per users requirement some provisions has to be done.

1.5 Objectives of PMTS

a) Integration of computer system, photogrammetric system and RTS
b) Overall control over the functioning of RTS using online command and data transfer between computer system and RTS
c) Photo-coordinate mapping to TS coordinate system and vice versa
d) Real time parameter updates
e) Reflector less, no optical marks/bar/symbols based measurement.
f) Image assisted precise Object Targeting.
g) Skipping absurd points.
h) Customizable environment for development of robotic applications.

The primary goal of PMTS is to integrate a powerful processing system with a photogrammetric system and an RTS for capturing precise 3D point cloud. To achieve it, the computer system must control functions of Digital Camera (DC) and RTS, which will require online command and data transfer between them. Digital camera comes with facilities for interacting with the computer system. Controller on RTS base has provision for offline data transfer. But the requirement for

PMTS is online data transfer. To have it, provisions for online command transfer are to be developed. Online command transfer between computer system and Robotic Base (RB) will require a development environment in some high level language like C, C++, and Visual Basic, etc. For controlling movements of RB, efficient mapping algorithm will be required to map photo coordinate into TS coordinate system and vice versa online and offline. The work of mapping depends on the mounting status of digital camera on RB. Thus the plan of mounting must reduce orientation work to a minimum level. If considerable time is consumed by application for surface profile capturing then there may be required to update station parameters to produce precise results. One option is to manually update them. But it will not be a good practice to suspend the scan work, update the parameters and resume the scan work. The work of update must be completed by some automatic means. Use of reflectors, optical marks, bar, etc. will restrict automatic functionalities of PMTS. Therefore, use of them must be avoided even for accessible points. Certain targets may exist, during the scanning of field, which will not reflect sufficient energy back to EDM and system may get engaged with it for infinite time. It will degrade performance and system initialization may be required. Therefore PMTS must have some automatic solution to handle such problems. Robotic applications of existing RTS are customizable at manufacturers end only. Users of RTS cannot modify or add new applications of their own interest. Thus, customization is a costly solution to fulfill day to day needs of surveyors. PMTS must have a simple customizing environment to provide a cost effective solution for this problem.

1.6 Overview of Thesis

Thesis work of PMTS is organized into the following chapters:

Chapter 1

This chapter is introductory chapter of PMTS. In it historical evidences of developments in the research area in brief, present trends in it, new scopes in the research area, and present gaps in it were discussed. It gives description regarding need of study and its importance. Finally, it concluded in research objectives.

Chapter 2

In this chapter a review of literature related to integration of the photogrammetric system with angle and distance measuring instruments was carried out in brief. A comparison of competitive technology in the field was made to know their usefulness and drawbacks. A summary of literature is prepared in the last to guide the path of research work.

Chapter 3

This chapter includes detailed description of PMTS architecture. It describes the important components responsible for functionality of the PMTS. Functional behavior of each component and their inter-relationship is described in details in the middle of this chapter. In the middle, a concept plan is given, which is helpful in the realization of PMTS. In the last, reverse engineering of robotic base for estimating its internal architecture and instruction set is discussed in details. It describes the reasons for performing reverse engineering. This chapter concludes with a sufficient set of parameter, variable and instruction set to integrate it with PMTS.

Chapter 4

This chapter is involved in developing a powerful processing and controlling system for robotic base. Development and deployment of interface for PMTS and its subroutines library is discussed in details. In the last an user interface, developed in C language, is discussed with the help of sample layouts.

Chapter 5

The major objective of integrating a photogrammetric system with TS is fulfilled in this chapter. In it mounting and optically integrating a single camera with TS is carried out. In the last method of mapping photo-coordinates to TS coordinates system is discussed in details. A new approach of modeling lens distortion for camera assembly was introduced in this chapter.

Chapter 6

Various methods of controlling movements of robotic base are discussed in this chapter. In this, an approach is presented to target an object with precise results. This approach increases accuracy of an existing method for setting a target.

Chapter 7

The task of scanning surfaces with TS is time consuming process. Measurements with it are prone to environmental parameters like, temperature, humidity and pressure. During execution of scan functions, values of these parameters may get changed. In this chapter a method for automatic update of these parameters, to maintain accuracy in measurement is presented.

Chapter 8

Various causes of system failure in PMTS and their solutions are presented in this chapter. Discussions and implementation of solutions have converted PMTS into a reliable system.

Chapter 9

This chapter concludes the thesis with main conclusions and suggests some possible area for further research work.

Chapter 2

Literature Review

2.1. Historical Background

One of the most important and basic functions of traditional terrestrial surveying is the precise measurement of points in 3D, until now which is immensely processed by artificial reflectors. But there are few places where it is impossible or even impractical to locate prisms at the region of interest. In these conditions advance image processing techniques could replace prisms, like Charge Coupled Devices (CCD) or Complementary Metal Oxide Semiconductor (CMOS) sensors used to collect spatial and spectral information of the target object radio-metrically. The photo-theodolite is well known in photogrammetry since more than 100 years, where the components such as aiming device, pitch circle, level and tripod are combined with the photogrammetric camera (Finsterwalder, R. et al., 1968). The combination of theodolite and CCD camera interfacing was described by (Gottwald, R., 1987); (Huep, W., 1988). Algorithmic design and instrumental description in detailed information was given in (Wester-Ebbinghaus, W., 1988a & 1988b).

Before 1960, it was difficult to manage and process data obtained from theodolite and measuring tapes etc. After this, electronic science has brought a revolution in the field of instrumentation. As a result first known commercial tacheometer, which has integrated angle measurement, distance measurement and feature register facility, available was Zeiss RecElta14 (1968) and the major problem with that device was its size (bulky). Before 1981, world famous manufacturers have started manufacturing of small size TS which were having measuring distance with reflectors, with further enhanced technology there was no use of reflectors for measuring distance with EDM. Although these measurements were delimited by short distances but were quite useful. This generation was named as Manual Reflector-less TS (MRTS).

Next generation shown in Table 2.1 was further simplified with special features like auto tracking, active and passive targets called it as motorized TS or Robotic TS (RTS). A single user can perform various surveying tasks and major robotic features have described and tested with instrument known as Topomat (Matthias, H., 1982). First prototype of reflector-less motorized TS was tested in 1995 and its first commercial version was released by Leica in 1999, after this many manufacturer have launched RRTS under their brand name. These TSs were steered with built-in programs which have introduced a scope of intelligent tacheometry and major limitation in this instrument that they are not customized at their users end. Next generations of TS repeat the history back to era of photo-theodolite and a fast measuring RRTS was integrated with camera i.e., at least one camera was used on eye piece and one or more camera for capturing images of field for photogrammetric use. This generation was called Image Assisted TS (IATS). First commercial example of it was Topcon 7000i integrated with camera launched in the year 2005 and it driven manually, therefore certain features like intelligent tachometry were missing from it. IATS was motorized in the year 2007 by Trimble and Topcon. This new generation TS called as Image Assisted Scanning TSs (IASTS). Major drawbacks in it include poor quality of images (i.e., low resolution) and are not distortion free. Certain important features partially implemented or yet to be implemented for RRTS, IATS and IATS includes intelligent tacheometry (intelligent scanning, edge/corner treatment, stake out etc.), photo-techeometry, documentation, visualization, ortho-photo, steering, concept of online and offline survey.

First example of integrating TS technology with Photogrammetric System was found in 1894 (Bridges-Lee photo-theodolite), in which a camera integrated with conventional theodolite. These analogue systems are replaced by advance digital equipment models and the major developments are related to processing speed, storage and automation etc. Digital technologies have come up with a revolution changes in surveying. Advance Robotic TSs have travelled a long journey of improvements starting from Egyptian Garoma and Dipotra. A series of developments, which includes in existence of TS, have a vast list of instruments like Plane Table, Theodolite, Photo-theodolite, Electronic-theodolite, Electronic Distance Meter (EDM) etc. and finally comes the device TS which is capable of processing and storing survey data like measuring angles, distance electronically.

On the other hand, the state-of-the-art RTS adds capabilities of automation and tracking to enhance surveying applications and positioning in the field, including urban settlement monitoring, bridge deflection and tunnel boring machine guidance (Shen, X.S. et al., 2011). At present, the main drawbacks of RTSs include the high investment and application costs and its limited capability to track only one point at a particular time.

Table 2.1 Generations of Total Stations and their main characteristics

Sr. No.	**Year**	**Type of Total Station**	**Added Measuring Method**	**Steering**	**Functions** (in addition to existing technology)	**Minimum number of operators**
1	1968	Tacheometer	Digital	manual	Angles and distance measurement along with feature ID	Team of multiple persons because of its bulky size
2	1977	TS	Reflector	manual	Same as tacheometer (small handy size)	Two (at station and target)
3	1982	Manual Reflector less TS	Reflector less	manual	Same as TS	Two (at station and target)
4.	1995	Robotic Reflector less TS	Reflector less, wireless	Motorized, steered by controller	Multiple robotic applications, Intelligent tacheometry and wireless control	Only one at target
5.	2005	Video TS IATS	Integration with camera	manual	Extracting information from images	Two
6.	2007	Scanning IASTS	Scanning	Motorized, steered by controller	Scan function	For station establishment and initialization

2.2 Photo-theodolite: (Bridges-Lee photo-theodolite, 1894)

Integration of digital camera with theodolite has been traced back to many years ago. Earlier examples of it are photo-theodolite developed by Porro in year 1865 and by Pagnini in year 1884 at Italy and Bridges-Lee photo-theodolite (1894) as shown in the Fig.2.1. In 1896, Dr. C. Koppe developed a new instrument for recording horizontal and vertical angles on the photographic negative directly. Later in 1950's, terrestrial photography was performed in which terrestrial digital camera was connected with a theodolite to compose a system named photo-theodolite. Various photo-theodolites are Zeiss Jena 19/1318 and DJS/1318-1 developed by Chinese, Wild P30, P31, P32, the Zeiss Jena UMK, and the Zeiss (Opton) TMK, etc., (Wang, Z., 1979; Deren, L. et al., 1992). This equipment abolished when photogrammetry came to digital era.

It is an arrangement of two photographic cameras, plates of which may be brought exactly into same plane, used in map making and surveying. The distance between two pictures taken at same instances can be calculated in all dimensions.

It contains basically a traditional theodolite, which is modified with the arrangement of digital camera in such a way that both camera and theodolite rotate about a common vertical axis. The upper portion of instrument is a standard Wild T2 and theodolite rests on a solid casting housing of the camera and was used for terrestrial photogrammetry.

Fig.2.1 Bridges-Lee photo-theodolite, 1894

2.3. Close Range Photogrammetry and Robotic Total Station

The short duration of field work measuring time is a remarkable feature of photogrammetry (Yakar, M. et al., 2010). Photogrammetric works are normally performed without any contact with the object, for this reason the photogrammetric methodology can be observed particularly for inaccessible locations and accomplished in the surveying of object targets that which cannot be physically accessible (Yakar, M., 2009).

Photogrammetric measurements are not performed on the object itself but on the images taken thereof. The images generated by cameras are handled as digital files by the computer. 2D measurements of digital files are mainly performed on a computer display (Fekete, K. et al., 2008).

The concept of photogrammetry is almost as old as that of photography itself. In first fifty years, the major application of photogrammetry were to close range architectural measurement rather than to topographical mapping. Photography was invented during the 1830s and 1840s by Fox Talbot in England, by Niepce and Daguerre in France. French military officer Laussedat experimented in 1849 on the façade image of the Hotel des Invalides. Laussedat has used lucida camera at that time and obtained photographic equipment in 1852. First photogrammetrists was Poi Villiers (1960) was not a surveyor but an architect. Meydenbauer, the German, gave a name “Photogrammetry” to the art of measurement with photograph in 1858 and used photographs to draw plans, in 1865, constructed an instrument called “Great Photogrammeter” and it was a fore runner of the photo-theodolite. He designed his own photogrammetric camera and developed graphical photogrammetric methods for the designing plans of building façades. Paganini (1884) and Deville , Thompson (1965) mapped vast areas of the Rockies in Canada and Jorden, mapped the Dachel oasis in 1873, which are examples of the objects to be measured are inaccessible or are difficulty in access.

There are few advantages of the close range photogrammetry when compared to the traditional measurement techniques. These are effective and fast to reduce time for collecting field data, safe and reliable, because measurements are accomplished from remote (Kraus, K., 2007).

(Atkinson, K.B., 1996) has said that developments in computer science have brought about numerous changes on 3D measuring technology. From these developments the two technologies i.e., Laser measuring techniques and close range photogrammetry techniques are affected. For an effective measuring technology for 3D modelling, the latest TS with robotic scanners being developed rapidly as an alternative or rival to current systems which can be generate by 3D coordinates of hundreds of points.

TS with robotic laser scanners can be used in definitive mapping processes. The other method attracting attention in 3D measuring technologies is the technique of close range photogrammetry. When compared to the classic measuring methods close range photogrammetry is more qualitative and as well as speedy; this minimizes the computational time meaningfully to field data acquisition on ground (Scherer, M. et al., 2009). The field data that collected in ten days by conventional techniques are collected in three days by this approach. Individual measuring point can be generated physically as non-contacting and it is absolutely a definitive approach (Carbonell, M., 1989; Kraus, K., 2007). Classification of conventional non-contacting methods is shown in Fig.2.2 (Luhmann, T. et al., 2006).

These days, laser scanner measuring concepts are applied in many technical fields by different instruments and methods. Generally, the meaning of non-contacting measuring an object is to execute processes in computer environment using the data obtained as cloud of points. Also, the meaning of 3D scanning process is to obtain the real coordinates of an object as three-dimensional (Kraus, K., 1992). The measurement principle of Laser instrument is to calculate the time taken between transmitting and receiving movements of distance signal when laser pulse is sent to object. This principle is known well from electronic tacheometer. In this instrument, the light

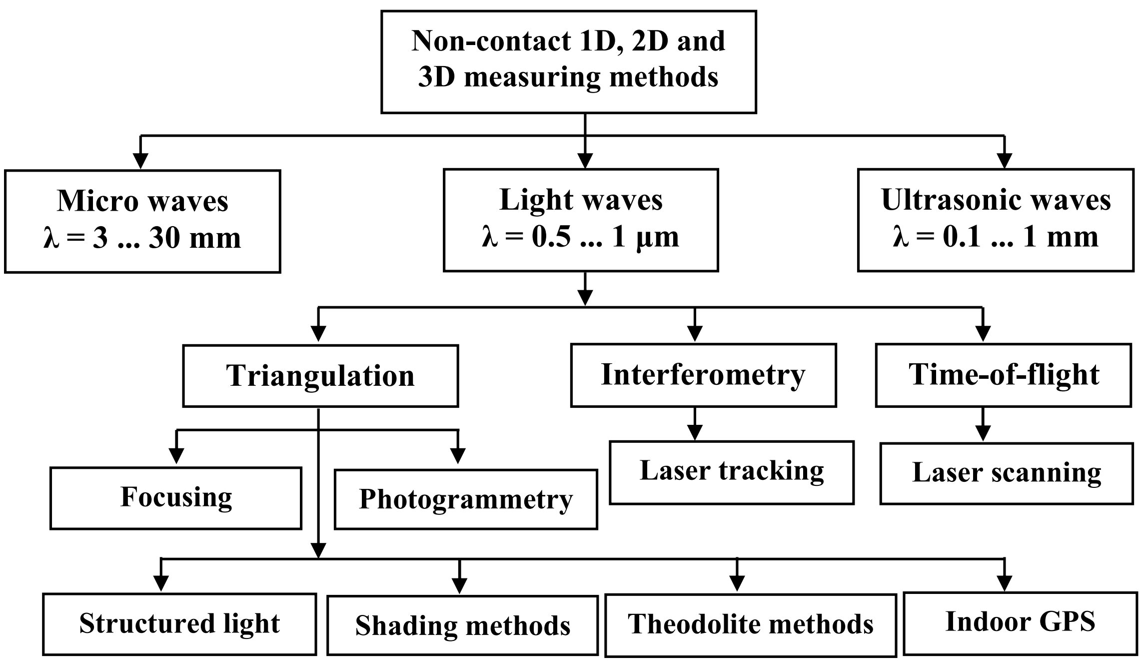


Fig.2.2 Conventional non-contacting measuring methods

signal is sent to a prism and it is recorded as time period of the light that is going-coming. Whereas, in laser measuring instruments, since there is no reflecting prism on object measured, the light reflecting from object itself is used (Lichti, D.D. et al., 2000). 3D laser scanner combines non-cooperation laser range finder and angle measure system. This makes us create dense digital surface model quickly and effectively. The principle of 3D laser scanner is: emit laser and reflected when touching the object.

2.4. Digital Terrestrial Photogrammetry with Photo Total Station System

An efficient and flexible digital terrestrial photogrammetric methodology has been developed and well adopted and supported with the equipment named Photo TS System (PTSS). This PTS System is a completely novel surveying instrument, which placed metric camera on the TS system to contrive an integration system jointly with the digital photogrammetric software system (Zhanga, Z. et al., 2005). This PTS System has involved three coordinate systems:

1) Coordinate system of TS (T-XYZ).
2) Coordinate system of image space (S-XYZ).
3) Ground coordinate system (G-XYZ).

While minimizing their shortcomings, PTS System takes the full benefits of digital photogrammetric techniques and accurate TS methodology that provide much better advantages of each system.

But in almost all cases these systems have been used individually, during which TSs are used to measure the target object coordinates in three dimensional control points for the photogrammetric process (Imura, M. et al., 2001); (Ikeda, S. et al., 2003). Carl presented a Computer Assisted Photogrammetry (CAP) system, which used to combine an ordinary camera with TS and provided corresponding software for analysing the data (Gravel, C. et al., 1999). Murai Shunji said "Integration of TS and camera for close range measurement: onsite processing for triangulation with ground based control survey has been developed. In future perspective, TS with digital camera should be developed." (Murai, S., 2002).

Jeong, J.H. et al. (2007) have used an imaging TS in their study to solve crack measurement using image control points, because imaging TS system can acquire image coordinates of an object target that which describes the measured point. They used the images collected by imaging TS as control points (ICP: image control point) for the exterior orientation of the camera. These ICP are Ground control points (GCPs) are essentially required for the rectification of images (Katiyar, S.K. et al., 2011). Later they evaluated the orientation results by comparing their 3D measurement accuracy with measurements of imaging TS. Instead of applying traverse and levelling approaches in the conventional surveying, nowadays use of TS is the general practice to resolute accurate positions of the object targets in the field, (Kavanagh, B.K., 2009). "Mainstream surveying research focuses on improving the accuracy of collected field data by computing, for instance, through the least square adjustment algorithm" (King, B.A., 1997); (Deren, L. et al., 1992).

Photogrammetric surveying is used extensively in engineering, 3D modelling, manufacturing and digital map production purposes (Lohani, B. et al., 2013). (Gruen, A. et al., 2013a) integrated surveying data obtained from UAV imagery and terrestrial Mobile Mapping System (MMS) data for the purpose of complete survey data acquisition (top and bottom). (Lohani, B. et al., 2014) proposed an approach to develop MMS as an intellectual property locally to bring down its cost of to a large extent. A very high resolution 3D city model was prepared by integrating Mobile LASER Scanning (MLS) data and UAV imagery (Gruen, A. et al., 2013b). This very high resolution 3D data obtained from MLS and UAV imagery was successfully used in change detection (Qin, R. et al., 2014). "Augmented Reality (AR) and Virtual Reality (VR) researches have resorted to photos as the most straightforward and cost-effective means of field data collection in the construction management domain" (Kamat, V.R. et al., 2011). Researchers and construction engineers tried to minimise the number of photos used by impressive geometric constraints and automatic model processing based on pattern recognition and feature detection, due to its computational complexity of photogrammetric surveying (Golparvar-Fard, M. et al., 2009; Hernández-López, D. et al., 2012). El-Omari, S. et al. (2008) have integrated both photogrammetric process and laser scanning technology to minimise the computational time which is desired for collecting field data and modelling. Golparvar-Fard, M. et al. (2009) have used field photographs to generate the point cloud data, then matched and pair the images to produce the as-planned and as-built models enabled by the techniques of Structure from Motion (SfM). Further, they reduced the modelling time and cost by generating the point cloud data from both images and structure from motion. Golparvar-Fard, M. et al. (2009) and Bhatla, A. et al. (2012) have demonstrated the successful point cloud data applications.

Point cloud data based applications are aimed to minimise the efforts used in 3D as-built modelling. However, during laser scanning modelling parameters and object should be stationary while removing the redundant or irrelevant information (noise data) requires considerable time and expertise. Thus, "point-cloud data" based techniques are not suitable for modelling a particular moving object on a near real-time basis in the field. For instance, research has extended from photogrammetry into video-grammetry, (Fathi, H. et al., 2013) these researchers measured dimensions of a building roof using two digital video cameras based on structure from motion.

Further, substantial video post-processing analysis is necessary to match the time mark of each video frame recorded by both digital cameras. Hence for 3D modelling, minimum three stationary ground control points are required in each video image frame and in this they used the simplified photogrammetry-enabled augmented reality methodology i.e., photo-AR.

Various methods used for measurement are shown in Fig.2.3 (Luhmann, T. et al., 2006). Out of these methods Interferometry has best accuracy (10^{-3} mm and better). Industrial Photogrammetry provides accuracy of order 0.5 mm to 10^{-2} mm. It is capable of measuring objects of size above 1m. Theodolite, Architectural and engineering photogrammetry, DGPS, and Tacheometry provide measurement accuracy in mm. Aerial photogrammetry; GPS and various remote sensing methods have accuracy in meters for measuring object's size in the range of 100 meters to kilometres.

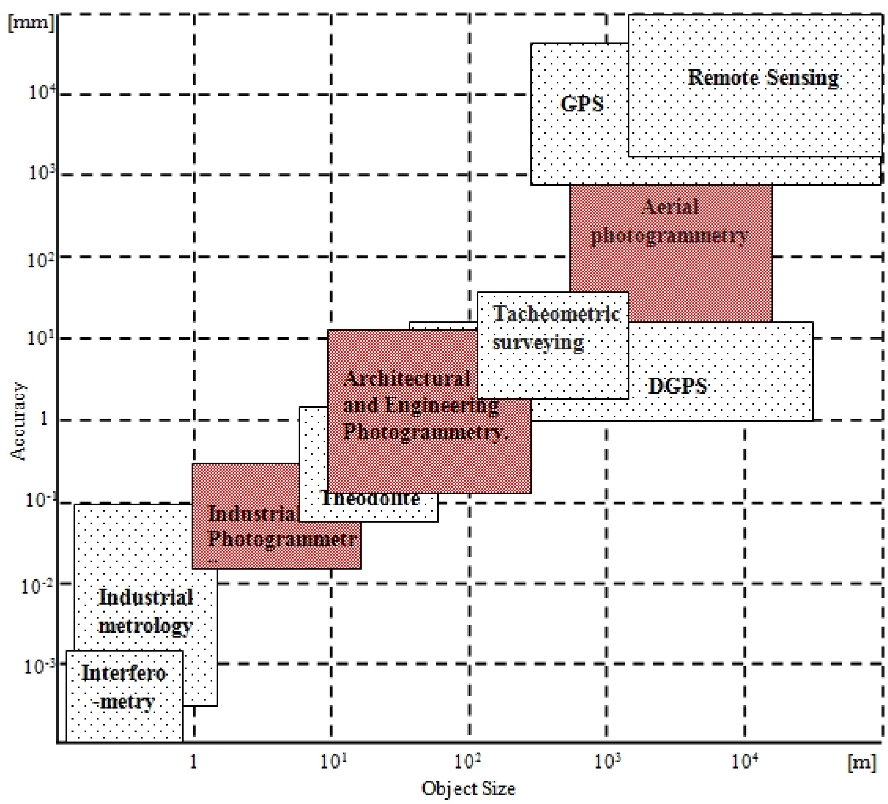


Fig.2.3 Relationship among various measuring methods.

GPS technology has also gained popularity in day to day life. Geo-coding techniques (Katiyar, S.K. et al., 2003) widened the applications of GPS technology.

Lerma, J.L. et al. (2014) presented a new approach to estimate the discrete-return point density. They applied this approach on airborne lidar survey data. It was observed that weighted arithmetic mean and harmonic mean methods produce better estimates. A comparison based on time, cost, accuracy and train independence of different levelling techniques was carried out by (Khalid, E.A. et al., 2014). Lerma, J.L. (2012) proposed a method to compute Ground Sample Distance (GSD) which balanced precision and speed in computation.

2.5. Comparison of 3D Survey Technologies

a). Total Station

Advantages:

- Easy to use topographic equipment and techniques.
- Precise, effective and rapid solutions (Khalid, E.A. et al., 2015)
- Standard modelling software, like AutoCAD or 3Ds Max, can be used to generate the model from the surveyed points.

Disadvantages:

- Surveying with topographic equipment and techniques is time consuming especially during the measurements phase.

b). Photogrammetry

Advantages:

- Easy to use because one can be flexible in choosing the type of source images and cameras: metric or non-metric
- Several software packages are available to choose from. Some examples:
- Photometrix, Apollo Photo3D, DigiCad 3D, etc.

Disadvantages:

- One has to do a precise camera calibration because this is a very important process that influences the quality of 3D model.

- Image resolution is related to the type of the camera used to acquire the pictures usually the capabilities of even the most advanced cameras are not sufficient for some projects. Hard to use in the case of tall buildings.

c). Laser scanning

Advantages:

- Fast acquisition and processing of a huge amount of 3D data in a short period of time (125,000 points/second), making the laser scanning probably the most efficient method for data acquisition (Lerma, J.L. et al., 2014); (Gruen, A. et al., 2013). Precise, effective and rapid solutions (Khalid, E.A. et al., 2015). Good metric accuracy - depending on what instrument one uses, it can be precise in millimetres (Bucksch, A. et al., 2007).

Disadvantages:

- Not so developed 3D modelling capabilities – for example modelling edges in software applications like FARO Scene is not an easy job.
- The huge amount of measurements makes data handling difficult, requesting some special hardware and software requirements.

2.6. Summary of literature review

Photo-theodolite began the era of integrating photogrammetric systems with total station and fundamentals of integration are same till date. During this process research works and advancement in technology are related to the methods for acquisition of parameters. Instruments are enhanced to digital form from their analogue nature, equipped with automation for faster speed, recording, processing and movements remained the major factors for advancements after development of photo-theodolite. In integration of the two technologies, one camera, fitted over eye piece of telescope, is used for live view of the field. This camera is in addition to the cameras used for photogrammetric purpose (one or two cameras) and complicates the orientation work. No attention was given to changes in environmental parameters (temperature, humidity, pressure, etc.) during execution of scan function. It degrades accuracy in measurement. Even during auto scanning, there may exist multiple targets which do not reflect sufficient amount of energy back to EDM. For such targets EDM will retry the process of distance measurement until a success is achieved. There are no provisions in the traditional equipment to skip such target automatically. Integration of computer system, total station and digital camera is still in development stage (no perfect solution for parallax problems and lens distortions). Moreover present systems are not customizable at user end and they are not capable of fulfilling their day to day challenging needs. Narrow view from telescope is still in use for setting the targets.

Yilmaz, H.M. et al. (2008) have stated that “photogrammetric method is 21.89% faster, 12.83 % more accurate, and its cost is 33.33% less,” on the average, when compared with the conventional techniques.

Chapter 3

ARCHITECTURE OF PMTS AND ITS WORK PLAN

3.1 Introduction

Photogrammetric Mapping with Total Station (PMTS) is an integration of four subsystems namely a photogrammetric system (digital camera), processing system (computer system), interface unit and RTS. Image from Digital Camera (DC) and a fictitious image (set of points from TS) are used for photogrammetric calculations. DC and telescope of TS are optically integrated with each other. Computer system works as a controller of whole system. There exists a provision for third party GCU and is not a part of PMTS.

3.2 Objective

Major objective of this chapter is to draw a layout diagram of PMTS architecture and to describe the functionality and interrelationship of components in PMTS. Establishing a communication channel between RTS and computer system for online information and control exchange is another important objective in this chapter.

3.3 Architecture of PMTS

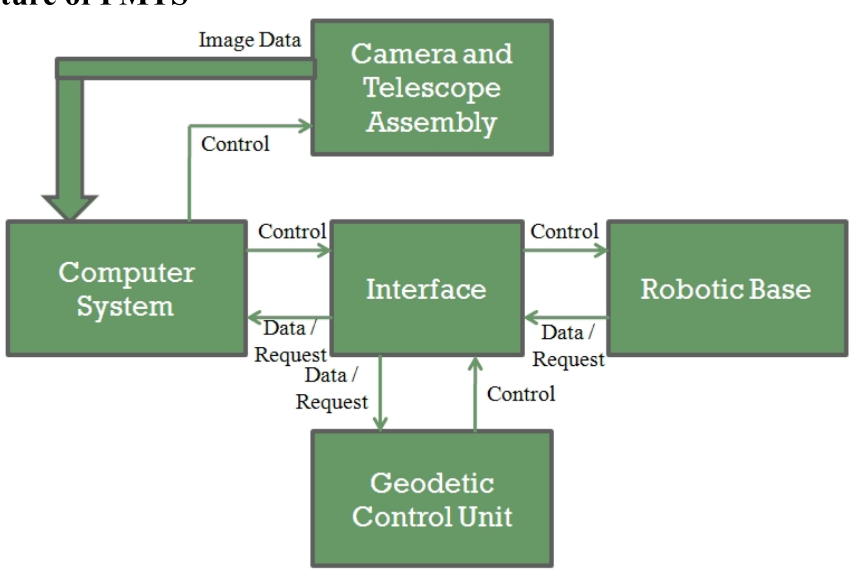


Fig.3.1 Architecture of Photogrammetric Mapping with Total Station

In the Fig.3.1 Geodetic Control Unit (GCU) is a third party device and is not a part of PMTS. Description of various components of PMTS is as under:

3.3.1 Components of PMTS

3.3.1.1 Camera and Telescope assembly

In PMTS single digital camera is used for both the purposes i.e. for capturing field image and for its live view. DC is rigidly mounted on the telescope of RTS using an assembly. Pre or post orientations integrate DC and telescope (RTS) together. In pre orientation both are oriented prior to execution of PMTS. Orientation is carried out after the execution (after taking sufficient observations) in case of post orientation.

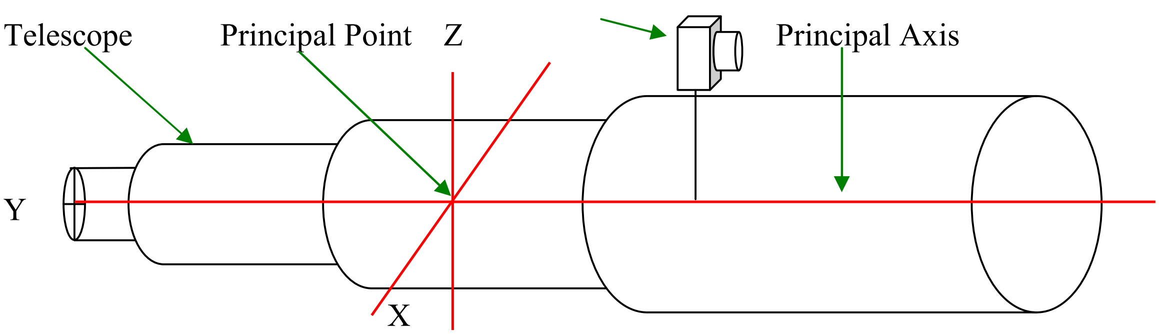


Fig.3.2 Camera Position inside Telescope coordinate system.

In PMTS all the three angular orientation parameters and X offset between DC and telescope are adjusted to zero value. Interrelationship between photo-coordinates (distortion less camera system) and station coordinates is shown in equations (3.1), (3.2), (3.3) and (3.4).

$$X' = \frac{f.X}{Y - Yoffset - f} \quad \ldots (3.1)$$

$$Z' = \frac{f.(Z - Zoffset)}{Y - Yoffset - f} \quad \ldots (3.2)$$

Where:

f is camera constant.

(X, Y, Z) represents an earth feature in station coordinate system.

(X’, Z’) is a projection of (X, Y, Z) in photo coordinates system.

Yoffset and Zoffset are camera offset in station coordinate system.

Using the lens formula, equations (3.1) and (3.2) represent transformation of station coordinates to photo coordinates.

$$X = \frac{X'(Y - Yoffset - f)}{f} \qquad \ldots (3.3)$$

$$Z = \frac{Z'(Y - Yoffset - f)}{f} + Zoffsets \qquad \ldots (3.4)$$

Equations (3.3) and (3.4) represent inverse transformation of equations (3.1) and (3.2). These equations are used to map photo-coordinates back to station coordinates. Method of recreating third dimension Y will be discussed in Chapter 5.

3.3.1.2 Interface Unit

Responsibility of Interface is to overcome electrical and electronic differences between computer system, RTS base and GCU. Its main function is to route/divert data and control among them. Instructions for routing are issued by computer system i.e. master control of PMTS. GCU is third party hardware and may be disconnected from interface. Two forms of disconnection provision are there e.g. in hardware form and software form. In hardware form GCU is physically removed from PMTS i.e. no GCU is there. In software form, GCU is physically connected with the interface but is kept idle.

3.3.1.3 Computer System or Processing Unit

It is the master controller of PMTS. Its major role is to control activities of other components by issuing control commands, receive data from them and processing of data. Various controls to DC include image parameters adjustments (like size, focal length, image/video format, contrast, intensity etc.) and functioning of DC (send image or video etc.). Programs for robotic applications are stored in computer storage. When an application is invoked control commands are sent to RTS base via interface. Robotic base send back results to computer system again via interface.

3.3.1.4 Robotic Base

It is measuring device of PMTS with automatic mechanical, optical and electronic functions. Its positioning and measurement activities are guided by the controllers (either by GCU or computer system). Presence of interface make it uninformed about the current controller i.e. it does not know from which controller the command is issued and to which controller measured data has to be sent.

3.3.1.5 Geodetic Control Unit

PMTS has a provision for third party controller. GCU plays role of slave controller in PMTS i.e. it will take control over the system whenever master controller allows it. It comes with set of programs for most common robotic applications and is not customizable at user end.

3.3.2 Interrelationship among components of PMTS

DC is optically integrated with telescope of RTS. Their relationship is represented by equations (3.1), (3.2), (3.3) and (3.5). The relationship represented by equation (3.1) and (3.2) is a complete relationship. Equation (3.3) and (3.4) represents a partial relation because third dimension (Y) is unknown and was lost during projection. Photogrammetric methods have to be applied for recreating it. Computer system is master controller of the whole system. It takes help of software application developed for PMTS to control various components. DC is connected to it via a serial port. Computer System can control/adjust settings of DC (Focal length, contrast, intensity etc.). DC sends pixel information (image, video) on demand generated by computer system. Interface unit is another device which is under direct control of it. GCU and RTS are under direct control of IU. Computer system sends control instruction to RTS via IU. RTS sends data/results to IU which bye passes them either to computer system or to GCU. Control instructions from GCU are sent to RTS via IU.

3.3.3 Functioning of PMTS

Establish station at position having best view of the field. Set Camera parameters to required values. Computer System sends control instructions to DC and RTS for capturing an image and its' HA, VA (for centre of image) as shown in Fig.3.3. It is the first step of PMTS station establishment. In second step, as shown in Fig.3.4, DC captures field image and send image data to computer system. Simultaneously RTS sends HA, VA of image captured to Computer System.

PMTS software will store image data and its metadata in program variables after inserting a cross hair at the centre of the image. Computer system sends command to DC for sending live video of field. Field image captured and live video of field containing a cross hair at its centre starts appearing on screen. Now PMTS is established and is ready for work as shown in Fig.3.5.

Fundamental services provided by PMTS are wide view of field and easy way of object targeting. For targeting an object surveyor has to click on object in the image. On clicking position in terms

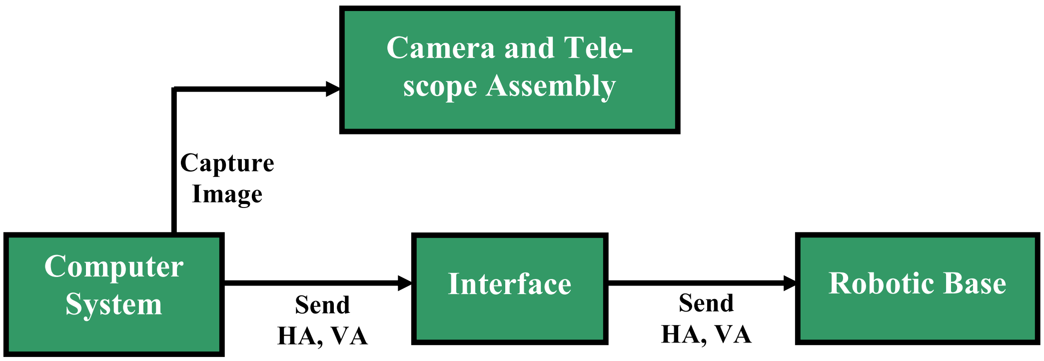


Fig.3.3 First step of PMTS station establishment

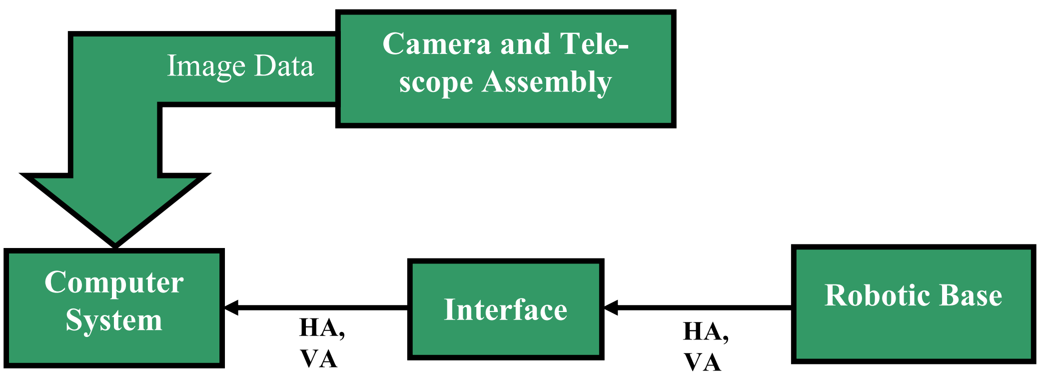


Fig.3.4 Second step of PMTS station establishment

of Target Horizontal Angle (THA), Target Vertical Angle (TVA) in reference of HA, VA is calculated. Control commands are sent to RTS to gain the position at (THA, TVA). Target image appears at cross hair of live video. Fine adjustments have to be done manually through telescope.

For measuring the target computer system issues control command for it to RTS. Spherical coordinates of target are sent back to computer system which will be converted to user's coordinate system.

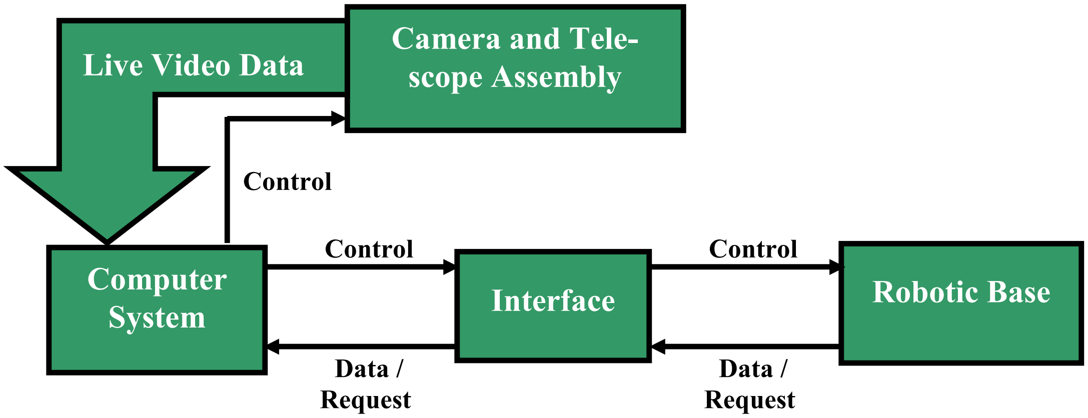


Fig.3.5 PMTS ready for its services

All other services provided by PMTS are a logical set of fundamental services discussed above.

3.3.4 Modes of PMTS

PMTS has following three modes:

a) Simultaneous control from computer system and GCU.
b) Control from computer system.
c) Control from GCU.

In Mode 1 computer system and GCU can control functioning of RTS simultaneously with a precaution to complete current task from one of the controller. For next task user may change the controller.

In case of Mode 2 computer system will block communication of GCU with PMTS. In this mode GCU is physically present but in software terms it is absent from PMTS.

In Mode 3 over all control of RTS is handed to GCU. No command except mode change can be issued from computer system. This mode is still under monitoring of computer system i.e. it is not completely removed from the system.

3.4 Work plan for PMTS

Various stages, opted for development of PMTS, are shown in Fig.3.6. Robotic Base (RB) is pivot component of PMTS. In phase 1 selection of a feasible RB was done. Important parameters for RB selection were its inter-operability with other components. It must have provisions of communication ports for online information exchange. Availability of instruction set to operate it via communication ports can play vital role in development of PMTS. Other parameters of interest are accuracy, precision, cost etc.

In development phase 2 a study of selected RB have to be carried out for complete control over it. Establish interface between RB and computer system to control RB from computer system.

In phase 3, a subroutines' library for interface between RB and computer system have to be developed. This library will consist of fundamental subroutines representing subtasks like set/reset station parameters, horizontal movement, vertical movement, slope distance measurement, switch on/off RB etc.

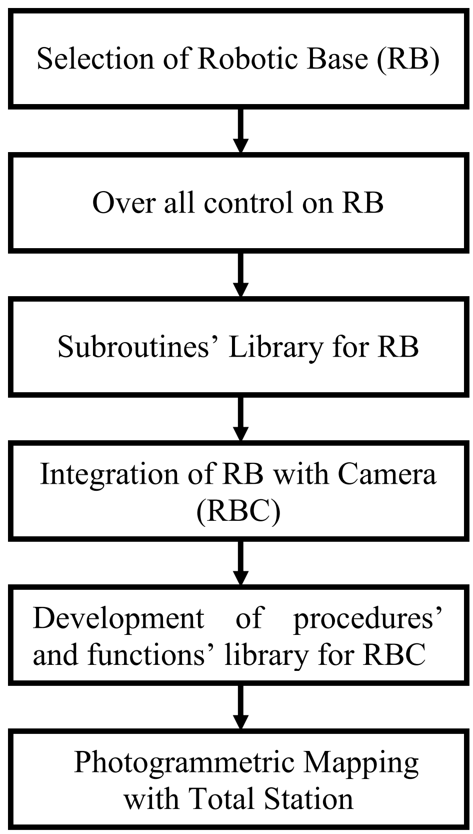


Fig.3.6 Development stages of PMTS

In phase 4 RB will be converted into a photogrammetric system by integrating it with a camera. Experiments related to orientation of camera with RB will be performed.

In next phase application software will be developed for photogrammetric application of PMTS. Development of a library for performing photogrammetric tasks will be major development in this phase.

In final phase applications have to be developed for photogrammetric use. These applications will be based on library functions and procedures developed in previous phase. Following applications have to be developed for mapping purpose:

- Object targeting.
- Stake outs.
- Surface profile and temporal surface data.
- Monitoring.

3.5 Reverse Engineering of Total Station

One of the major objectives of development of PMTS is to have online data transfer and online command transfer between RTS and Computer System. To achieve this online information transfer, an interface between them was required. To develop such an interface, internal architecture and instruction set of RTS and technical datasheets of port selected on Computer System was required. For this purpose a request for technical information of RTS was made to manufacturers of RTS. No help was provided by them as expected. Next option was to unscrew all the parts of RTS such that a component level study can be made to understand the RTS interface characteristics. This option was again not advisable under certain technical aspects. Last option was to use connection pins between RTS and detachable Geodetic Control Unit (GCU) to study operational behavior of RTS. This option was most feasible and was opted for development work.

c)Camera


b) Computer


a)Robotic Base

3.5.1 Feasibility study for selection of Robotic base

Three basic Requirements of PMTS are:

a) Robotic Base and its accessories
b) Computer System
c) Digital Camera (Metric / non-metric)

First step is to select a feasible Robotic Base (RB) suitable for other two components of PMTS. No RTS is available in the market which can fulfill requirements of PMTS directly. Therefore little customization was required to make it compatible with PMTS. For this there were three options namely:

a) Development of compatible RB.
b) Customized RB from manufacturer.
c) Customizing existing RB.

Third option was under all the constraints, was selected for PMTS. RTS Trimble 5600 DR200+ available in surveying laboratory of Geomatics Engineering section, IIT Roorkee was selected for customization to make it compatible with PMTS.

3.5.1.1 Limitations of Trimble 5600 DR200+ RTS

GCU of this RTS comes with following limitations:

- Programs are available only for few Robotic Applications.
- No application development environment is provided at user end.
- It provides offline data transfer.
- It provides command transfer only for offline Data Logging.
- There is no provision for online command transfer between RTS and Computer System.

These limitations of GCU suggested its replacement and designing of a new controller for RB.

3.5.2 Challenges with Trimble 5600 DR200+ RTS

RB of Trimble 5600 DR200+ RTS must have following facilities to be a part of PMTS:

- Provisions for interfacing with computer system
- Suitable space for mounting photogrammetric system over it.

Second facility was not a big issue with it. But first one had multiple technical issues. Successful interface required prior knowledge of technical and operational behavior of this device. Plenty of knowledge is available for communication channels of computer system. Unavailability of technical details of RTS gave rise to an idea of reverse engineering the RTS.

3.5.2.1 Options for RE of RB

RE of RB could be done either by internal study of machine by disassembling it or by external study based on behavior of the machine without disassembling it. Disassembling of RB could disturb its factory set calibration and hence research work was carried out with second choice. For performing behavioral study a communication channel was needed.

3.5.2.2 Available interaction channel with RB

After removing GCU, available external pin connections with RB are shown in Fig.3.7. These pins work as a gate way for RB.

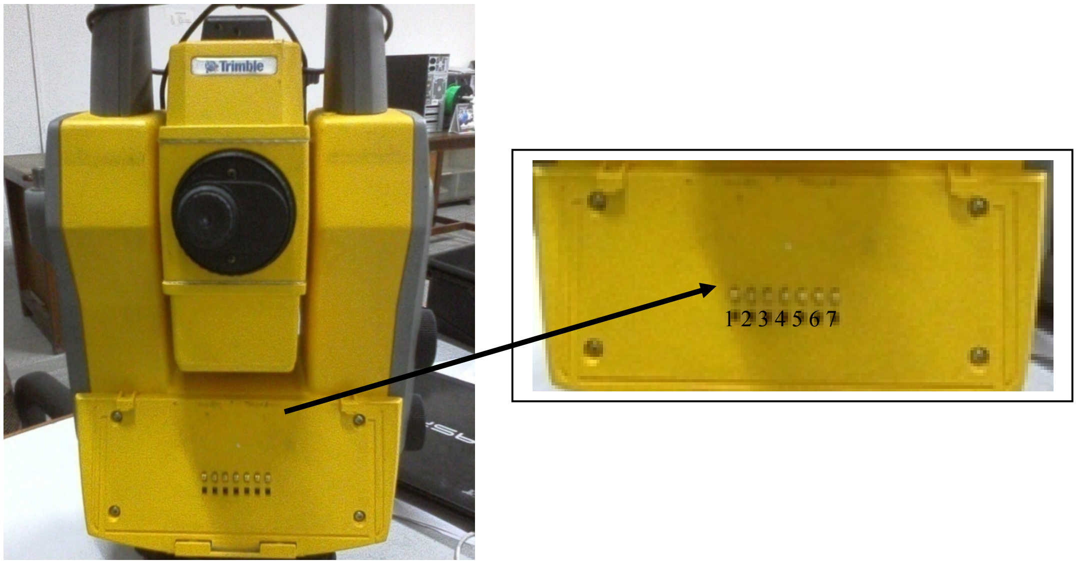


Fig.3.7 Pin connections available on Robotic Base

No specifications about these pins were available from the manufacturer side. Thus as a last option, reverse engineering of RB was carried out.

3.5.3 Reverse Engineering of RB

Methodology for reverse engineering a device is greatly dependent on nature of the device. Procedure of RE for an optical device, mechanical device or electronic device will differ at a large extent. RE is also affected by classes and sub classes of the device e.g. methodology of RE an analog device has differences with digital devices.

Important parameters for reverse engineering a digital opto-mechanical device, like RTS to interface it with computer system, are its pin connection characteristics, communication standards, transfer speed and data interpretation.

RTS is an optical, mechanical and electronic device. From an engineering point of view optical and mechanical components are encapsulated under its boundaries and there is no need to work out for these parts during RE. These parts are controlled and manipulated by internal processing components. Processing components communicate with outside world using interface connections.

For RE a digital device, it was kept under surveillance of a high speed monitoring device in asynchronous mode. Asynchronous mode is required because name or type of terminal/wire and information transfer speed is unknown. High speed ensure that no single bit of information change is missed (speed must be at least 8 times fast as compared to speed of communication channel under surveillance).

Responsibility of monitoring device is to keep a record of information flow in each pin connection and create a log file without involving itself into the process. This log file is analyzed for behavioral study of RTS. To create a log file, the monitor is activated and a program say program number 1 is executed from RTS. On completion of the program the monitor is stopped and a log file is saved.

Before start of actual analysis, problem of replication of data bits due to speed mismatch must be handled first. In the sequence of bits from a pin connection, number of continuous repetition n (frequency) of each bit is calculated and the least value of n is selected. Divide the frequency of each bit by this least value n as shown in example 1. Sequence of bits are arranged with new frequency and it represents the actual bit stream from the pin connection.

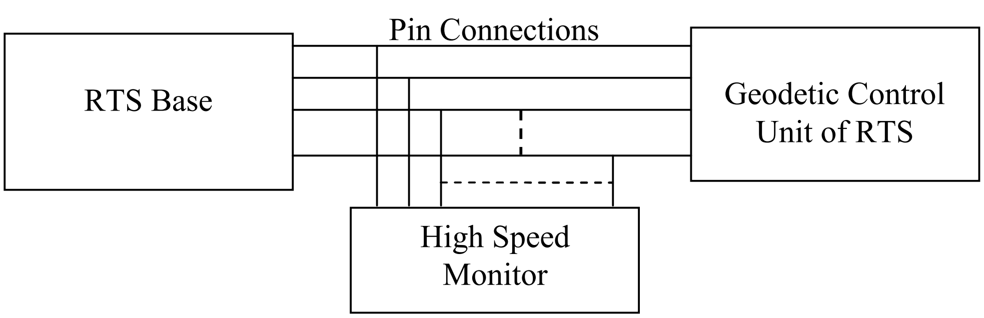


Fig.3.8 Pin Connections of Monitor with Robotic Total Station

Example 1:

Sequence of bits observed by monitor at nth pin connection:

111111000000111111111111000000111111000000000000000000111111111111……..

Bit face value	Frequency
1	6
0	6
1	12

0	6
1	6
0	18
1	12

Least value of frequency, n = 6

Therefore the actual bit stream should be:

10110100011…………

Frequency of last bit in the sequence may not be completely divisible by n. For it integral part was considered after dividing by n.

3.5.3.1 Identification of nature of pin connection

To identify nature of a pin connection there was requirement of proper judgment, experience, decision making power and some intuitions. The pattern of bits in bit stream gives a lot of information as explained below:

A). Constant bit value stream

It means that no change in bit value is observed throughout a process run in RTS. For example:

Stream j: 111111111111111111111111111111111111111111111111………

Stream k: 000000000000000000000000000000000000000000000000………

If there exist only two or more such bit streams one with bit value '0' and other with bit value '1' then intuitively these pins should be part of power supply pins, otherwise pin connections with such bit streams may be, enable or disable control pins, request signal pins etc. To detect a pin connection as power supply pin, insulator was inserted at contact point of GCU pin with RTS pin. If GCU does not turn on, the pin connection will be a power supply pin. If GCU gets turned on but proper communication with RTS is not established then the pin will be enable pin, request signal pin etc.

B). Rare change in bit value

Very less frequent change in bit value was predicted as a trigger for initializing and or finalizing a process or routine, enable/disable pin, a signal or flag etc. But it can never be part of power supply.

C). Frequent change in bit value

If bit value is changing continuously in a bit stream then the pin connection is a data/info pin. After classifying it as a data pin, multiple data sets (set of observation from CU and pin connection value) were prepared under different status of RTS for the purpose of decoding of data stream.

Example:

Stream j:

11111111000000000000000000000000111111111111111111111111000000000000000000000000

01111111100000000000000000000000000000000000000000000000000000000011111111111111

11000000

Bit Value	Frequency
1	8
0	24
1	24
0	24
1	8
0	24
1	16
0	16
1	16
0	6

Minimum Frequency (ignore last reading): 8

Bits stream j: 10001110001000110011

Bit Groups in stream j:

1000111000

1000110011

After many trials and errors, we found that removing start bits (intuitively for RS232 port) 10 from each group, bits in each group became:

00111000

00110011

In ASCII codes 00111000 represent digit ‘8’ and 00110011 represent digit ‘3’. Thus data value from stream j is 38.

3.5.3.2 Grouping of Pin connections for standard port identification

After having sufficient information about individual pins or wires characteristics, next step was to study their group behavior. Let x represent number of power supply pins, y represent number of less frequently changing pins, z represent number of frequently changing pins in the group.

Value of x will be very small in nearly all cases and it can be ignored in identifying characteristics of group. Thus y and z will become decision making parameters. If value of z is very small say below 3 and or value of y is larger than group of pins represent a serial communication port. If value of z is larger than the group may represent a parallel communication port or a data bus. Parallel port and data bus are physically distinguishable (ports always have one open end).

3.5.3.3 Identification of Data format and encoding

It is complex step of RE. In all previous steps monitor and algorithms can automate process of RE. But process of identifying data format and type of encoding cannot be automated completely (Complete automation will require at least one known live data port). The process can be partially manual / partially automated.

In case of devices which make use of standard data formats and encoding like EBCDIC, ASCII etc., process of encoding data will be less complex for them. To identify data format and encoding we run a specific program on RTS like program number 1, this shows live status of RTS on display of GCU. Monitor was allowed to observe current status of RTS and status from GCU was noted down manually. Observations were repeated by slightly changing status of RTS. The changes in bit values observed by monitor were correlated with changes in value noted down from GCU by trial error. A one or two digit change in status can be best to start with less complexity. Changes were first correlated with standard data formats. In case of failure, proprietor data format used by RTS was recognized.

3.5.3.4 Observations

Following hardware and software were used for RE of RTS Trimble 5600 DR200+

- Monitor : Desktop computer i80486
- Monitor port : parallel printer port
- Connection wire : printer cable
- Operating System: DOS 6.22

- Programming Language : ANSI C

3.5.3.4.1 Observations of Reverse Engineering for data

Steps followed during observations

- Station was initialized and was left idle.
- Data/command/flag/control pins were monitored.
- Interpretation of bit stream, coming in and going out from RTS base, was tried.

Status of RTS was noted down manually from its display. For it monitor had prepared a log file as shown below:

Total Station Status

Time 11:46

HA: 159.48.18

VA: 86.33.06

Observations by Monitor

,31-2551, 2551

15-1,31-1,15-5,31-1,15-1,31-1,15-3,31-2,15-1,31-1,17 15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-,15-2,31-2,17 15-1,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,16 15-1,31-1,15-1,31-4,15-2,31-1,15-1,31-1,15-2,31-3,17 15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,15-2,31-3, 18 15-1,31-1,15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15 15-2,31-2,15-1,31-2,15-2,31-1,15-4,31-3,15-2,31-1,20 15-1,31-2,15-2,31-2,15-2,31-1,15-4,31-3,15-2,31-1, 20 15-1,31-1,15-1,31-2,15-4,31-1,15-1,31-1,15-5,31-1,18 15-1,31-1,15-3,31-2,15-1,31-1,15-2,31-1,15-1,31-1,14 15-3,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,18 15-1,31-1,15-1,31-1,15-1,31-2,15-2,31-1,15-1,31-1,12 15-1,31-4,15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,18 15-1,31-3,15-1,31-2,15-2,31-1,15-1,31-3,15-1,31-2,17 15-2,31-1,15-2,31-3,15-1,31-1,15-2,31-1,15-1,31-1,15 15-1,31-1,15-1,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15 15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15-1,31-1,15 15-3,31-2,15-2,31-1,15-1,31-1,15-1,31-1,15-1,31-2,15 15-2,31-1,15-3,31-1,15-5, 12,31-2548, 2548

15-1,31-1,15-5,31-1,15-1,31-1,15-3,31-2,15-1,31-1,17 15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15-2,31-2,17 15-1,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,16 15-1,31-1,15-

1,31-4,15-2, 31-1,15-1,31-1,15-2,31-3,17 15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,15-2,31-3,18 15-1,31-1,15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15 15-2,31-2,15-1,31-2,15-2,31-1,15-4,31-3,15-2,31-1,20 15-1,31-2,15-2,31-2,15-2,31-1,15-4,31-3,15-2,31-1,20 15-1,31-1,15-1,31-2,15-4,31-1,15-1,31-1,15-5,31-1,18 15-1,31-1,15-3,31-2,15-1,31-1,15-2,31-1,15-1,31-1,14 15-3,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,18 15-1,31-1,15-1,31-1,15-1,31-2,15-2,31-1,15-1,31-1,12 15-1,31-4,15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,18

15-1,31-3,15-1,31-2,15-2,31-1,15-1,31-3,15-1,31-2,17 15-2,31-1,15-2,31-3,15-1,31-1,15-2,31-1,15-1,31-1,15 15-1,31-1,15-1,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15 15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15-1,31-1,15 15-3,31-2,15-2,31-1,15-1,31-1,15-1,31-1,15-1,31-2,15 15-2,31-1,15-3,31-1,15-5, 12,31-25 48, 2548

15-1,31-1,15-5,31-1,15-1,31-1,15-3,31-2,15-1,31-1,17 15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15-2,31-2,17 15-1,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,16 15-1,31-1,15-1,31-4,15-2,31-1,15-1,31-1,15-2,31-3,17 15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,15-2,31-3, 18 15-1,31-1,15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15 15-2,31-2,15-1,31-2,15-2,31-1,15-4,31-3,15-2,31-1,20 15-1,31-2,15-2,31-2,15-2,31-1,15-4,31-3,15-2,31-1,20

15-1,31-1,15-1,31-2,15-4,31-1,15-1,31-1,15-5,31-1,18 15-1,31-1,15-3,31-2,15-1,31-1,15-2,31-1,15-1,31-1,14 15-3,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,18 15-1,31-1,15-1,31-1,15-1,31-2,15-2,31-1,15-1,31-1,12 15-1,31-4,15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,18 15-1,31-3,15-1,31-2,15-2,31-1,15-1,31-3,15-1,31-2,17 15-2,31-1,15-2,31-3,15-1,31-1,15-2,31-1,15-1,31-1,

A self repeating block of data at parallel port of monitor was observed. Consider it only once as shown below:

Observations by Monitor

15-1,31-1,15-5,31-1,15-1,31-1,15-3,31-2,15-1,31-1,17 15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15-2,31-2,17 15-1,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,16 15-1,31-1,15-1,31-4,15-2,31-1,15-1,31-1,15-2,31-3,17 15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,15-2,31-3, 18 15-1,31-1,15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15 15-2,31-2,15-1,31-2,15-2,31-1,15-4,31-3,15-2,31-1,20 15-1,31-2,15-2,31-2,15-2,31-1,15-4,31-3,15-2,31-1,20 15-1,31-1,15-1,31-2,15-4,31-1,15-1,31-1,15-5,31-1,18 15-1,31-1,15-3,31-2,15-1,31-1,15-2,31-1,15-

1,31-1,14 15-3,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15-2,31-1,18 15-1,31-1,15-1,31-1,15-1,31-2,15-2,31-1,15-1,31-1,12 15-1,31-4,15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,18 15-1,31-3,15-1,31-2,15-2,31-1,15-1,31-3,15-1,31-2,17 15-2,31-1,15-2,31-3,15-1,31-1,15-2,31-1,15-1,31-1,15 15-1,31-1,15-1,31-2,15-2,31-1,15-2,31-2,15-1,31-2,15 15-2,31-1,15-1,31-1,15-3,31-2,15-2,31-1,15-1,31-1,15 15-3,31-2,15-2,31-1,15-1,31-1,15-1,31-1,15-1,31-2, 1515-2,31-1,15-3,31-1,15-5, 12,31-2548, 2548

It was observed that a sequence data 15 and 31 had been arriving at pins of parallel port i.e. only one bit is (left most out of 5 pins under observation) changing its value frequently. This pin was numbered as pin 1. After extracting bit stream from pin 1 from block of data, observation for pin 1 became:

Bits' stream at Pin number 1

1010000010	1000110100	1010001100	1001101100	1001101100
1010111100	1010011100	1001101100	1001110100	1010001100
1001101100	1000011100	1011001100	1000011100	1010110000
1010000010	1000110100	1010001100	1001101100	1010101100
1010111100	1010001100	1011101100	1011101100	1001110100
1010101100	1001101100	1010001100	1010001100	1010101100
1000100000				

Decoded Decimal values at pin 1

65	44	49	54	54	61	57	54	46
49	54	56	51	56	13	65	44	49
54	53	61	49	55	55	46	53	54
49	49	53	4					

ASCII Codes for output at pin 1

A,166=96.16838 (Carriage Return) A,165=177.56115

Conclusion:

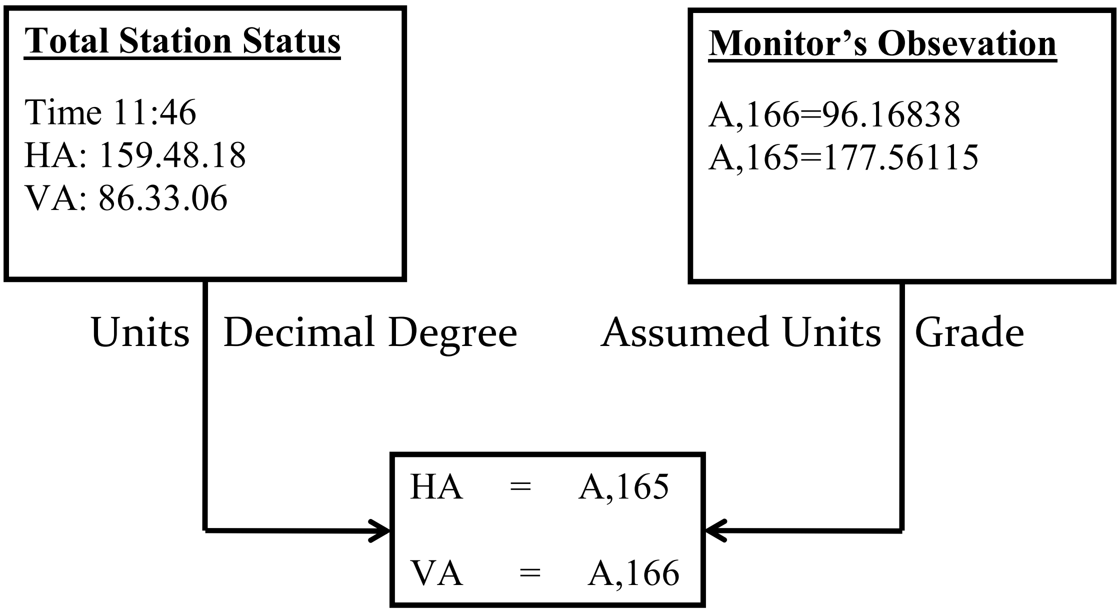


Fig.3.9 Decoding of RTS data

Units at RTS were confirmed to decimal degree (from station setting). At monitoring units were assumed to be grade and a conversion was tried.

96.16838 grade = 86.551542 degree = 86 degree 33.09252 minutes
= 86 degree 33 minutes 5.5512 seconds

Conversion results matched with VA. Thus observation conclude to

VA = A,166 i.e. A,166 is a coded representation of vertical angle.

Similarly: A,165 is coded form of horizontal angle.

Result

Decoding for all other data/parameters like slope distance, temperature, humidity, pressure etc. was completed and a sufficient list of parameters along with their code representation was prepared.

3.5.3.4.2 Observations of Reverse Engineering for Commands

Initial conditions before starting observation for RE for commands

- Bring RTS out of idle state by issuing certain commands from GCU e.g. LASER ON / OFF

- Start monitoring with intensive care
- Internal behavior was recorded by monitor and outer behavior was recorded by RE Engineer

Rest part of observations is exactly similar to as done in article 3.4.3.4.1.

<u>Sample codes of program to make LASER pointer of RTS in on state are as under.</u>

```
*WV,102=0
0.8
*PV,8=9
240.8
*PV,4=0
*WV,102=1
0.8
*WV,102=0
0.8
*PV,3=0
240.8
*WV,102=1
0.8
```

A line with '*' as its first character in a program refer to command to Robotic base otherwise line is data from it.

(a) List of Programs for which RE was completed

- All menu commands
- All Keyboard command
- All programs stored in GCU

(b)Result

Decoding for all programs of GCU was completed and a sufficient list a programs listing was prepared to prepare instruction set of RTS.

3.5.4 Final Result

All the pin connections of RTS were decoded. A sufficient list of parameters' codes and instruction was prepared for interfacing RTS with computer system.

- Pin1 is data out pin connection.
- Pin2 is data input pin connection.
- Pin3 can be a Soft reset / Start / Stop pin.
- Pin4 is 5V supply pin, pin5 is 12Vsupply pin, pin6 is 12V supply pin, and pin7 is ground.
- Variable for holding angles are denoted by 'A'
- Various angle variables are uniquely identified by a numeric code assigned to them
- Letter 'V' is used to denote variable/parameter
- Letter 'W' refer to write and 'R' for read
- Copy of certain RB parameters like temperature, humidity, pressure etc. is also maintained in GCU separately.

3.6 Conclusion

External integration of components in PMTS gives partial standalone independence to them i.e. components can work independently for certain tasks. This may lead to data losses and improper functioning of the system. To avoid it internal integration was done. For example various components were integrated or interfaced via their communication ports which introduces loose coupling among them. They must share their data buses for perfect coupling.

The task of RE was completed up to the required level. Description of all pin connections is known. A list of instructions, their description, station parameters and variable is ready and is sufficient for implementation of controller of PMTS.

Chapter 4

CONTROLLER FOR ROBOTIC TOTAL STATION AND COMPUTER SYSTEM

4.1 Introduction

An interface is introduced between RB and computer system to overcome technical differences between RB and computer system. This interface will establish a communication channel between them. Computer System is a more versatile device as compared to GCU. Presented Interface provides a way to develop applications for RTS. Drawbacks of GCU are the good reasons for the usefulness of the research work presented here. The main drawback of GCU is that it comes with minimum required programs for most common Robotic Applications, further are add-on to standard programs. It may be one of the reasons that RTS could not become popular as a normal Total Station in terms of the cost and gains. In the work presented here, an Interface is developed to make online communication possibilities between RTS and CPU; for commands and data transfer. Based on it, an instruction set is developed which is Embeddable in High Level Language (HLL) like C, Visual Basic, etc. This instruction set provides a platform to interact with RTS and HLL instruction set helps in designing screen layouts, data management, data processing, data presentation, etc.

4.2 Objective

Development of an interface for RB and computer system, instructions set or library of sub-procedures for it to facilitate the users of RTS with a programming tool on Computer System such that Robotic Applications can be developed in any High Level Language (C, Visual Basic etc.) at users' end in accordance of their day to day requirements.

4.3 Selection of Communication Port from Processing Unit (Computer System)

Communication port selected from Processing Unit (PU) should correspond to nature of RB pin connections. A serial communication was observed between RB and its GCU. Therefore a serial port selection was found suitable for PU to make an interface circuit less complex. Although any type of port can be selected from PU at the cost of interface circuit complexity of the communication standard conversion.

4.4 Interface Design for Robotic Base and Processing Unit

There are two options for interface design based on selection of GCU to be present or not in the system. If GCU is removed from the interface then it must be capable of performing all tasks performed by GCU. Interface along with GCU will facilitate user with freedom to interact with RTS via GCU or PU. The second option was selected and interface design used for PMTS has provision of both as shown in Fig.4.1.

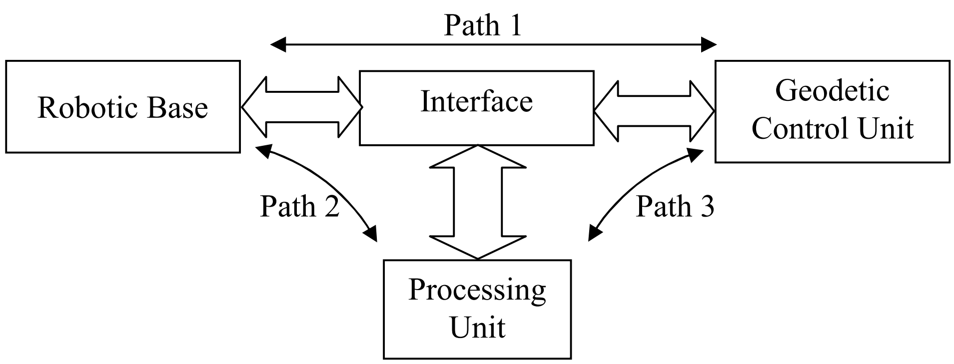


Fig.4.1. Block Diagram of Interfacing Robotic Total Station with Processing Unit

The interface has provision of three communication paths (path1, path2 and path3). When only path 1 is activated a direct communication between RB and GCU will be there and it will demonstrate original behavior of RTS. If path1 and path 3 are deactivated then GCU will appear isolated from the system. In this case over all control goes into the hand of PU. To demonstrate simultaneous control sharing path2 and path3 must be active. Flow of controls and data will observe following path:

Communication path for PU: PU ↔ Interface ↔ RB

Communication path for GCU: GCU ↔ Interface ↔ PU ↔ Interface ↔ RB

The user can interact with RB either via PU or CU. Care must be taken in this mode. After starting a task from any one of the controller user have to wait for completion before issuing another task from another controller. Otherwise system can go into a deadlock situation or results will be inconsistent.

Major responsibilities of the interface will be:

- Creating Isolation Layer among various components.

- Adjustment of logical voltage levels.
- Communication standard conversion.
- Providing switching paths among various components.

4.5 Interface for PMTS

The interface used in PMTS is shown in Fig.4.2.

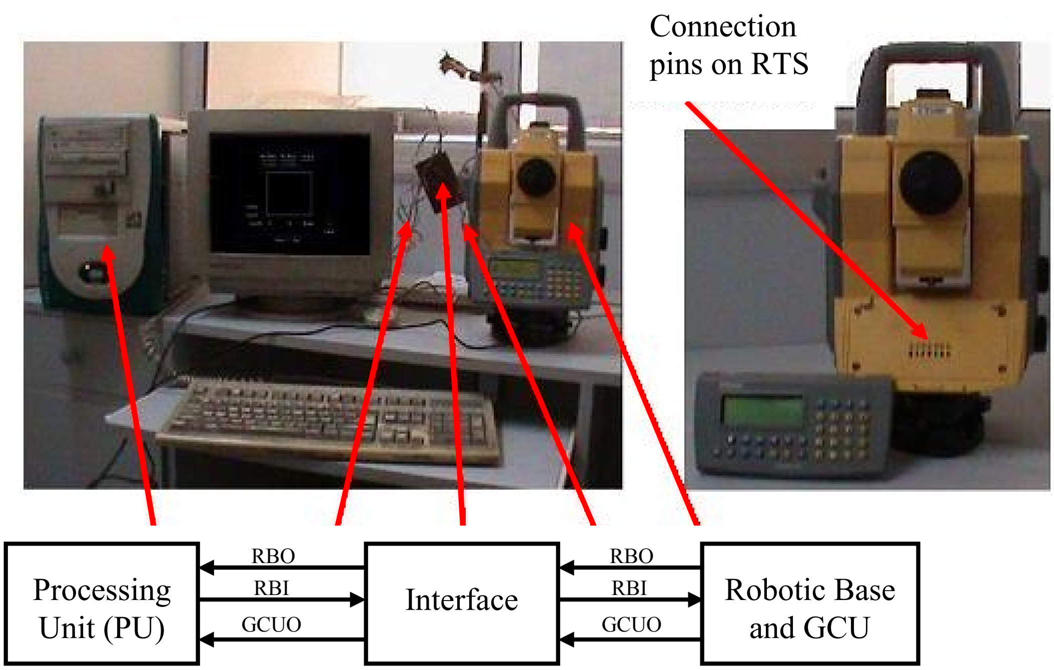


Fig.4.2. Interface for PMTS

Where:

RBO – Output from robotic base

RBI – Input to robotic base

GCUO – Output from the geodimeter control unit

Input to the geodimeter control unit is internally connected to RBO and is not shown in Fig.4.2. RBO is connected to the input of the interface which is bypassed to PU. Output from PU i.e. RBI becomes input to RB via the interface. GCUO is either diverted back to robotic base as RBI by the interface or becomes a separate input to PU via the interface.

4.6 Library of interface routines

The library contains routines for basic operations of RB like initialization, parameter setting, movement of RB, slope distance measurement, etc., along with routines for certain surveying operations to assist the surveyor in surveying with faster speed. Separate libraries are developed in C and Visual Basic programming languages. Routines' name remains same in both the libraries. A sample of library routines, along with their description, is given in Table 4.1. For more details about all library functions and subroutine refer to Annexure II.

Initialization operation is performed at the time of switching ON the RB at the time of station establishment / whenever needed to restart RB. Certain micro operations are performed to bring RB in workable condition. Start ( ) library function will initialize RB to make it ready for survey.

Table 4.1 list of sample routines in the library for PMTS interface

Sr.No.	Routine Name	Description	Parameters	Return value
1	Start( )	To switch ON and initialize robotic base; on success, returns a true value	nil	True/false
2	Set( )	It will assign a value to a station parameter; on success, returns a true value	Parameter ID and its value	True/false
3	Get( )	Return current value of a parameter	Parameter ID	Parameter value
4	movH( )	Move or set telescope of TS at a given horizontal angle	Horizontal angle in grades	True/False
5	movV( )	Move or set telescope of TS at a given vertical angle	Vertical angle in grades	True/False
6	movHV( )	Move or set telescope of TS at given horizontal and vertical angles	Horizontal and vertical angles in grades	True/False
7	Birdeye ( )	To capture panoramic view of the field delimited by horizontal angle	Horizontal angle in grades	Image of field
8	Image_cap_plane( )	Capture an image of field currently in view and places three bench marks on it	nil	Image of field
9	Image_cap( )	Capture an image of field currently in view without any bench marks on it	nil	Image of field

Parameters like temperature, pressure, humidity level, direct/indirect mode, units of measurements, etc. are to be initialized or set before the start of the actual survey. Set(parameter

ID, Value) library function will set the value of particular parameter and Get (parameter ID) will return the current value of the parameter.

Horizontal and vertical movements of TS are controlled by movH(Horizontal angle), movV(Vertical angle) and movHV(Horizontal angle, Vertical angle) functions. The first function is meant for horizontal movements of TS, the second function is meant for vertical movements of TS and third function is meant for movements in both directions simultaneously.

Application routines, for assisting surveyor, are groups of basic routines to provide an easy way for surveying. Panoramic view of field can be obtained with Birdeye (H_angle) routine, where 360 degree view can be delimited by H_angle e.g. Birdeye (275) will generate 275 degree view of the field. Image_cap_plane( ) routine will capture images of the field currently in view and will automatically mark three benchmarks on the image and also record metadata of the image. Image_cap( ) routine capture image along with image metadata and does not place any benchmark. In it benchmarks will be decided by the surveyor.

4.7 Parallel Execution with other components

There are five major components of the system which will execute in parallel:

a) Digital Camera
b) Interface Circuit (IFC)
c) GCU
d) RB
e) PU

Except interface circuit all others have built in processing capability and can work independently. PU has to interact with all these components simultaneously. PU deals directly with Digital Camera and interface circuit. GCU and RB remain hidden from it. Therefore, from the point of view of PU, parallel execution of Interface Circuit and Digital Camera must be managed in an efficient and reliable way.

First application developed in Visual Basic was based on time sharing of PU between DC and IFC using timer control. Operations were observed for three months. It was observed that the system went into a deadlock situation in average time duration of three days.

Live Video mode of Digital Camera is time critical and consumes most of the execution time of PU. On the other hand time interval between two requests or two responses from IFC is comparably large. Thus a decision to make event based interaction with IFC was taken. It results in a big improvement of two to three times failures in a month.

The main reason of failure observed was execution time of a RB routine. As RB is a mechanical device and it takes time to complete a routine. On starting RB routine PU completely becomes engaged with IFC and no time is given to DC. It results in overflow of video frames and brings the system in a deadlock situation. Thus again revised version was developed with the provision of halting DC for the duration of RB routine execution. It results in good improvement of one failure in a month in the form of corrupted video.

As a final improvement, TS routine execution was further divided at the micro instruction level and in one cycle of PU only one micro instruction was allowed for execution without halting DC. No system failure was observed after this improvement.

4.7.1 Execution Cycle on an Event from IFC

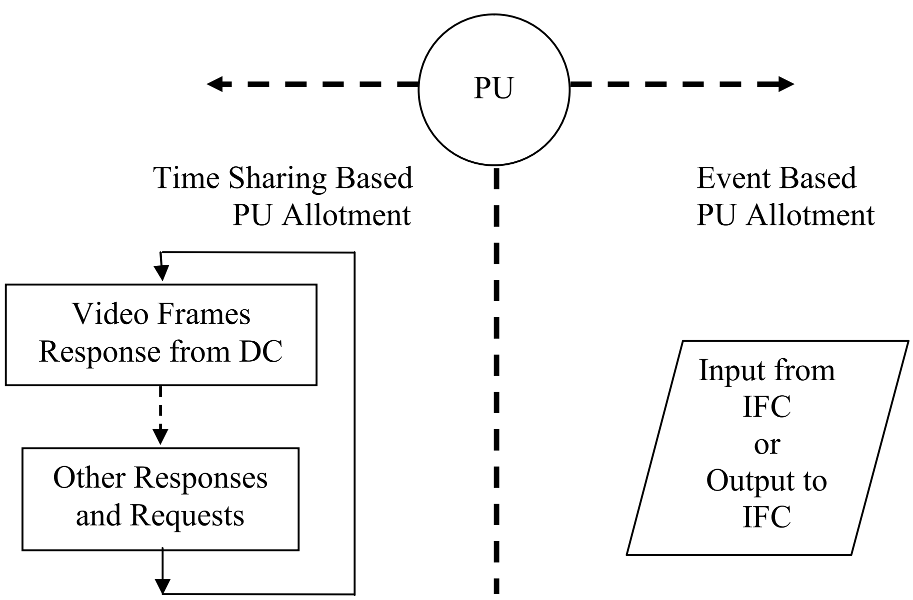


Fig.4.3 PU allotment and scheduling for PMTS

In case no event is generated by IFC, video frames are received in time sharing mode with surveyor responses, input stream parsing, etc. When a micro event, I/O or similar to I/O request, is generated by IFC then it is added to time sharing mode and PU starts interacting with IFC. On completion of I/O request previous time sharing mode will be resumed again.

IFC will generate an event only when it wants to send data to PU. On receiving data PU either consume it or send it back to IFC. In this case, PU work like a bypass. No event will be generated when PU sends data to IFC. Example of bypassing data is when GCU sends data to RB. The path of data flow will be from GCU to PU and then from the PU to RB via IFC i.e. from IFC to PU and from PU back to IFC.

4.7.2 Execution Cycle of TS routine

By calling a TS routine system variable k is set to a value equal to the number of micro instructions in the routine and n is initialized with value 1. TS routine is now ready to participate in time sharing mode with other components of the system.

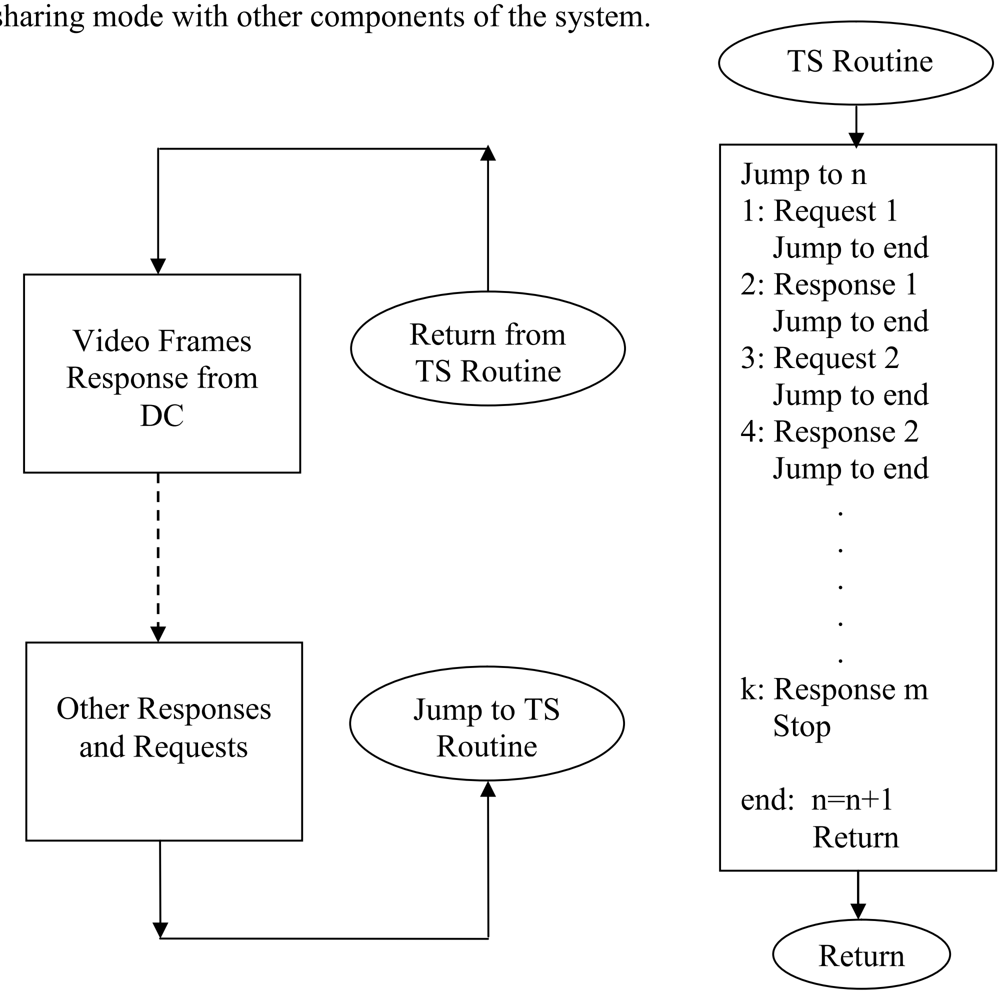


Fig.4.4 Execution Cycle on calling a TS Routine

On the turn of TS routine PU will issue only one micro instruction to IFC for TS. A request is a micro instruction of type command given to TS to perform a micro task. Against each command, TS will return a response to PU. In case of a Response, PU will wait for TS status. If wait is complete, control is transferred to instruction next two response else PU time is shared with other components of the system.

4.8 Controller of PMTS in C Language

The first version of controller developed in C language for controlling various functions of RTS from the computer system is described below:

4.8.1 Hardware and software requirements

- Computer system with two free serial communication ports.
- RTS with GCU.
- Interface card.
- Operating system: MS-DOS/Windows 98/Windows XP.
- Runtime environment for C programs.

4.8.2 Important Features

- Real time data transfer to the computer system.
- Controlling Robotic Functions from the computer system.
- Modes of command transfer: a) From GCU, b) From CPU.
- Both modes of command transfer are active simultaneously.
- Conversion of VA, HA and slope distance into ENH (Easting, Northing, Height).
- Drawing online map.
- Permanent storage of survey data.

4.8.3 Robotic Total Station (Trimble 5601 DR200+)

All experimental results shown are based on RTS of Trimble (5601 DR200+). In RTS 5601 DR200+ purpose of the laser pointer is same as of sighting vein, EDM: to measure distances electronically, telescope: to precisely locate the target feature, antenna: to receive signals containing control commands from a remote location, electronic theodolite: to measure angles (VA and HA), servo control knobs: to control servo motors for horizontal and vertical movements, Geodimeter Control Unit (GCU) is the user interface with RTS.

Fig.4.5 Robotic Total Station (Trimble 5601 DR200+)

4.8.4 Layout of user interface

A user interface was developed in C language as shown in Fig.4.5.

Responses from the user are received in the form of keys shown in red color. Description of user responses is given on next page:

Fig. 4.6 Layout design of interface software developed in C language

R – Press R to record / save survey data into a file for the permanent storage.

Arrow keys – Press arrow keys (left, right, up and down) to adjust horizontal and vertical positions of theodolite by one step.

S – Press S to set the value of one step of the arrow keys (current step = 5 minutes).

Responses from computer system:

Hor. Angle: Horizontal angle, Ver. Angle: Vertical angle, Distance: Slope distance

Point ID: Unique identification of feature under observation.

E: Easting i.e. X value, N: nothing, i.e. Y value, Height: Height i.e. Z value.

4.8.5 Working Procedure of Controller Developed in C Language

Step1. Station establishment: It include

a) Station position selection.
b) Centering and leveling of RTS.
c) Interface connections with RTS and CPU.
d) Activation of RTS and software application.
e) Station parameters setting.

After station establishment output screen was as shown in Fig.4.6. Name of the RTS along with the current value of horizontal and vertical angles was displayed on the screen.

Fig. 4.7 Output Screen on successful connection of RTS with CPU

Fig. 4.8 Slope Distance measurement – Press D from CPU or A/M from GCU

Step2. Slope distance measurement:

Data from electronic theodolite i.e. value of angles (HA, VA) is always available without any user action. But to know slope distance one is required to issue a command either from the CPU or from GCU. There are two ways to measure it. One way is to press 'D' from the keyboard of the computer system and the other way is to press 'A/M' key from the keyboard of GCU. of a second (less accuracy) to few seconds (good accuracy) to measure the distance. Time taken in distance measurement is proportional to the accuracy requirements. In success result will be shown under the label 'Distance'.

press ('D' or 'A/M') EDM starts measurement of slope distance and it may take a fraction

Step3. Coordinate conversion:

Conversion from polar to rectangular coordinates will be automatically done after slope distance measurement in the GCU. In case of computer system, users will be required to press 'M' from the keyboard for coordinate conversion. The formula used for conversion is shown in equation (4.1).

$$H = sd \times \cos\left(\frac{11 \times va}{700}\right) \quad \ldots (4.1)$$

$$Y = sd \times \sin\left(\frac{11 \times va}{700}\right)$$

$$E = Y \times \cos\left(\frac{11 \times ha}{700}\right) \quad \ldots (4.2)$$

$$N = Y \times \sin\left(\frac{11 \times ha}{700}\right) \quad \ldots (4.3)$$

Fig. 4.9 Conversion from Polar coordinate system to rectangular coordinate system

Where: va and ha are vertical and horizontal angles in fractional grades.

sd – Slope distance, E-easting, N-northing and H-height.

Results are shown under the labels E, N and Height as shown in Fig.4.8

Step.4 Registration of Data:

Press 'R' to record or register 3D data captured in the previous step. An automatic pointID will be generated and if a user wants to change it, then press 'P'. In case of GCU to register 3D data can be registered by pressing ‘REG’ key from the keypad of GCU. It must be noted that data file in GCU will be maintained separately, a data file in the computer system no relation with it, like number of points stored, data format etc.

Step 5. Repeat:

If there are more earth features pending for registration, then set the total station to point next feature using either control knobs on the RTS or arrow keys of computer system. If there is no pending earth features, then stop.

Fig. 4.10 Assigning Feature ID to currently recorded feature.

4.9 Results

Controller for PMTS is functioning properly as per requirements. Logical voltage levels and communication differences among various components of PMTS are compensated. All types of data encoding, decoding and format conversions are handled by PU. PU is also doing the job of translation and interpretation of RB’s instructions. Two separate libraries of subroutines were developed (Annexure II). One out of these libraries is for developing application in C language and the other is for Visual Basic application development. Both the libraries are replicas of each other i.e. they contain exactly the same number of subroutines with the same name. A subroutine present in both the libraries will perform same subtask. The difference is in their writing syntax according to the language under consideration.

4.10 Conclusion

This chapter concludes with a fundamental platform for PMTS. This platform is capable of handling function of PMTS at low level details and hides them from the application developers. A programmer can develop programs for robotic applications for RB as per the requirements without using hardware details.

Chapter 5

INTEGRATION OF CAMERA WITH TOTAL STATION

5.1 Introduction

Integration of Photogrammetric System (Digital Camera) and Total Station involved in mounting of camera on RB with a rigid support and its optical orientation. In PMTS single camera is used for capturing the image and live view of the field (one task at a time). For it, suitable place for mounting the camera is the telescope of TS. The camera view was used to assist TS movements and targeting i.e. camera replaces the functions of the telescope in an RTS. It requires that camera view must be parallel to telescopic view, i.e. all angular orientation parameters must be zero.

In the first phase of integration, mounting of the camera on telescope was carried out. A second phase was involved in orientating the camera w.r.t. Telescope. Mapping of station coordinates to photo-coordinates and vice versa was done in the last phase.

5.2 Objective

Integration of the photogrammetric system with total station is the primary objective in this chapter. Other objectives include assignment of all telescopic functions to the camera system and to prepare a base for automatic object targeting for making surveying work an effortless, less time consuming and fatigue free task.

5.3 Assumptions

Throughout the research work following assumptions were made:

- Total Station is represented by its telescope i.e. total station coordinates will refer to the coordinates of the telescope.
- Y-axis of the telescope represents a reference line (nothing).
- X-axis of the telescope represents Easting.
- Z-axis of the telescope represents Elevation.
- To maintain homogeneity with TS coordinate system, photo coordinate system was assumed as X and Z axis, i.e. Y axis of photo coordinates is represented by Z axis.

5.4 Mounting Camera on Total Station

Proper planning for mounting the camera on total station will make the task of mapping camera coordinates, i.e. photo coordinates to total station coordinates and vice versa, less complex and better understood.

Integration of the photogrammetric system with total station can make use of one, two or more cameras. Mounting the camera over the handle of the Total Station will fix the vertical movement of camera view and will lead to requirement of additional camera fixed to the telescope for live view as shown in Fig.5.1. If this option is used, then the main camera fitted over handle must be of high resolution camera and live view camera may be a low resolution camera. This arrangement introduces more complexity to the system. It requires an extra orientation work for additional camera and may result in hybrid system. A second camera if fitted over eyepiece will provide a parallel view with a telescope, but it will get narrowed up to the telescopic view level and will not provide the required wider width (for more freedom). Moreover, such arrangement will require frequent orientation work.

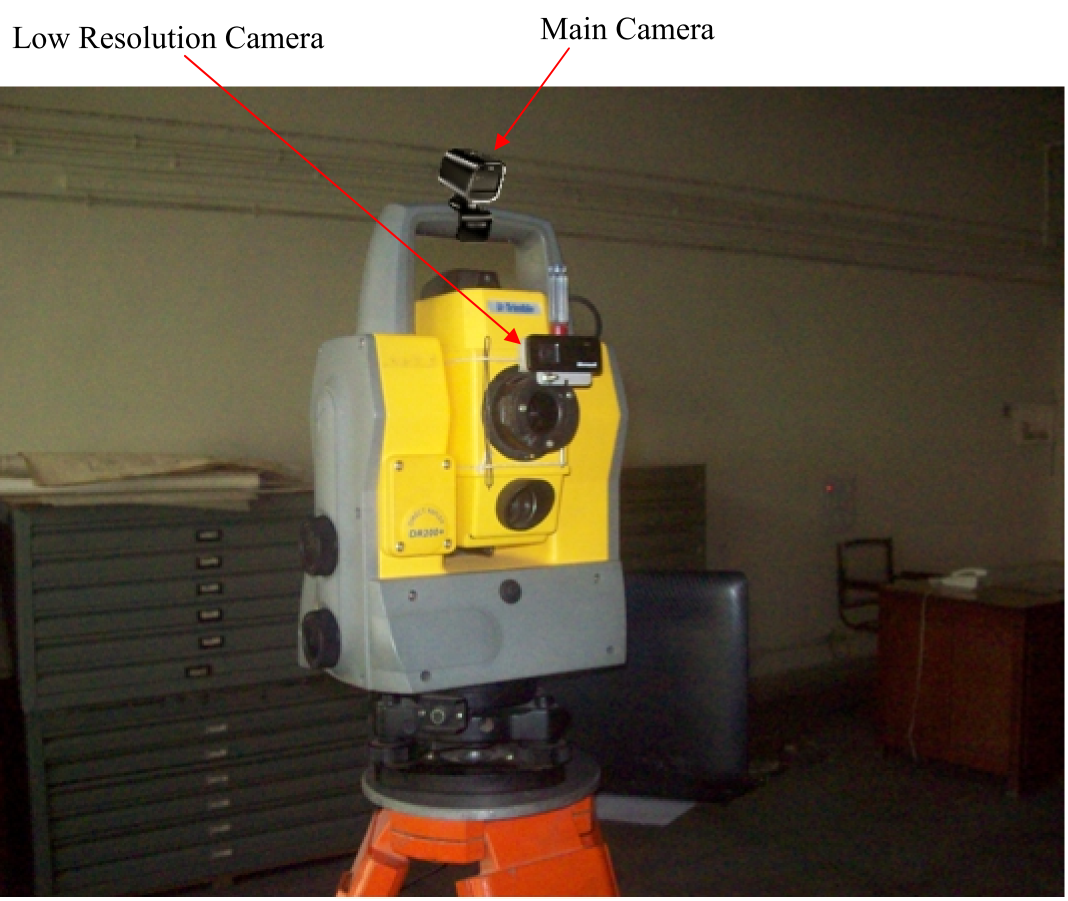


Fig.5.1 Camera mounting over handle position of Total Station

Another option was to have a single camera mounted over telescope at a suitable position other than an eye piece to have a broader view of the field as shown in Fig.5.2. All the angular orientation parameters have to be initialized to zero value to have a parallel view with the telescope. On capturing a high resolution image of the field, this camera is no more required until a next image is to be captured. The same camera was used for live view of the field (by default digital cameras come into a live video mode after capturing an image). Video resolutions can be altered by issuing parameter setting command. Each image captured has to be oriented separately. There is a provision for changing camera constant for full coverage of area for the same station position by capturing multiple images (near and far areas). Again orientation work has to be carried in it also. After station establishment TS Coordinate System (TCS) gets oriented with Ground Coordinate System (GCS). For camera orientation, there are two options a) Orientation relative to GCS, b) Orientation relative to TCS. For second option station offsets parameters (E, N, and IH) will not be used during orientation work and complexity will get reduced online. After completing the survey, final observations will be oriented relative to GCS for the purpose of geo-referencing.

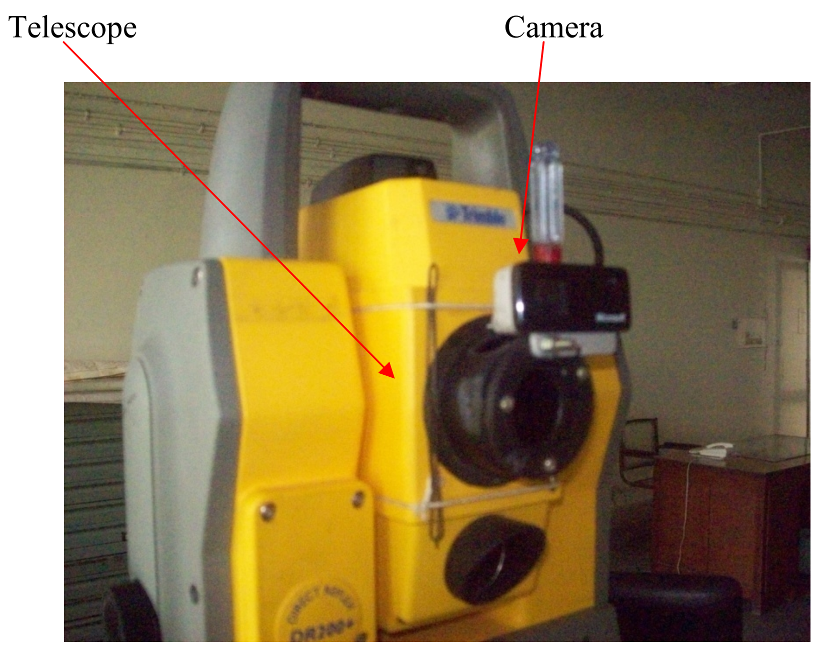


Fig.5.2 Single Camera arrangement for live view and Mapping

The second option was selected for PMTS. In PMTS all angular orientation parameters were initialized to zero value.

5.4.1 Angular Orientation

In PMTS camera will replace the functions of the telescope. Thus, both must have parallel view. It is possible to orient both the devices for non zero angular orientation parameters, but it will restrict practical use of PMTS. To nullify these parameters following calibration procedure was done:

5.4.1.1 Camera twist removal: Using Plum Bob

Twist removal is much simpler, but if present, will make a mathematical model of the system much complex. It was removed first. Following steps were used to remove it.

Fig.5.3 Alignment of plumb bob with cross-hair of live video.

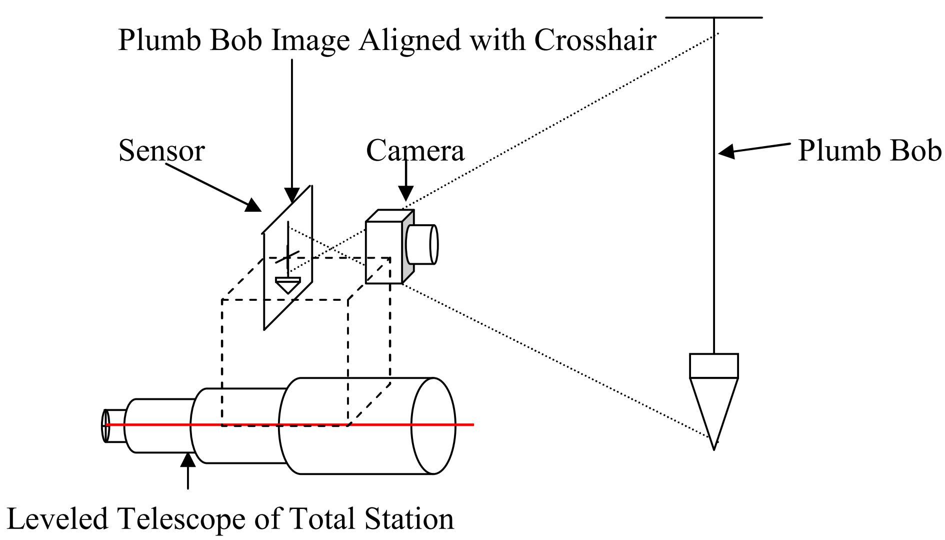


Fig.5.4 Camera Twist Removal Arrangement

a) PMTS Station establishment (only leveling is required)
b) A Plum Bob was hanged in front of camera with sharp and full visibility in the image as shown in Fig.5.3 and shown in Fig.5.4.
c) A cross hair was drawn at the centre of the image.
d) Vertical line of cross hair was aligned with the plum bob image in the photograph by rotating the camera about the Y axis (refer to Fig.5.3).

5.4.1.2 X-parallax and Z-parallax removal

Parallax removal was completed in two phases. In phase1 parallax was calculated and in phase2 parallax was verified.

Phase1: Parallax calculation (Assuming Yoffset = 0).

To calculate X and Z parallax following steps were performed:

a) A station was established in a plane area.
b) Vertical angle was set to zero value (parallel to the horizon, in RTS Trimble 5600 VA=90 degrees).
c) A white board WB1 was placed in front of the telescope at distance 2D and was leveled with plum bob shown in Fig.5.5.
d) A black sheet BS1 was positioned (aligned with plum bob) on white board such that its right top corner coincided with cross hair of the telescope.
e) The camera was adjusted such that cross hair at the centre of the image coincided with the right top corner of BS1.
f) The telescope and camera were kept untouched for the rest of the steps.
g) Another white board WB2 was placed in front of the telescope at distance D and was leveled with plum bob shown in Fig.5.5.
h) A black sheet BS2 was positioned (aligned with plum bob) on WB2 such that its right top corner ‘A’ agreed with cross hair of the telescope.
i) Another black sheet BS3 was positioned (aligned with plum bob) on WB2 such that it’s left bottom corner ‘B’ agreed with cross hair of the camera image.
j) A vertical line was drawn from ‘A’ and horizontal line from ’B’ to meet at ‘C’.
k) X offset was measured as twice the length of BC and Z offset as twice the length of AC

From right angled and similar triangles A’C’O and ACO shown in Fig.5.6 (a) and (b).

$$
\begin{aligned}
A'C' / AC &= A'O / AO \\
&= 2D / D \\
&= 2
\end{aligned}
$$

Therefore Zoffset, A’C’ = 2AC

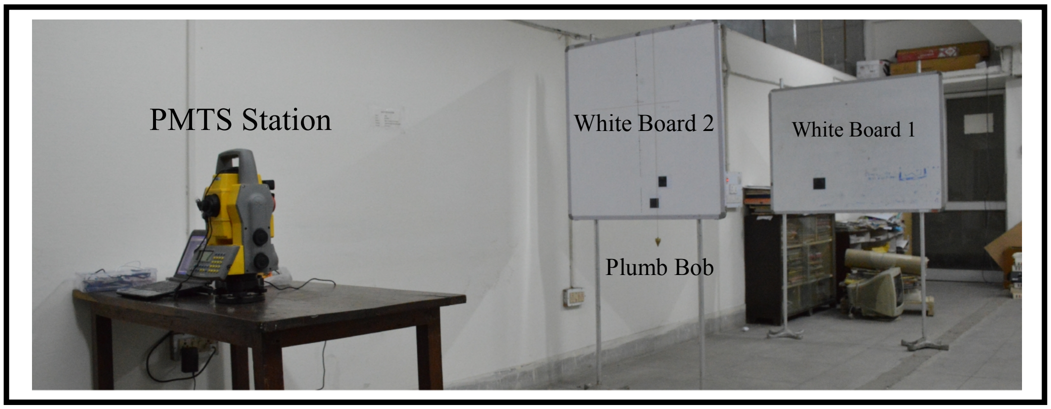
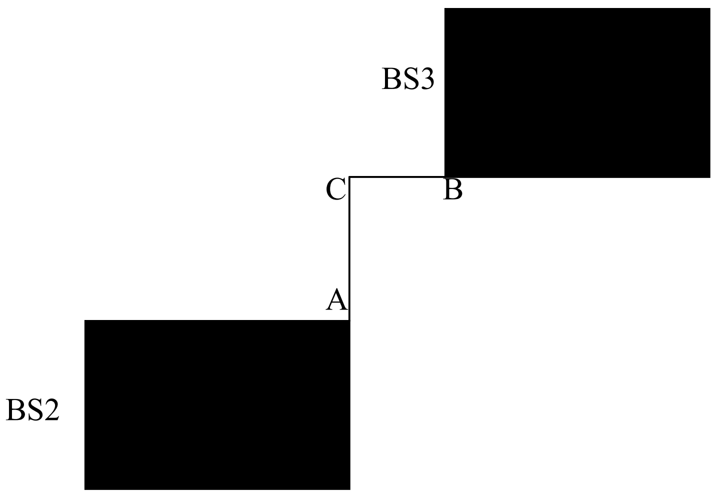
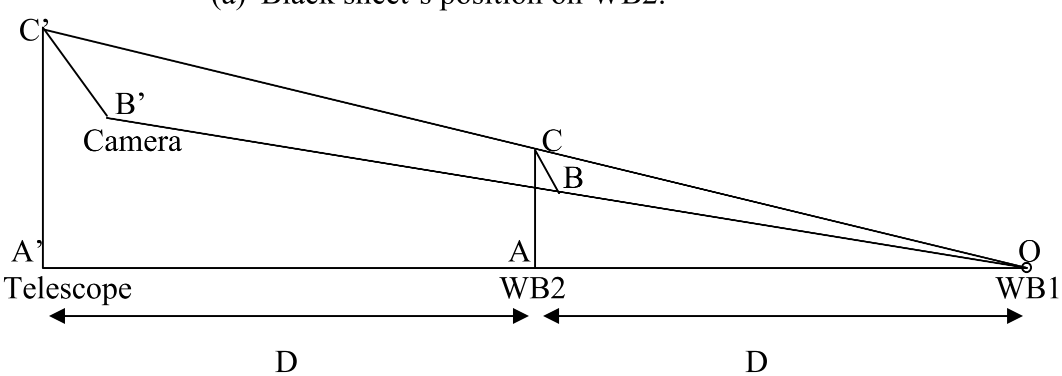


Fig.5.5 Arrangement for parallax removal in PMTS.



(a) Black sheet’s position on WB2.



(b) Schematic Diagram of positions of Telescope, Camera and White Boards

Fig.5.6 X and Z parallax removal

Similarly from triangles B’C’O and BCO

Xoffset, B’C’=2BC

Note: In case of non zero Yoffset

Distance of WB2 from Station position = D - Yoffset

Distance of WB1 from Station Position = 2D - Yoffset

Value of D: Distance of the first white bread from station position has a compromise with its value. Its value is mainly delimited by a) Size of pixel at D, b) Range of the telescope. At larger distances, size of a pixel may be enlarged enough to become comparable with X offset or Z offsets and hence offsets will become unobservable in the camera image. Therefore D must be greater than the minimum limits of the telescope and camera focus; D must be smaller than the distance where the pixel size becomes larger than either of the offsets.

5.4.2 Orientation Offsets

Selected RTS has certain limitations for mounting camera system over it. In this article all possible combinations for camera offsets are explored in suitability analysis. It must be noted that all equations described in this article assumed that the telescope and camera are leveled with the horizon.

5.4.2.1 All zero offsets

The best case is when principle points and principle axis of both the device are common Fig.5.7, i.e. the camera is mounted in the telescope of TS such that both of them have same principle point and same principle axis. This is the simplest case for mapping perspective space to 3D space and vice versa. Processing complexity will be at a minimum level. This case will disturb the functioning of EDM, telescope and camera itself. The LASER beam from EDM will disturb projection of the field on the sensor. The camera will become an obstacle for LASER beam during distance measurement. Therefore, some arrangement like in SLR camera will be required in this case.

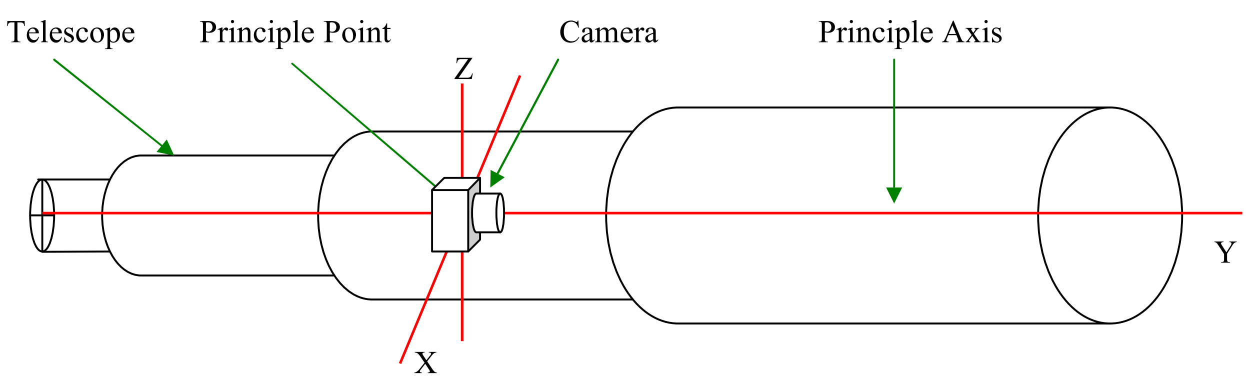


Fig.5.7 Arrangement with common principle point and principle axis for camera and telescope

Let three dimensional plane PL (aX + bY + cZ + k=0), represents a portion in the field. A point P (X, Y, Z) in plane PL is projected on the sensor at P'(X', Z'). Using the lens equation, the value of X' and Z' will be given by following equations:

$$X' = \frac{f.X}{Y-f} \qquad \dots (5.1)$$

$$Z' = \frac{f.Z}{Y-f} \qquad \dots (5.2)$$

Where: f is Camera Constant.

Equation (5.1) and (5.2) will map TS coordinates to Photo coordinates. Equations (5.3) and (5.4) are derived from equations (5.1) and (5.2) will work in reverse direction i.e. mapping of photo coordinates to TS coordinates.

$$X = \frac{X'(Y-f)}{f} \qquad \dots (5.3)$$

$$Z = \frac{Z'(Y-f)}{f} \qquad \dots (5.4)$$

On left hand side of equations (5.3) and (5.4)

- f is known.
- X' and Y' will be obtained from the image of the field.
- Y is unknown.

Unknown Y was lost during the process of projection and can be recreated by finding the intersection point of equations (5.3) and (5.4) with equation of plane PL.

5.4.2.2 One non zero offset

Mounting a camera with single non-zero offset will serve as a better option. In this case the principle point of the camera will be positioned on one of the principle axis (X, Y and Z) of the telescope and is away from the origin (principle point of the telescope) as shown in Fig.5.8. There are three possible cases of it:

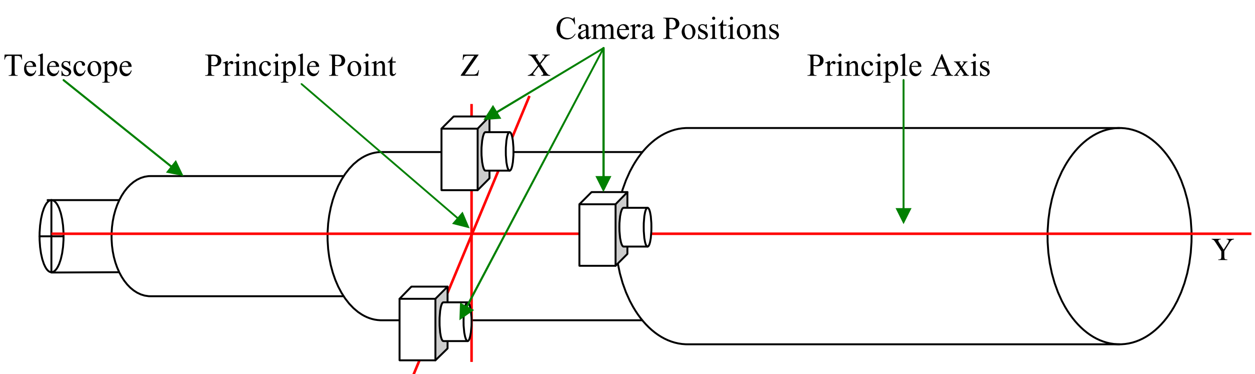


Fig.5.8 Camera Positions in reference to Telescope with one non zero offset.

a) Non zero X offset:

Principle point of the camera lies on the trunnion axis of the telescope. Perspective space will be symmetric along Z axis, but not along the X axis of telescope, which complicates the process of mapping.

A point P (X, Y, Z) in plane PL will be represented by Point P' (X-Xoffset, Y, Z) in photo coordinates. Equation for perspective transformation will be obtained by replacing X with X-Xoffset in equation (5.1) and (5.2) i.e. Telescope coordinates to photo coordinates conversion will be given by following equations:

$$X' = \frac{f.(X-Xoffset)}{Y-f} \qquad \ldots (5.5)$$

$$Z' = \frac{f.Z}{Y-f} \qquad \ldots (5.6)$$

Similarly, photo coordinates to telescope coordinate conversion can be derived from equation (5.3) and (5.4) by replacing X with X – Xoffset as given below:

$$X = \frac{X'(Y-f)}{f} + \text{Xoffset} \qquad \ldots (5.7)$$

$$Z = \frac{Z'(Y-f)}{f} \qquad \ldots (5.8)$$

In equations (5.7) and (5.8) value of X, Y, and Z will be calculated in reference of plane equation PL because of unknown Y in left hand side.

b) Non zero Y offset:

Perspective space will be symmetric along X axis and Z axis; thus the mapping process will be simple. Functioning of EDM, telescope and camera will be mutually disturbed and some arrangement like in SLR camera will be required.

Equations:

Non zero Y offset will produce Y parallax between Telescope and Camera. Any horizontal and vertical movement of telescope / TS will produce spatial movement of objects in the image. Telescope coordinate to perspective Photo coordinate conversion can be derived from equations (5.1) and (5.2) by replacing Y with Y – Yoffset as given below:

$$X' = \frac{f.X}{Y-Yoffset-f} \qquad \ldots (5.9)$$

$$Z' = \frac{f.Z}{Y-Yoffset-f} \qquad \ldots (5.10)$$

Perspective photo coordinates conversion to telescope coordinate conversion will be achieved using equation of plane PL and following equations:

$$X = \frac{X'(Y - Yoffset - f)}{f} \quad \dots (5.11)$$

$$Z = \frac{Z'(Y - Yoffset - f)}{f} \quad \dots (5.12)$$

c) Non zero Z offset:

PP of the camera lies on the Z axis of the telescope. Perspective space will be symmetric along X axis, but not along the Z axis and mapping process will be less complex.

Non zero Zoffset equations for telescope coordinates to perspective photo coordinates conversion are as under:

$$X' = \frac{f.X}{Y - f} \quad \dots (5.13)$$

$$Z' = \frac{f.(Z - Zoffset)}{Y - f} \quad \dots (5.14)$$

Conversion of perspective coordinates to Telescope coordinates will be done using equation of plane PL and equations given below:

$$X = \frac{X'(Y - f)}{f} \quad \dots (5.15)$$

$$Z = \frac{Z'(Y - f)}{f} + Zoffset \quad \dots (5.16)$$

5.4.2.3 Two non zero offsets

In this case only one of the three offset will be zero. PP of camera will rest inside one of the three principle planes, i.e. either in XY plane, XZ plane or YZ plane as shown in Fig.5.9. There are three cases for it:

a) Zero X offset: PP of the camera lies in the YZ plane.
b) Zero Y offset: PP of the camera lies in the ZX plane.
c) Zero Z offset: PP of the camera lies in the XY plane.

Mapping process will be comparatively simple in case of Zero X offset and Zero Z offset because perspective space will be symmetrical along one of the axis X or Z. In case of Zero Y offset perspective space will not be symmetrical to any axis.

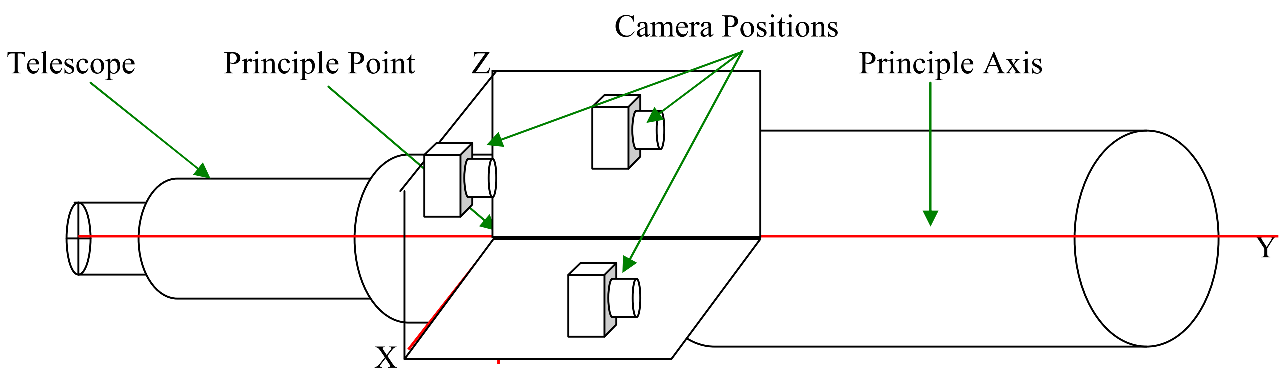


Fig.5.9 Camera positioned inside one of the Principle Planes of Telescope.

Telescope coordinates to the perspective photo coordinates conversion for all three cases derived from equations (5.1) and (5.2) are as under:

a) Zero Xoffset:

$$X' = \frac{f.X}{Y-Yoffset-f} \quad \ldots (5.17)$$

$$Z' = \frac{f.(Z-Zoffset)}{Y-Yoffset-f} \quad \ldots (5.18)$$

b) Zero Yoffset:

$$X' = \frac{f.(X-Xoffset)}{Y-f} \quad \ldots (5.19)$$

$$Z' = \frac{f.(Z-Zoffset)}{Y-f} \quad \ldots (5.20)$$

c) Zero Zoffset:

$$X' = \frac{f.(X-Xoffset)}{Y-Yoffset-f} \quad \ldots (5.21)$$

$$Z' = \frac{f.Z}{Y-Yoffset-f} \quad \ldots (5.22)$$

Perspective photo coordinates to telescope coordinate conversion in conjunction with equation of plane PL derived from equations (5.3) and (5.4) are as under:

a) Zero X offset:

$$X = \frac{X'(Y - Yoffset - f)}{f} \qquad \dots (5.23)$$

$$Z = \frac{Z'(Y - Yoffset - f)}{f} + Zoffset \qquad \dots (5.24)$$

b) Zero Y offset:

$$X = \frac{X'(Y - f)}{f} + Xoffset \qquad \dots (5.25)$$

$$Z = \frac{Z'(Y - f)}{f} + Zoffset \qquad \dots (5.26)$$

c) Zero Z offset

$$X = \frac{X'(Y - Yoffset - f)}{f} + Xoffset \qquad \dots (5.27)$$

$$Z = \frac{Z'(Y - Yoffset - f)}{f} \qquad \dots (5.28)$$

5.4.2.4 All offset are non zero

This is the worst case because of its maximum complexity. In it, three perspective translations will be required before the mapping of camera and telescope coordinates. PP of camera does not rest on any of the principle axis as shown in Fig.5.10.

Telescope coordinate system transformation to Perspective photo coordinate is derived from the equation (5.1) and (5.2) by replacing X with X-Xoffset, Y with Y-Yoffset and Z with Z-Zoffset is given below:

$$X' = \frac{f.(X - Xoffset)}{Y - Yoffset - f} \qquad \dots (5.29)$$

$$Z' = \frac{f.(Z - Zoffset)}{Y - Yoffset - f} \qquad \dots (5.30)$$

Perspective photo coordinate transformation to telescope coordinate system is derived from the equation (5.29) and (5.30), using cross multiplication, is given below:

$$X = \frac{X'(Y - Yoffset - f)}{f} + Xoffset \qquad \dots (5.31)$$

$$Z = \frac{Z'(Y - Yoffset - f)}{f} + Zoffset \qquad \ldots (5.32)$$

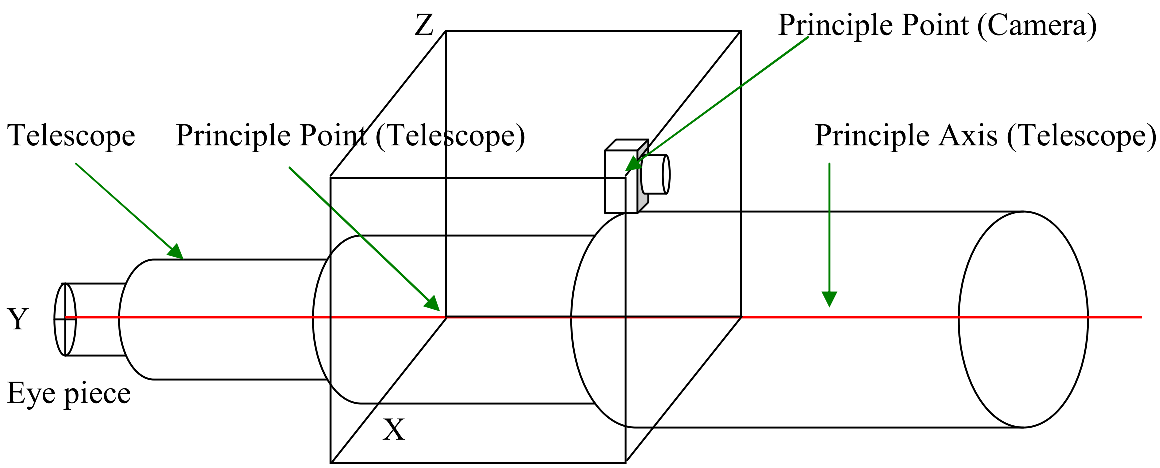


Fig.5.10 Camera Position in Telescope Coordinate System with all non zero offsets

5.4.2.5 Selection of place for mounting Camera on Telescope

While selecting a place for mounting the camera an approach of minimal value of offsets was used. As discussed earlier, fitting the camera inside the telescope may disturb its factory setup or calibration. Thus mounting is bounded by casing of the telescope. Most suitable place found for it was above the telescope with zero value of Xoffset.

5.5 Mapping of Total Station coordinates to Photo coordinates

Mapping here refers to the establishment of an optical relation between the two coordinate systems such that photo coordinates of a given point P (X, Y, Z) in total station space can be calculated and vice versa. Perspective projection of a point P on the sensor of DC will convert its coordinates to photo coordinates. The process of mapping photo coordinates to the TCS will involve two dimensional to three dimensional mapping, i.e. recreation of third dimension lost in process of projection. Photo Coordinates contains only X and Z values and each pixel is portrayed in Rectangular Coordinate System (RCS). Total Station measures surveying features in Spherical Coordinate System (SCS) i.e. Slope Distance (SD), Horizontal Angle (HA) and Vertical Angle (VA). Simultaneously TS also provide X, Y and Z values in Cartesian Coordinate System (CCS) by applying trigonometric functions on SCS values.

In intermediate processing GCS will not participate during coordinate conversions. Total station Coordinate System (TCS) will be central coordinate system, i.e. the coordinates of the optical center of the telescope will be (0, 0, 0) for intermediate processing. Final results will be translated to GCS by amount of station coordinates. It will save a lot of processing time during station movements and in other activities.

Prior to starting mapping certain basic terms are discussed here.

5.5.1 Basic elements

To simplify the mapping process certain additional elements of field which can describe it in a better way, virtual components which provide the linkage between two physical components in a simpler manner and various variable used during the process of mapping are described below:

5.5.1.1 Polygon Plane in 3D (PP3D)

A PP3D is a region inside field which can be considered as a smooth area under given engineering scale. It may or may not be perfectly smooth, but in reference of currently used engineering scale it must be as good as a perfectly smooth area.

Equation of PP3D was obtained by measuring three suitable points inside it with the help of TS in reference of the image taken.

Let θ and α are the horizontal and vertical angles of the photograph of the field. P' (r_p, θ_p, α_p), Q' (r_q, θ_q, α_q) and R' (r_r, θ_r, α_r) are three points inside PP3D measured with TS. In reference to images taken these points are to be rotated by - θ horizontally and by -α vertically. Thus transformed points will be P (r_p, θ_p-θ, α_p-α), Q (r_q, θ_q-θ, α_q-α) and R (r_r, θ_r-θ, α_r-α). Let these points are represented in Cartesian coordinate system as P (x_p, y_p, z_p), Q (x_q, y_q, z_q) and R (x_r, y_r, z_r). Equation of PP3D embedded in three dimensional Euclidean space passing through three non collinear points will be:

$$C_1X + C_2Y + C_3Z + K = 0 \qquad \ldots (5.33)$$

To find the value of C_1, C_2, C_3 and K first calculate non zero vector $\vec{n}$ orthogonal to the plane using cross product of two vectors on the plane as shown below:

$$\vec{n} = \overrightarrow{PQ} \times \overrightarrow{PR} = (x_q - x_p, y_q - y_p, z_q - z_p) \times (x_r - x_p, y_r - y_p, z_r - z_p)$$

$$= n_x.i + n_y.j + n_z.k$$

Equation of plane in vector form is given by the dot product of general vector on plane from point P and normal vector n from point P as shown below:

$$\vec{n} \, . \, \overrightarrow{PN} = 0$$

or

$$n_x.(X-X_p) + n_y.(Y-Y_p) + n_z.(Z-Z_p) = 0 \quad \ldots (5.34)$$

After solving equation (5.34) all coefficients of equation (5.33) will be obtained.

5.5.1.2 Field

Surveying Field is described as a set of PP3Ds of the maximized area with no overlap to avoid redundancy. Representation of curved areas of field in term of PP3Ds will be analogous to football shape.

5.5.1.3 Threshold Distance

Threshold Distance (TD), shown in Fig.5.11, is the distance from station position at which size of pixels is equal to engineering scale. Beyond TD, pixel size does not satisfy it. Circle with centre at station position and radius equal to TD is called Circle of TD (CTD).

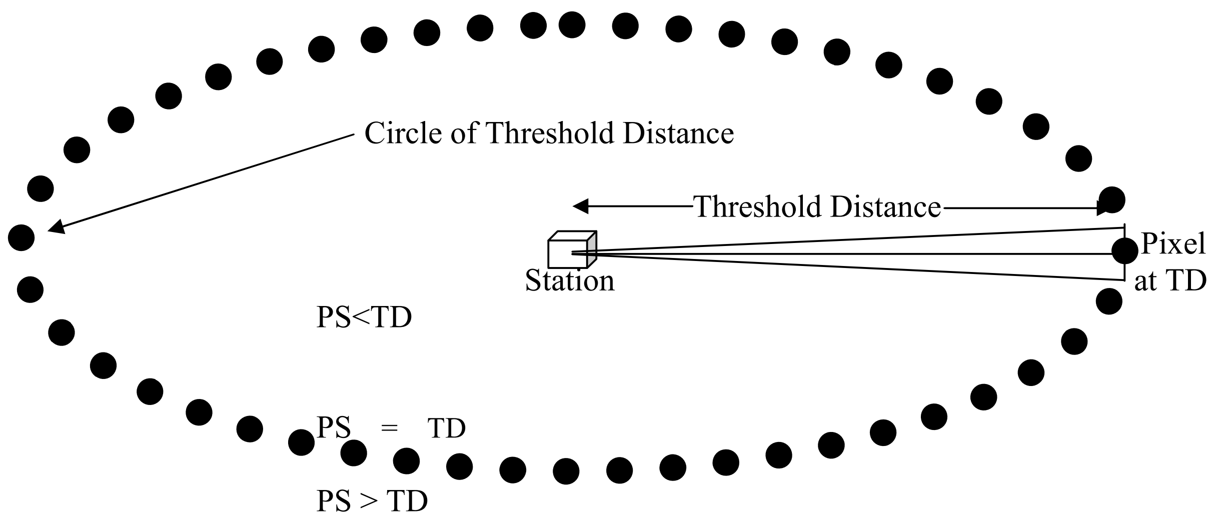


Fig.5.11 Circle of Threshold Distance

Area inside CTD of a given Station Position (SP) was surveyed using that SP. To survey the area outside CTD a shift of SP was required.

5.5.1.4 Online Feature and Offline Feature

All the surveying features measured with TS by surveyor online in the field are called online features. All the surveying features measured with 3D recreation technique offline in photographs of the field are called offline features.

5.5.1.5 Projector Equation (PE) (Camera Assembly Representation)

For a given camera position, if a projector is projected at pixel P then all features in line of sight of the projector are represented by P and the closest will be visible as shown in Fig.5.12. There exist a unique projector for each pixel and Projector Equation was derived, without the help of features/object's coordinates. Each projector has a cone shape with the base facing away from the pixel. PE for pixel P (Xp, Zp) in parametric form is given below:

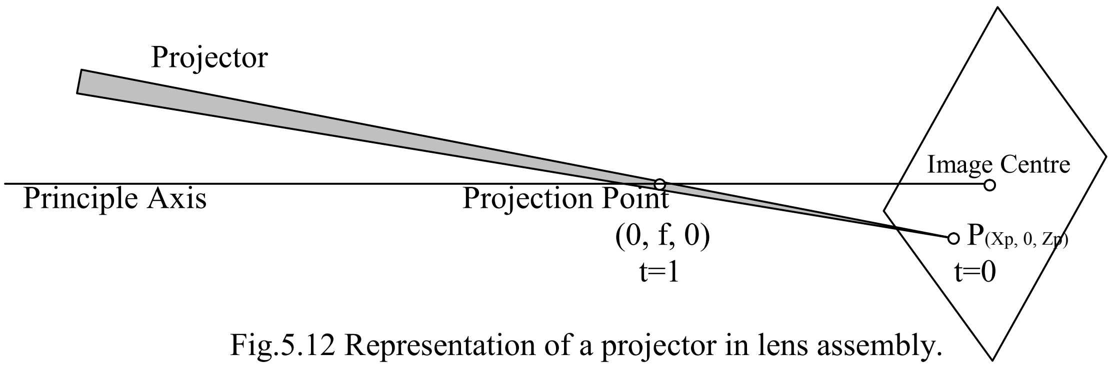


Fig.5.12 Representation of a projector in lens assembly.

Two points on the projector are P (Xp, 0, Zp) and projection point (0, f, 0). With these points PE in parametric form is:

$$X = Xp - Xp * t$$

$$Y = f * t$$

$$Z = Zp - Zp * t$$

Where:

t is a single unknown parameter and was assumed values from zero to infinity. For a given lens and sensor assembly each pixel has a unique and fixed PE in reference with camera coordinate system, i.e. camera assembly represented by a set of PEs for each pixel on the sensor. Set of PEs can play important role in 3D recreation.

5.5.1.6 Bound check function

A bound check function BCF (point, polygon) was implemented in software developed for PMTS. This function receives two parameters. The first parameter to it is a 3D point and second one is a polygon (boundary of a region in the field). It returns a true value if the point lies inside of the polygon, else it returns a false value. This function is helpful in mapping photo-coordinates to telescope coordinates.

5.5.1.7 Distortion Model of lens assembly

A model of the lens assembly, based on practical observation, was prepared. This model is based on the concept of WYSIWYG (What You See is What You Get) with no mathematics involved. Its mathematical model is represented by the lens formula. The differences between calculated and observed values of photo-coordinates are the net amount of distortion in it.

The following assumptions were made prior to modeling:

- Radial distortions are symmetrical around principle point.
- Tangential distortions are negligibly small.

The basis of these assumptions is:

- Focal length of the camera is very small and the image of an object beyond 3 metre (minimum limit of TS) will be created at the focal point.
- Lens geometry has a perfect spherical shape on both the sides.

All locations in the same radial distance from principle point will have similar behavior/properties/distortion amount as depicted in Fig.5.13.

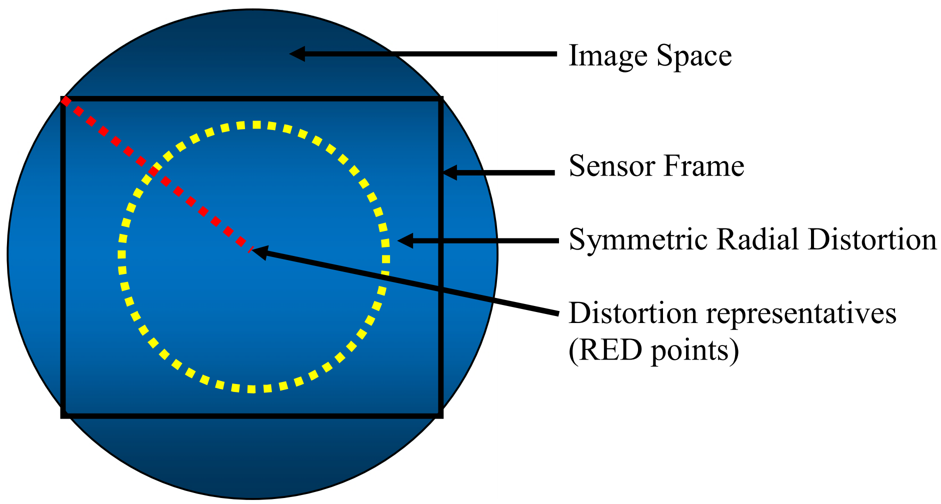


Fig.5.13 Minimal set of pixel (RED) to represent lens assembly

All yellow color locations are at the same radial distance and their representative point is in red color. Locations on red line are sufficient for modeling of the lens assembly. All red points were observed with TS (Camera position with zero Yoffset and zero Xoffset). The difference of observed and calculated photo-coordinates value was stored in a lookup table. This table is known as distortion table of the lens assembly. Number of points on Red color line can be reduced to an optimum level. In this case interpolations of existing points will give distortion amounts for the remaining points.

In Fig.5.14, distortion model of camera used in PMTS is shown. For preparing the model, camera was fitted over handle of the RTS with all angular orientation parameters initialized to zero value. Xoffset and Yoffset were also set to zero value. Angular measurements (horizontal angle) were carried out by fixing a target at distances 5.333m, 9.999m and 15.003m respectively. At the time of measurement Target was observed, from image centre, in the image at a gap of 30 pixels by rotating the TS horizontally in anti clockwise direction.

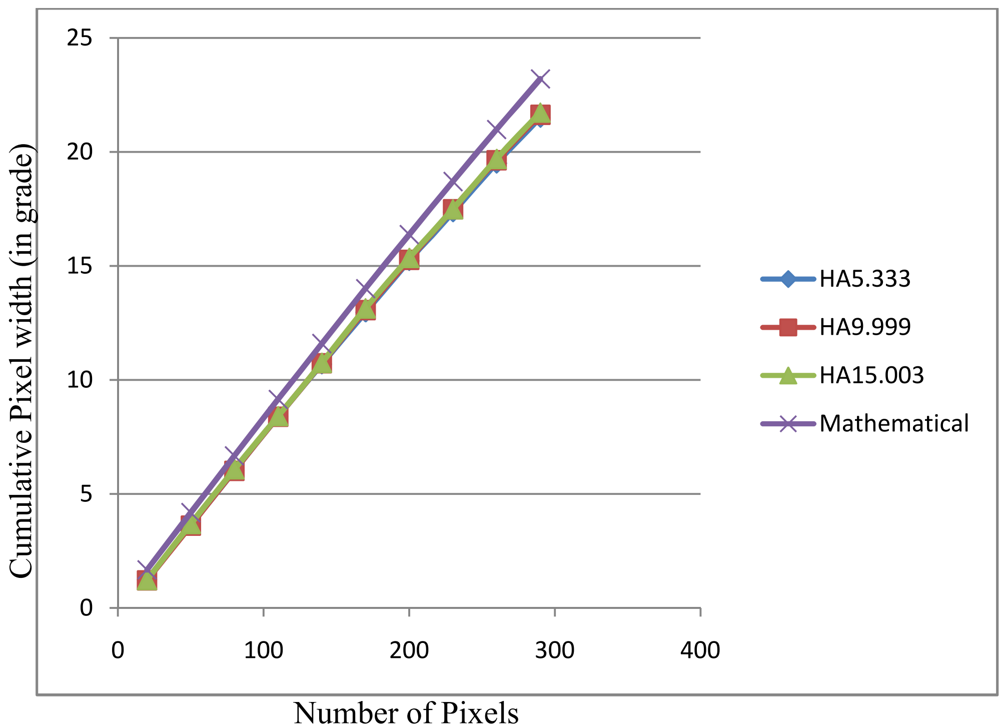


Fig.5.14 Distortion Model of Camera (Microsoft Lifecam HD5000)

A reference line (violet color) was calculated using lens formula (mathematical) and was drawn along with measurements taken with TS to estimate amount of distortion. Blue colored line represent measurement taken with target at slope distance 5.333 meter, for red colored line target was at a distance of 9.999 meter and in case of green colored target was positioned at location 15.003 meter from camera position. From observations following facts were noticed:

a) Negligible variation in cumulative pixel width of about 0.1 grades for different slope distance at extreme left or right positions of the image was observed. This shows small amount of tangential distortion in the lens assembly.
b) Deviation from curved line representing the lens formula prove considerable amount of radial distortions (1.48121 grades at pixel position 290) in the lens assembly.

Distribution of pixel width of the lens assembly shows that the size/width of pixels near centre of the image is larger as compared to extreme position pixels shown in Fig.5.14. Thus engineering scale for middle pixels is poor. A maximum pixel width of 0.083719 grades near the centre and minimum pixel width of 0.066547 grades at pixel location 630 was observed as shown in Fig.5.15. All these observation were taken in VGA mode (640X480) of the camera.

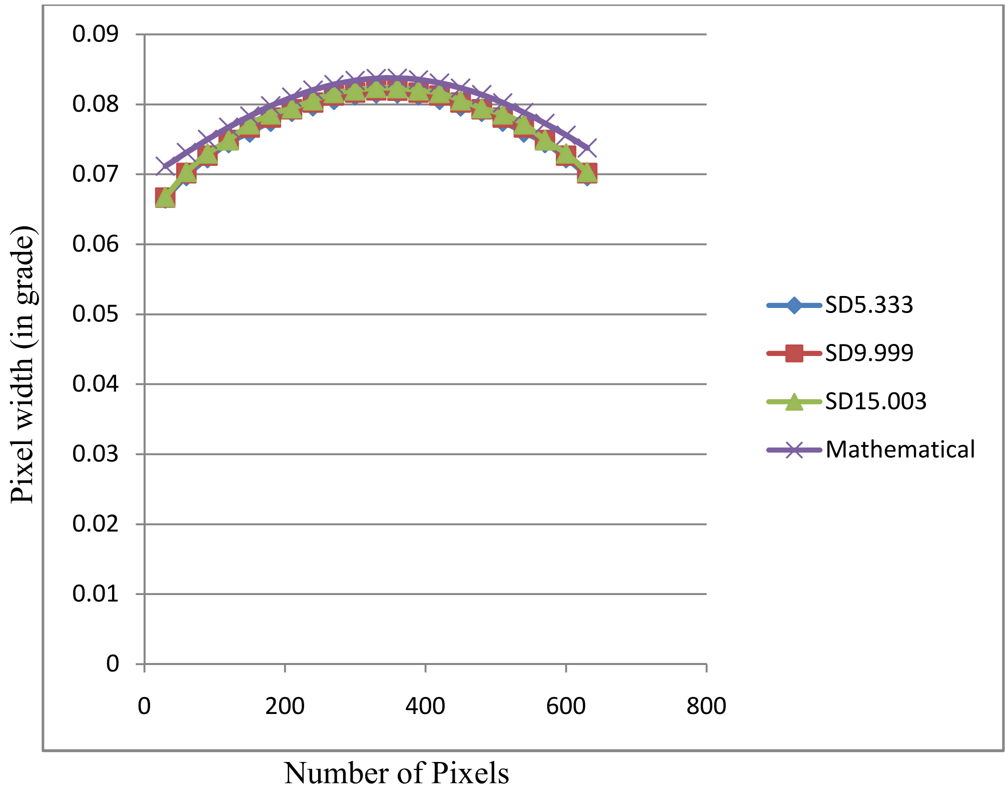


Fig.5.15 Pixel width distribution in lens assembly of Microsoft Lifecam HD5000

5.6 Mapping Photo-coordinates

No procedure is required to map telescope coordinates to photo coordinates, because the image of the field is a natural mapping of the two coordinate systems.

The following steps were observed to map photo-coordinates of a selected feature into telescope coordinates:

Step1. Selected Photo-coordinates were rectified using the distortion table to get P'(X', Z')

Step2 The equation of projector for P'(X', Z') was calculated and was called as PE.

Step3. All PP3D of the field were marked as unseen.

Step4. If there were no more unseen PP3D then went to step8.

Step5. Equation of one unseen PP3D was selected and was given a name PP.

Step6. The intersection point P(X, Y, Z) of the PE and PP was calculated.

Step7. If (BCF (P(X, Y, Z), PP3D) then returned P(X, Y, Z)

Else PP3D was marked as seen and went to step4.

Step8. Returned P(0, 0, 0)

Note: If the above mentioned procedure has returned a point (0, 0, 0) then photo-coordinates cannot be mapped in the given field.

5.7 Conclusion

The camera was successfully integrated with the total station. A distortion table of digital camera (Microsoft Lifecam HD5000) was prepared for rectification of photo-coordinates. Mapping procedure was tested with acceptable results.

Chapter 6

IMAGE CONTROLLED TOTAL STATION MOVEMENT

6.1 Introduction

An RTS makes use of two types of targets viz. active targets (RTS Prism) and passive targets (white sheet containing optical symbol). In case of active target, within a specified range, RTS can automatically point out the target precisely. Major issue with it is manual fixing of active target, i.e. movement of surveyor, holding it, in the field. It is a laborious task. In passive target, it becomes even worse. In addition to active target, setting the target by peeping through the narrow view of the telescope is a time consuming and exhausting task. With Image Controlled Station Movement (ICSM) the job of setting the target becomes easy and efficient. One or two clicks on the image will set the target easily. In this chapter various methods for ICSM are described. A user can opt out any one of them.

6.2 Objective

Development of a method to set a target for RTS by clicking over its image is the major objective in the present work. Other objective is to have control over movements of RTS with non-metric DC for targeting objects and to reduce its complexity and improve the precision.

6.3 Methods for ICSM

All methods for ICSM described here are free from propagation of error because the principle point of image is a common reference for movement calculations. Let presently telescope is pointing towards point X and the next point for movement is Y. Although movement angles are calculated in reference of image centre, but a direct flight from X to Y makes it time and energy efficient. Based on the accuracy and complexity, following methods were developed for ICSM:

6.3.1 Average pixel angle based ICSM

This method of ICSM is simplest but suffers from poor accuracy. In it average angle subtended by a pixel or Average Pixel Angle (APA) is used for RTS movement. To calculate horizontal APA, the telescope was leveled with the horizon (initialize HA to 90^0 degree value). Two objects were selected, one at the extreme left of the image and other at extreme right. The horizontal angle subtended by these objects at station position was measured using RTS theodolite. Let it be HA. Let NPH represent the total number of pixels in image width. Horizontal APA denoted by PH will be given by the equation (6.1).

$$PH = \frac{HA}{NPH} \quad \dots (6.1)$$

Similarly, vertical APA was calculated as shown in equation (6.2)

$$PV = \frac{VA}{NPV} \quad \dots (6.2)$$

Where: PV- vertical APA, VA-Total number of pixels in image height.

APA calculated for Microsoft Lifecam 5000HD (at resolution 640X480), image taken from a distance equal to 11 meters.

NPH =640

NPV=480

HA= 63.8694 grades

VA= 47.9020 grades

On substituting values in equation (6.1) and (6.2) following results were obtained:

PH =0.09979594 grade

PV= 0.09979583 grade

Fig.6.1 Calculation of Horizontal APA and Vertical APA

6.3.1.1 RTS Movement Calculation

RTS movement calculation in this method is simple. The image of the target was clicked. Number of horizontal and vertical pixel were counted from the centre of image. Number of pixels were multiplied with APA to get rotational angle. These angles were added to angles at which image was taken. The station was moved by an amount equal to the result obtained.

In the image shown in Fig.6.2, point A (X_A, Z_A) represent centre of the image and point C (X_9, Z_9) represents the target 9. Calculation of RTS movement is described below:

Number of horizontal pixels, nPH = ($X_9 - X_A$)   i.e. Length of line segment CB.

Number of vertical pixels,   nPV = ($Z_9 - Z_A$)   i.e. Length of line segment BA.

Horizontal angle subtended by target, HA_9 = nPH × PH

Vertical angle subtended by target, VA_9 = nPV × PV

Let PHA and PVA are horizontal and vertical angles at the time of image capturing. SHA and SVA are horizontal and vertical angles for RTS movement.

$$SHA = PHA + HA_9 \qquad \dots (6.3)$$

$$SVA = PVA + VA_9 \qquad \dots (6.4)$$

After issuing the command movHV(SHA,SVA), RTS is assumed to be moved at target point marked as 9.

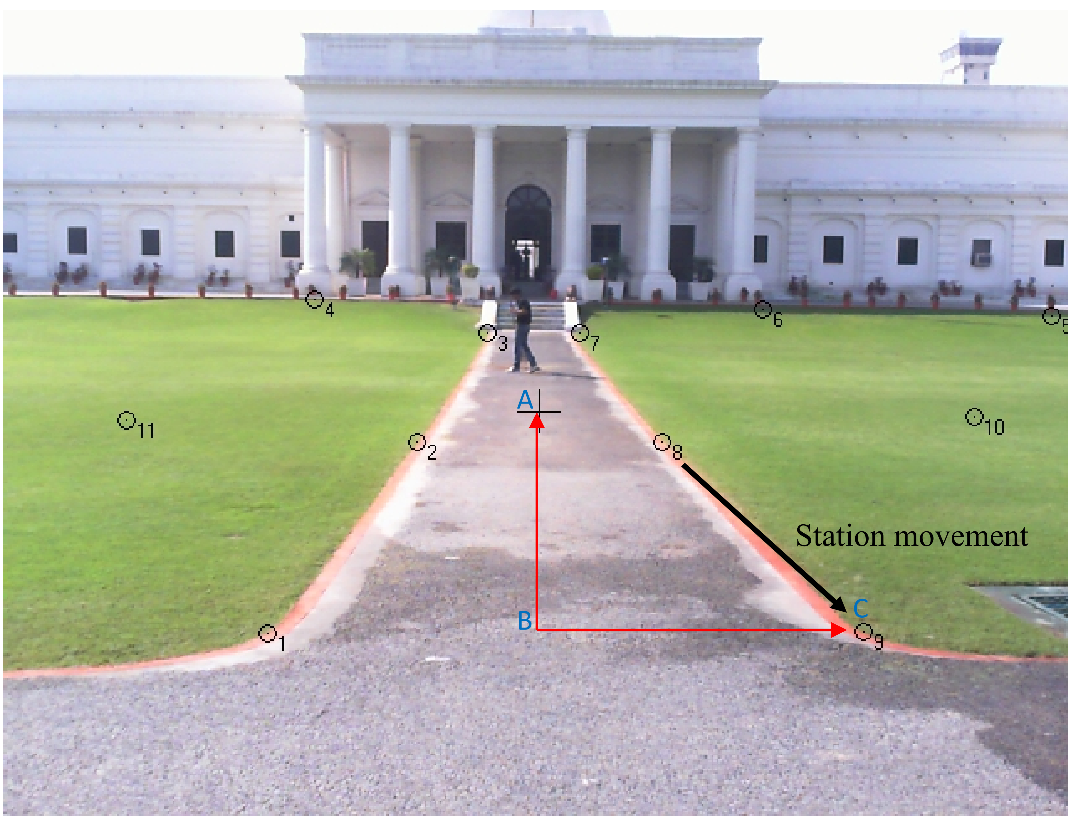


Fig.6.2 Target selection for RTS movement

The angle subtended by a pixel remains constant irrespective of length of projectors coming to it. But this method suffers from a major drawback that the angle subtended by each pixel is not same. A pixel near the image centre subtends Larger angle as compared to outer most pixels. Noticeable errors were observed in this method of TS movement (as shown in Table 6.1).

6.3.1.2 Observations

Image Data:

Resolution = 640 × 480

Centre = (315,240)

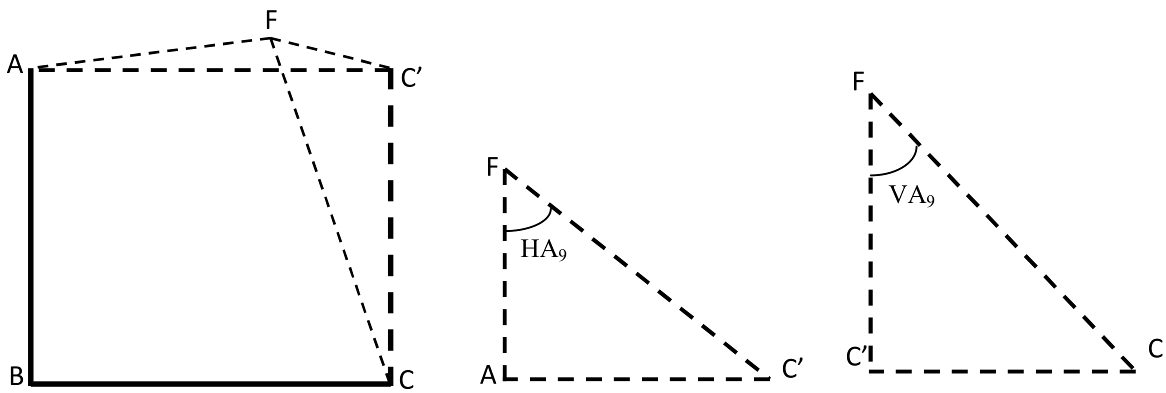
Image capturing angles PHA =199.3587, PVA= 105.9808

Table 6.1 Directly Observed with RTS and Calculated angles for APA based Movement

Sr. No.	Direct Observation with RTS			Photo Coordinates		Calculated APA movement			
Point ID	SD (meters)	SHA (grade)	SVA (grade)	X	Z	SHA (grade)	SVA (grade)	Error (grade) (HA, VA)	
1	5.7207	186.1377	116.7947	157	371	186.8787	116.2629	0.74	-0.53
2	13.5674	193.5452	107.3914	246	257	193.8643	107.3151	0.32	-0.08
3	37.3680	197.0413	102.0311	288	192	197.1609	102.2132	0.12	0.18
4	47.1846	188.4685	100.3806	185	172	189.0765	100.6434	0.61	0.26
5	43.0422	225.0055	101.2052	624	182	223.5336	101.4283	-1.47	0.22
6	42.0871	210.6903	100.8757	452	178	210.0333	101.1144	-0.66	0.24
7	37.5357	201.6181	102.0304	343	192	201.4779	102.2132	-0.14	0.18
8	13.7009	205.6967	107.3915	392	257	205.3239	107.3151	-0.37	-0.08
9	5.6509	215.6838	116.7122	512	370	214.7427	116.1845	-0.94	-0.53
10	16.4792	221.1775	106.1548	578	242	219.9230	106.1377	-1.25	-0.02
11	16.2820	179.1463	106.3195	73	244	180.2856	106.2947	1.14	-0.02

6.3.2 Tangential Pixel Angle based ICSM

In Tangential Pixel Angle (TPA) method, movement angles are calculated using trigonometric functions to overcome drawbacks of previous method. The principle axis of camera system is perpendicular to image plane. In Fig.6.3, points A, B and C correspond to the points shown in Fig.6.2. Point F in it represents the focal point of the lens assembly. Extra lines are drawn on it to demonstrate RTS movement.



(a) RTS movement to point 9 (b) Horizontal movement (C) Vertical movement

Fig.6.3 Calculation of movement angles using the inverse tangent function.

For horizontal movement, RTS moves from point A to point C' followed by a vertical movement from point C' to C as shown in Fig.6.3(a) and Fig.6.3(c).

Let "f" is camera constant. In ΔAFC' shown in Fig.6.3 (b):

f = AF

nPH = AC'

Horizontal movement is calculated using following equation:

$HA_9 = \angle AFC'$

$HA_9 = \tan^{-1}(\frac{nPH}{f})$ … (6.5)

From ΔFC'C shown in Fig.3 (c):

f = FC'

nPV = C'C

Vertical movement is calculated from equation shown below:

$VA_9 = \angle C'FC$

$VA_9 = \tan^{-1}(\frac{nPV}{f})$ … (6.6)

The values of SHA and SVA were calculated using equations (6.3), (6.4), (6.5) and (6.6).

The command movHV(SHA,SVA) was executed for moving RTS to target the point marked as 9.

This method produced better results as compared to the APA based RTS movement. It is observed that objects close to station position have more error for RTS movement as compared to objects at far distances. Camera offsets are major parameters for such distribution of errors. Thus, this method requires improvements.

6.3.2.1 Observations

Image Data:

Resolution = 640 × 480

Centre = (315,240)

Capturing angles PHA =199.3587, PVA= 105.9808

Focal Length = 784 pixels

Table 6.2 Observed and Calculated angles for TPA based Movement.

Sr. No.	Direct Observation with RTS			Photo Coordinates		Calculated TPA movement			
Point ID	SD (meters)	SHA (grade)	SVA (grade)	X	Z	SHA (grade)	SVA (grade)	Error (grade) (HA, VA)	
1	5.7207	186.1377	116.7947	157	371	186.7035	116.5166	0.57	-0.28
2	13.5674	193.5452	107.3914	246	257	193.7724	107.3605	0.23	-0.03
3	37.3680	197.0413	102.0311	288	192	197.1680	102.0896	0.13	0.06
4	47.1846	188.4685	100.3806	185	172	188.9019	100.4751	0.43	0.09
5	43.0422	225.0055	101.2052	624	182	223.2502	101.2816	-1.76	0.08
6	42.0871	210.6903	100.8757	452	178	210.3677	100.9588	-0.32	0.08
7	37.5357	201.6181	102.0304	343	192	201.6305	102.0896	0.01	0.06
8	13.7009	205.6967	107.3915	392	257	205.5887	107.3605	-0.11	-0.03
9	5.6509	215.6838	116.7122	512	370	215.0246	116.4376	-0.66	-0.27
10	16.4792	221.1775	106.1548	578	242	219.9554	106.1431	-1.22	-0.01
11	16.2820	179.1463	106.3195	73	244	180.3063	106.3055	1.16	-0.01

6.3.3 Offset Adjusted TPA (OATPA) based ICSM

In PMTS non-zero camera offsets are Yoffset and Zoffset. Values of HA_9 and VA_9 have to be calculated using equation (5) and (6). Let SD be the slope distance of target. Offset adjustment to them is as under:

Offset adjustment to the horizontal angle (δHA_9):

$$\delta HA_9 = \sin^{-1}\left(\frac{Yoffset \times \sin(HA9)}{SD}\right) \quad \ldots (7)$$

Offset adjustment to vertical angle (δVA_9):

$$S = Yoffset^2 + Zoffset^2$$

$$\delta VA_9 = \sin^{-1}\left(\frac{\sqrt{S} \times \sin(VA9)}{SD}\right) \quad \ldots (8)$$

Subtract offset adjustments from respective angles to get:

$$OHA_9 = HA_9 - \delta HA_9 \quad \ldots (9)$$

$$OVA_9 = VA_9 - \delta VA_9 \quad \ldots (10)$$

Where:

OHA_9 – Offset adjusted horizontal angle

OVA_9 – Offset adjusted vertical angle

Angles for RTS movement are given below:

$$SHA = PHA + OHA_9 \quad \ldots (11)$$

$$SVA = PVA + OVA_9 \quad \ldots (12)$$

After applying offset adjustments, observed errors in setting the target further get reduced.

6.3.3.1 Observations

Table 6.3 Observed and Calculated angles for OATPA based Movement.

Sr. No.	Direct Observation with RTS			Photo Coordinates		Calculated OATPA movement			
Point ID	SD (meters)	SHA (grade)	SVA (grade)	X	Z	SHA (grade)	SVA (grade)	Error (grade) (HA, VA)	
1	5.7207	186.1377	116.7947	157	371	186.52	116.70	0.38	-0.08
2	13.5674	193.5452	107.3914	246	257	193.74	107.37	0.19	-0.02
3	37.3680	197.0413	102.0311	288	192	197.16	102.08	0.12	0.05
4	47.1846	188.4685	100.3806	185	172	188.88	100.46	0.41	0.08

5	43.0422	225.0055	101.2052	624	182	223.30	101.27	-1.71	0.06
6	42.0871	210.6903	100.8757	452	178	210.39	100.95	-0.30	0.07
7	37.5357	201.6181	102.0304	343	192	201.64	102.08	0.02	0.05
8	13.7009	205.6967	107.3915	392	257	205.63	107.37	-0.07	-0.02
9	5.6509	215.6838	116.7122	512	370	215.26	116.62	-0.43	-0.08
10	16.4792	221.1775	106.1548	578	242	220.06	106.14	-1.12	-0.01
11	16.2820	179.1463	106.3195	73	244	180.21	106.31	1.06	-0.01

Image Data:

Resolution = 640 × 480

Centre = (315,240)

Image capturing angles PHA =199.3587, PVA= 105.9808

Focal Length = 784 pixels

Yoffset = 0.085 m

Zoffset = 0.052 m

6.3.4 Rectified OATPA Results Against Lens Distortion

Table 6.4 Rectified results of OATPA based Movement.

Sr. No.	Direct Observation with RTS			Rectified OATPA movement			
Point ID	SD (meters)	SHA (grade)	SVA (grade)	SHA (grade)	SVA (grade)	Error (grade) (HA, VA)	
1	5.7207	186.1377	116.7947	186.1377	116.7947	0.03	-0.01
2	13.5674	193.5452	107.3914	193.5452	107.3914	0.05	-0.02
3	37.3680	197.0413	102.0311	197.0413	102.0311	0.04	0.01
4	47.1846	188.4685	100.3806	188.4685	100.3806	0.02	0.02
5	43.0422	225.0055	101.2052	225.0055	101.2052	-0.05	0.05
6	42.0871	210.6903	100.8757	210.6903	100.8757	-0.02	0.01
7	37.5357	201.6181	102.0304	201.6181	102.0304	0.04	0.01

8	13.7009	205.6967	107.3915	205.6967	107.3915	-0.05	-0.02
9	5.6509	215.6838	116.7122	215.6838	116.7122	-0.03	-0.02
10	16.4792	221.1775	106.1548	221.1775	106.1548	-0.06	-0.01
11	16.2820	179.1463	106.3195	179.1463	106.3195	0.06	-0.01

The lens distortion model, shown in Fig.5.8, of Microsoft Lifecam HD5000 was applied on observations given in Table 6.3. The rectified results obtained from it are shown in Table 6.4. The amount of error in each row is less than the angle subtended by each pixel. This shows that rectification against lens distortion has produced considerable results for TS movement. This method of TS movement was adopted for automatic object targeting for given photo coordinates. The for manual object targeting with precise results is discussed in article 6.4.

6.4 Precise Object Targeting in PMTS

Precise object targeting is based on "Best from worst" i.e. using non-metric camera set up producing the best results. For example if camera setup is of 90% accuracy (if the target is at 100th pixel location, then RTS will be moved in between 90th to 110th pixel location) then repeating the process of movement twice will produce 99% accurate result and one more repetition will produce precise results. Maximum three repetitions i.e. three mouse clicks will produce precise results with camera setup of 90% accuracy.

6.4.1 Methodology for precise movement

To demonstrate the method, APA based ICSM is considered for station movement. Live video of field helped in revising results with better accuracy.

Image of the field was captured and its angles (horizontal and vertical) were recorded. A target for RTS movement was selected by clicking on its image. Number of horizontal and vertical pixels were calculated by subtracting image centre photo coordinates from target's photo coordinates. The result were recorded as Target's Horizontal pixels (TH) and Vertical pixels (TV).

Movement offset angles OHA (Horizontal offset Angle) and OVA (Vertical offset Angle) were calculated by multiplying TH, TV with angle subtended by one pixel respectively.

A command was issued to move total station to angles HA=PHA + OHA, VA=PVA + OHA. Here PHA and PVA are angles when the image was captured. The RTS was in proximity of the target.

The target was clicked in live view (Video) of the field. LHA and LVA (the live offset angles) were calculated. HA= HA + LHA and VA = VA + LVA, the movement angles, were calculated. RTS was moved to the revised values of HA and VA. These steps were repeated until final results were obtained.

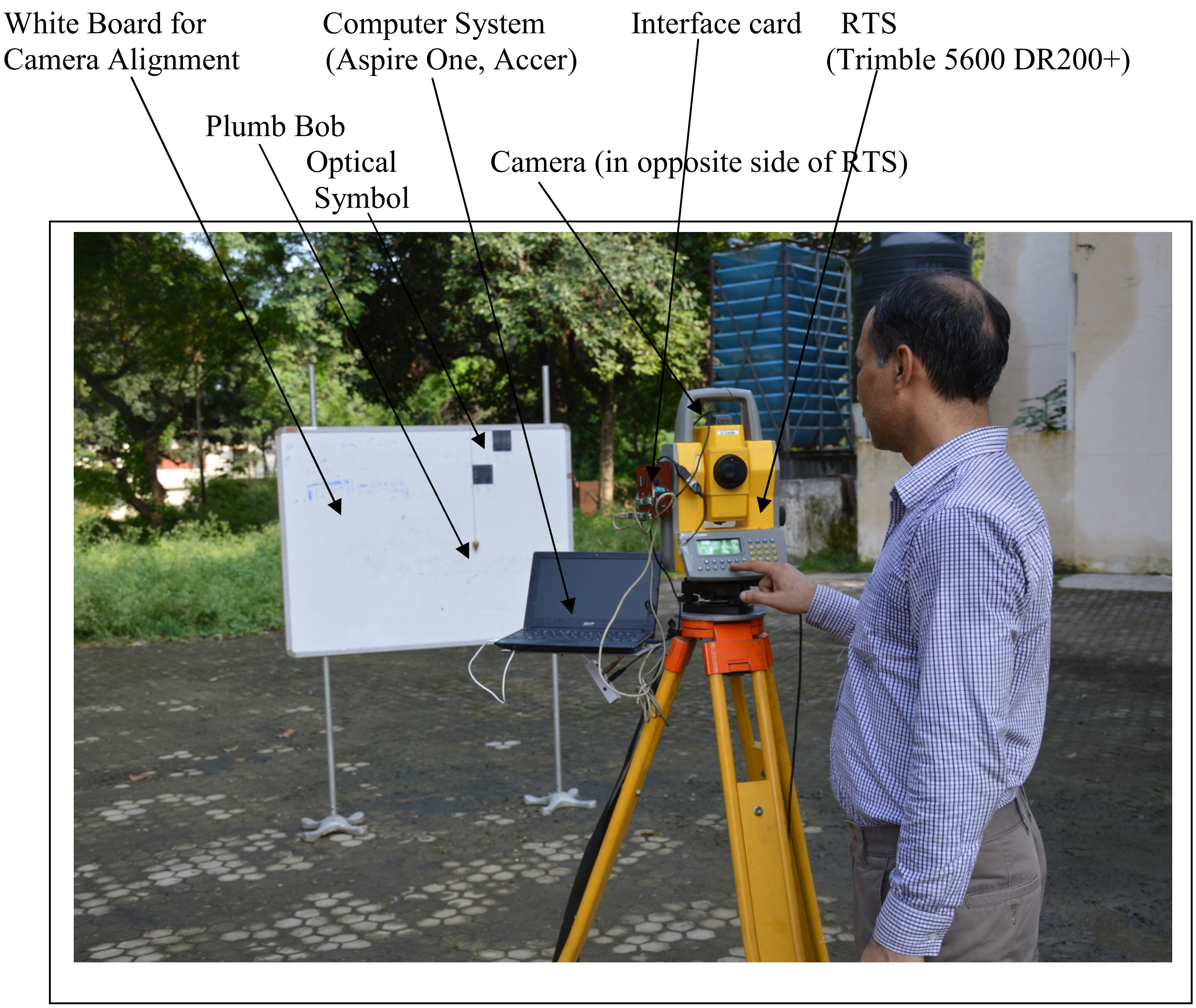


Fig.6.4 System Setup for Precise Object Targeting in PMTS

6.4.2 Hardware and Software Requirements

- Computer System with three free USB ports
- Interface card for RTS and Computer System
- Robotic Total Station: Trimble 5600 DR200+
- Webcam: Microsoft HD6000
- RTS accessories

- Operating System: Microsoft Windows Xp/Windows 7/Windows 8
- Development Environment: Microsoft Visual Basic 6.0

6.5. Flow Chart

The flow chart of precise object targeting is shown in Fig.6.5. It describe a procedure of enhancing accuracy of a given algorithm or method by revisions. It is useful in manual object targing. In first try if there exists offsets to reach the target then the process of moving the station is repeated on the offset. In one or two repeatitions taargetwill achieved successfully with precise results.

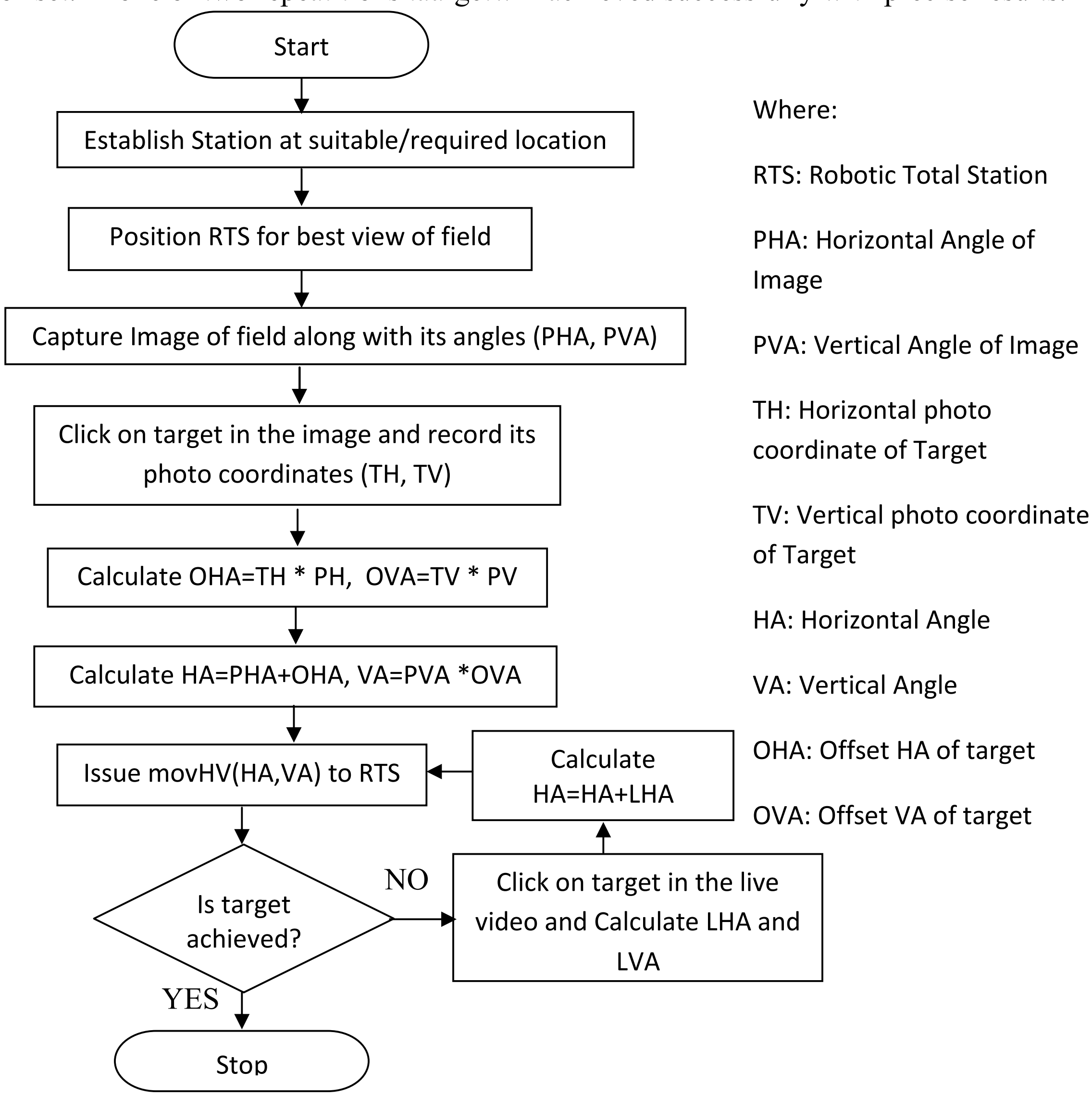


Fig.6.5 Flow Chart for Precise Object Targeting in PMTS

6.6 Working

Various steps followed for precise object targeting (as shown in Fig.6.5) are as under:

Step1. After station establishment, application software for PMTS was executed and RTS was switched on.

Step2. Camera (RTS) was positioned for best view of field and image of the field was captured by pressing "Capture" command button.

Step3. A target was selected in the image by clicking on it as shown in Fig.6.6.

Fig.6.6 Target selection in image of the field

After target (1) was selected , the calculated value of HA and VA of the target were displayed in the text box at right bottom corner of the display window (refer Fig.6.6).

Step4. "Move" button was pressed to position RTS on calculated value of HA and VA

It was observed that the target was not at the cross hair of live video (AS shown in Fig.6.7, the centre of video)

No exact movement (observe cross hair)

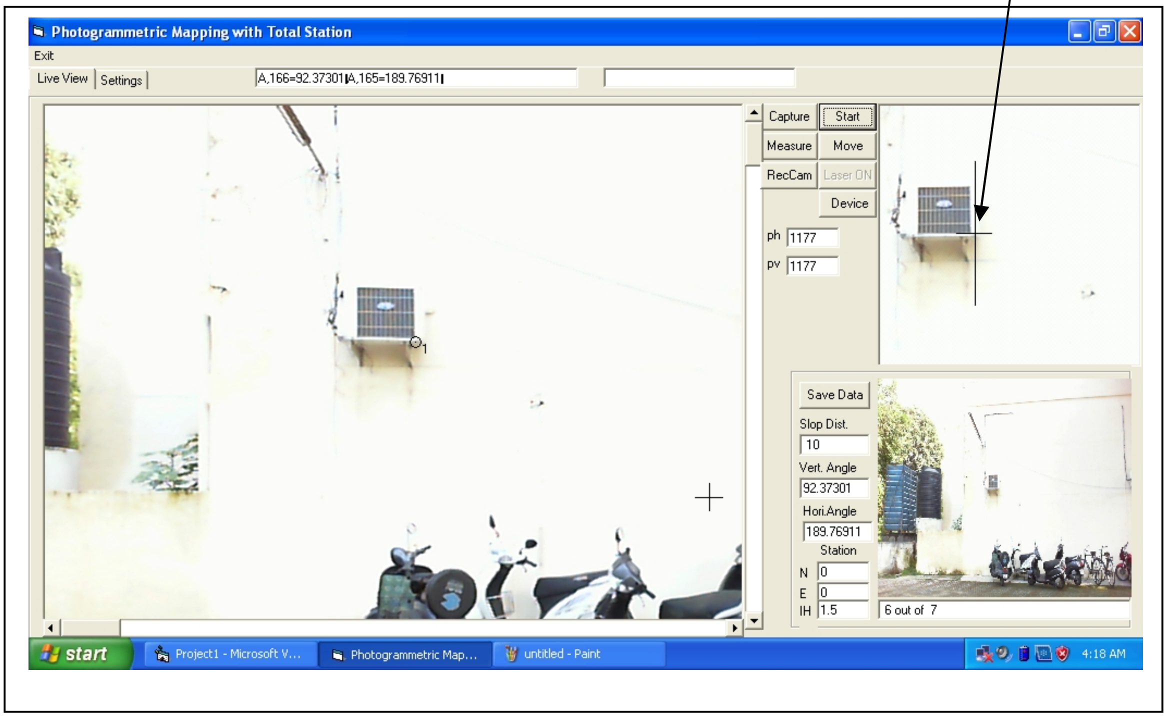


Fig.6.7 Station position after the first movement.

Step5.The target was clicked in Zoomed live view (Fig.6.7).

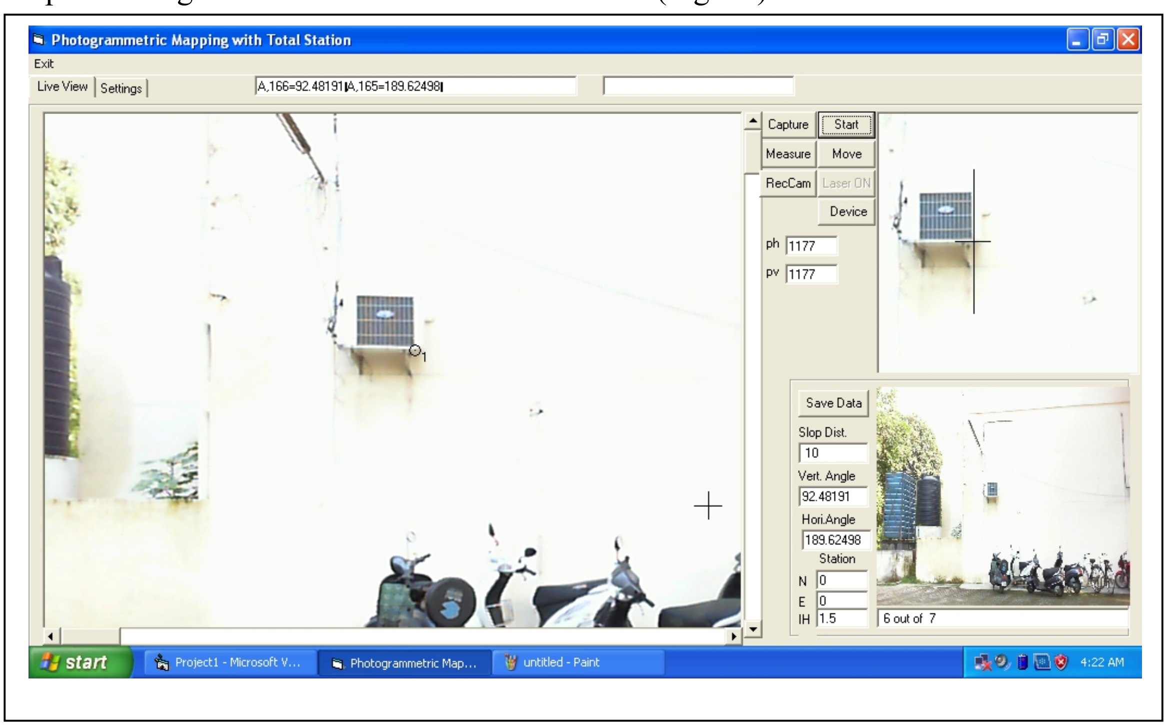


Fig.6.8 Station View after second movement

The station is now perfectly aligned with cross hair of zoomed video (Fig.6.8).

*Note: Step5 can be repeated a number of times to achieve the target.

Similarly, RTS and camera was moved to the opposite corner of the object (as shown in Fig.6.9)

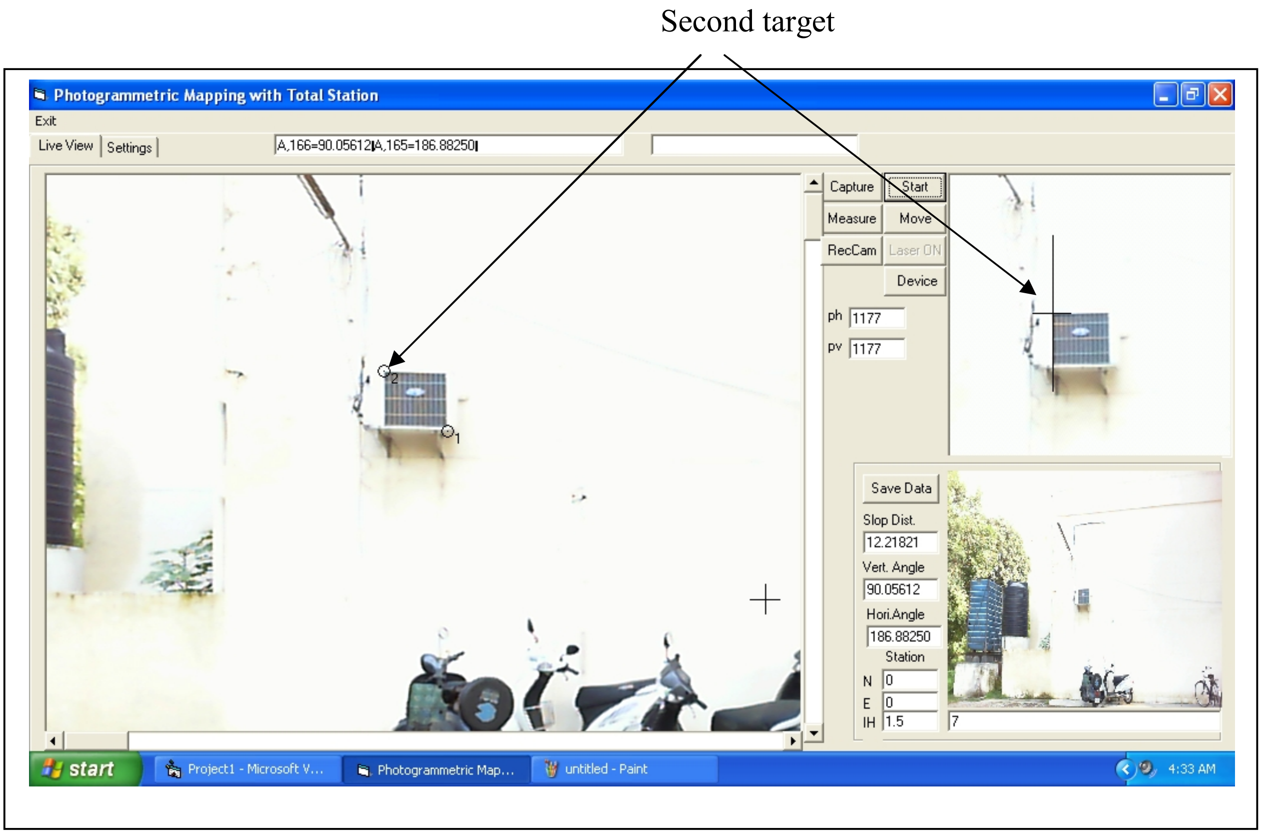


Fig.6.9 Station position with perfect alignment with second target

6.7 Observations

Coordinates of the targets in Spherical Coordinate System:

Target No.	HA (radians)	VA (radians)	Slope distance (metres)
1	189.4871	92.41961	12.54168
2	186.88252	90.05625	12.21821

Photo coordinates of the targets

Target No.	X	Y
1	340	217
2	286	166

Station Coordinates:

Northing = 1000m

Easting = 1000m

Elevation = 100m (Note: These are assumed station coordinates)

Image Data:

Horizontal Angle : 203.99851 radians

Vertical Angle : 99.99157 radians

Image size : 1280 X 720

Image Principle point : 610, 240 (shown by cross in the image)

And the image of the field is shown in Fig.6.10.

Fig.6.10 Image of the field

6.8 Result and Conclusion

The system or subroutines developed for precise object targeting in PMTS worked satisfactorily. Three repetitions were observed in rare cases. In few cases target get aligned in one step. In maximum cases two steps were required for targeting the object precisely. The method is better and easy to use as compared with manual method of targeting objects through the telescope of RTS.

Chapter 7

ONLINE TOTAL STATION PARAMETERS UPDATE FOR PRECISE MEASUREMENTS

7.1 Introduction

Precise measurements with TS are affected by its parameters (Temperature, Pressure/Elevation, and Humidity). Therefore a change in value of these parameters during surveying will require their regular update. Modern TS requests for these parameters each time a station is established or shifted to next Station Position (SP). For longer stay on an SP, the surveyor has to decide for parameter update.

In PMTS, recording surface profile for photogrammetric mapping is an automatic process. It is not feasible to pause it in between execution of scan function for parameter update. In scanning a large surface with small pitch, sufficient time was consumed during which TS parameters got changed and parameters update was required multiple times.

In this chapter a study was carried out to observe variation in parameters' values during surveying hours and its impact on measurement to conclude whether an automatic parameter update was required or not. If it is required then judgment of update intervals and selection of feasible sources of parameters for update has to be done.

Finally, it was decided to go for automatic parameters update and subroutines were developed in Microsoft Visual Basic 6.

7.2 Objectives

1) Analyses of impact of temperature, pressure and humidity on measurements with Total Station.
2) Deciding update interval, sources of parameters.
3) Development of subroutines to update these parameters online.

7.3 Impact of environmental parameters on measurements by TS

Manufacturers of total station calibrate the device under certain environmental conditions. The values of environmental parameters at the time of calibration become references for measurements.

An adjustment has to be applied to the measured value against the change in value of parameters. For example the vertical-index error and the collimation error are dependent on the temperature and a correction has to be applied in them for ambient temperature as shown below in equation (7.1):

Vertical angle corrected by the vertical-index error [87]

$$V_{T,C} = V_T - e_{1,Ref} - \Delta t_{Device} \times e_{1,Temp} \quad \ldots (7.1)$$

Where:

$V_{T,C}$	Corrected vertical angle against the vertical-index error
V_T	Vertical angle measured by the device at ambient temperature
$e_{1,Ref}$	Vertical-index error at reference temperature say 20^0C
$e_{1,Temp}$	Temperature coefficient for vertical-index
Δt_{Device}	Difference in temperature (device temperature – reference temperature)

Similarly, corrections are to be applied on distances measured at ambient temperature. Equation (7.2) shows the relation between measured distance and distance corrected for refractive index error.

$$D_{CORR} = (1 + \Delta t_{Device} \times n \times 10^{-6}) \times D_{MEAS} \quad \ldots (7.2)$$

Where:

D_{CORR}	Ambient temperature corrected distance
n	number of parts per million
D_{MEAS}	Measured distance
Δt_{Device}	Difference in temperature (device temperature – reference temperature)

Value of n for distance measurement is 1.

The refraction correction for distance measurement is as follows:

$$D_{CORR} = (nR / nL)\, D_{MEAS} \quad \ldots (7.3)$$

Where:

nL	Ambient refractive index
nR	Reference refractive index (manufacturer's specifications)

In general, impact of temperature, humidity and pressure on distance measurement by TS is summarized as

a) 1^0C change in temperature produces 1ppm error in distance measurement.
b) For 100% variation in humidity, net error in distance measurement will be in between from 1ppm to 2ppm
c) Per kpa change in pressure will introduce an error of 1ppm in distance measurement.

7.4 Analysis for Update Interval

Survey Time may vary from place to place. Survey time assumed here is the time duration between 7:00a.m. to 5:00 p.m. Two dimensions, most important for this study, are time and location. In the same time there can be large variations in parameters even in locations with closer proximity.

7.4.1 Temperature Variation

Observed variation in temperature for Roorkee on 15-05-2014 from 6:00a.m. to 6:00p.m. is 12^0C (Min. 23^0C at 6:00a.m., max. 35^0C at 4:00p.m.).

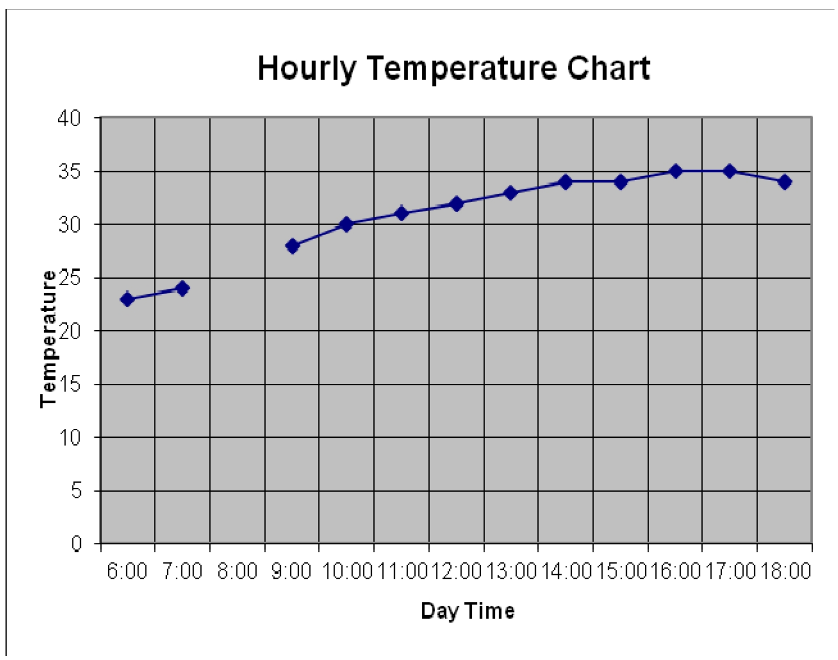


Fig.7.1 Hourly Temperature Chart of Roorkee (Dated 15-05-2014)
(Data source: http://www.theweathernetwork.com/)

An average change of 1.2^0C in temperature suggests that temperature parameter of EDM must be updated with a frequency of at least 30 minutes for precise measurements. A large change in temperature (6^0C) was observed from 7:00 a.m. to 10:00 a.m. Thus, in the morning update intervals of 15 minutes is suggested. From 10:00 a.m. to 2:00 p.m. change in temperature is 1^0C per hour and an update after each 45 minutes will be sufficient. For rest duration an hourly update may be sufficient.

7.4.2 Humidity Variation

Considerable variation in humidity was observed on 15-05-2014 in Roorkee during 6:00a.m. to 6:00p.m. as shown in Fig.7.2. A gradual decrease in percentage humidity was observed in the morning.

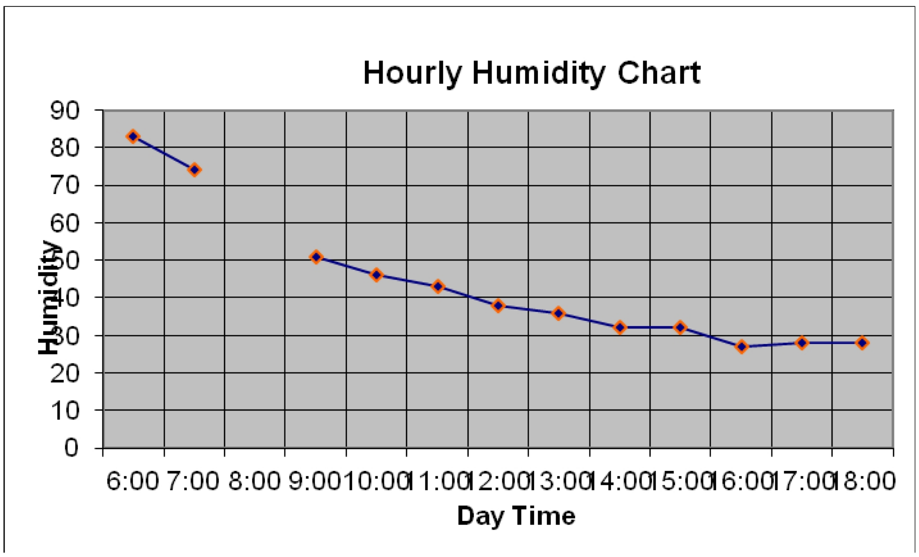


Fig.7.2 Hourly Humidity Chart of Roorkee (Dated 15-05-2014)

(Data source: http://www.theweathernetwork.com/)

Average change of 4.4% per hour in humidity (min. 28% and max 83%) were observed. Humidity has negligible impact on precise measurement, but an update of 3 or 4 times for it is suggested in the morning.

7.4.3 Pressure Variation

An increase in pressure will increase air density (medium) and hence the wavelength/speed of light traversing through it increases/decreases. It will produce an error in measurements. Minor changes are observed in pressure during 6:00a.m. to 6:00p.m. on 15-05-2014 in Roorkee. A change of 0.4 Kpa was observed. Generally it takes days to have a considerable change in it. Occasionally sudden changes in pressure, are observed during storms. This time is not suitable for surveying. Therefore, suggested update frequency for pressure is once a day for same location.

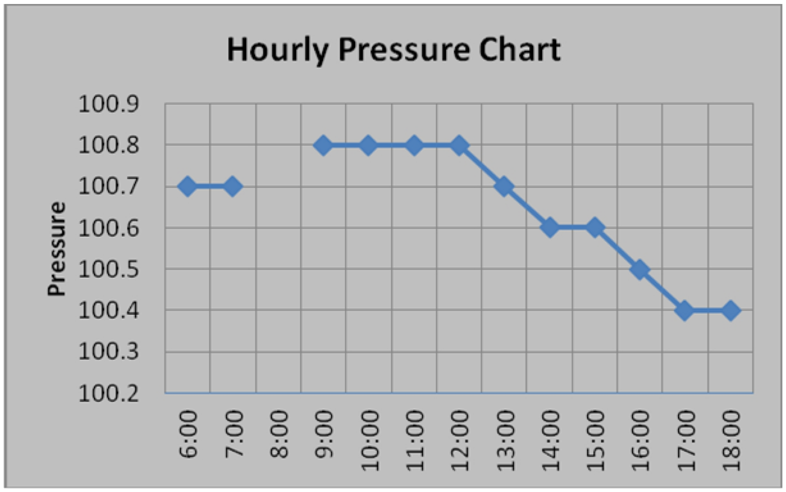


Fig.7.3 Hourly Pressure Chart of Roorkee (Dated 15-05-2014)

(Data source: http://www.theweathernetwork.com/)

7.4.4 Conclusion

The best choice for parameters update is the time when there is a considerable change in its values. But it will result in wastage of processing time and cost. Thus fixing update intervals can be a better choice. Statistical study of variation in temperature, humidity and pressure shows that during the survey time change rate of temperature and humidity is high. Minor changes are observed in pressure for climate suitable for surveying. Based on analysis, it is suggested to update temperature, humidity at a frequency of 30 minutes. For pressure update frequency can be once a day for the same location. Following options for users' interest can considered during subroutines development:

a) Two Hourly update b) One hourly update c) Half hourly update d) Never update.

The last option refers to no automatic update. Users' will do it whenever required.

7.5 Parameters' Sources

User can select one out of the following sources of parameters:

a) Internet

b) Manual

c) Digital instruments.

The internet can be a good choice but it provides average value for larger area not for specific place. Values for exact place can be obtained from the other two sources but will be costly source. In case of second source a user has to read the values from a measuring device and have to enter this manually into the system. In case of third source system will fetch parameters automatically whenever required.

7.6 Flow Chart

After system initialization, frequency of update and source of parameters have to be selected. Manual parameters' entry is not part of flow chart shown in Fig.7.4.

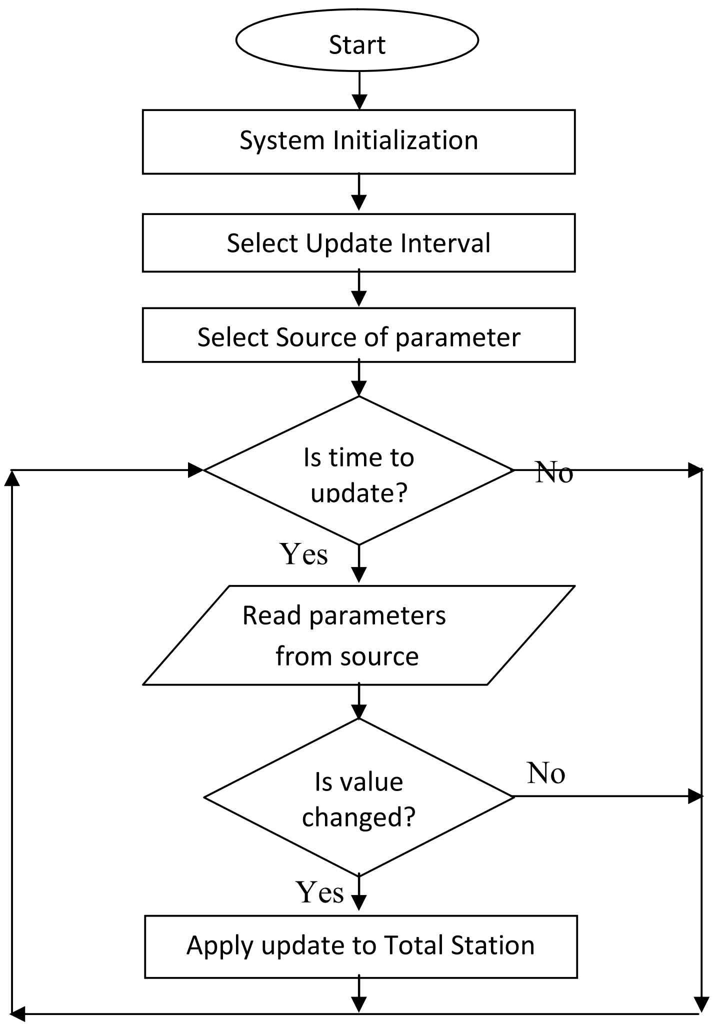


Fig.7.4 Flow Chart for Online Total Station Parameters Update

7.7 Hardware and Software Requirement:

- Robotic Total Station : Trimble 5600 DR200+
- Computer System with three free USB Ports
- Interface for Total Station and Computer System
- Microcontroller Pic18 based temperature meter
- Internet Connection
- Operating System : Windows-XP
- IDE : Microsoft Visual Basic 6.0

For the third option of parameters sources only temperature source was used. Humidity and pressure were entered manually.

7.8 Developed Graphical User Interface

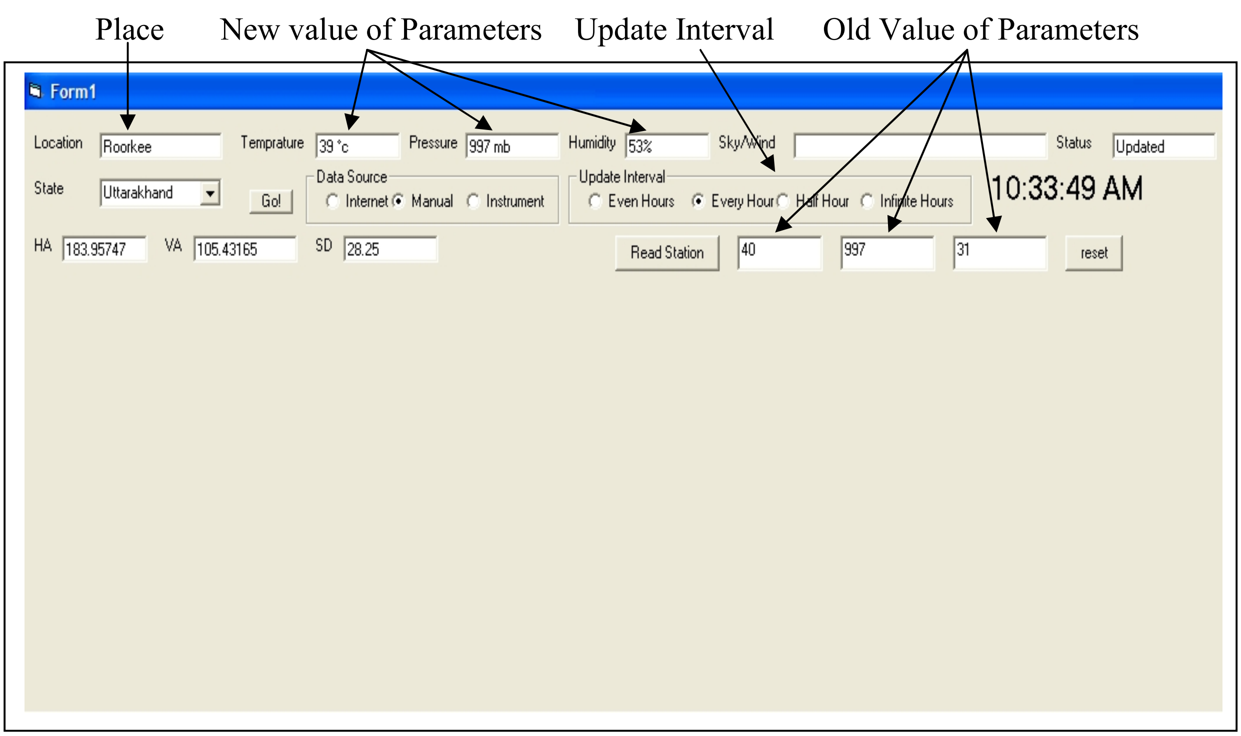


Fig.7.5 Online Parameters Entry with Data Source as 'Manual'

In case of parameter source as 'Manual' and 'Instrument' the entries for place i.e. location and state are not compulsory. But it adds semantics to the information. In the output HA refer to horizontal angle, VA refer to vertical angle and SD refer to slope distance. These are the current readings from Total Station. The command button 'Read Station' is used to fetch current value of the parameters stored in the Total Station. Whenever 'GO!' command button is pressed an immediate update to the parameters will be done despite of update interval.

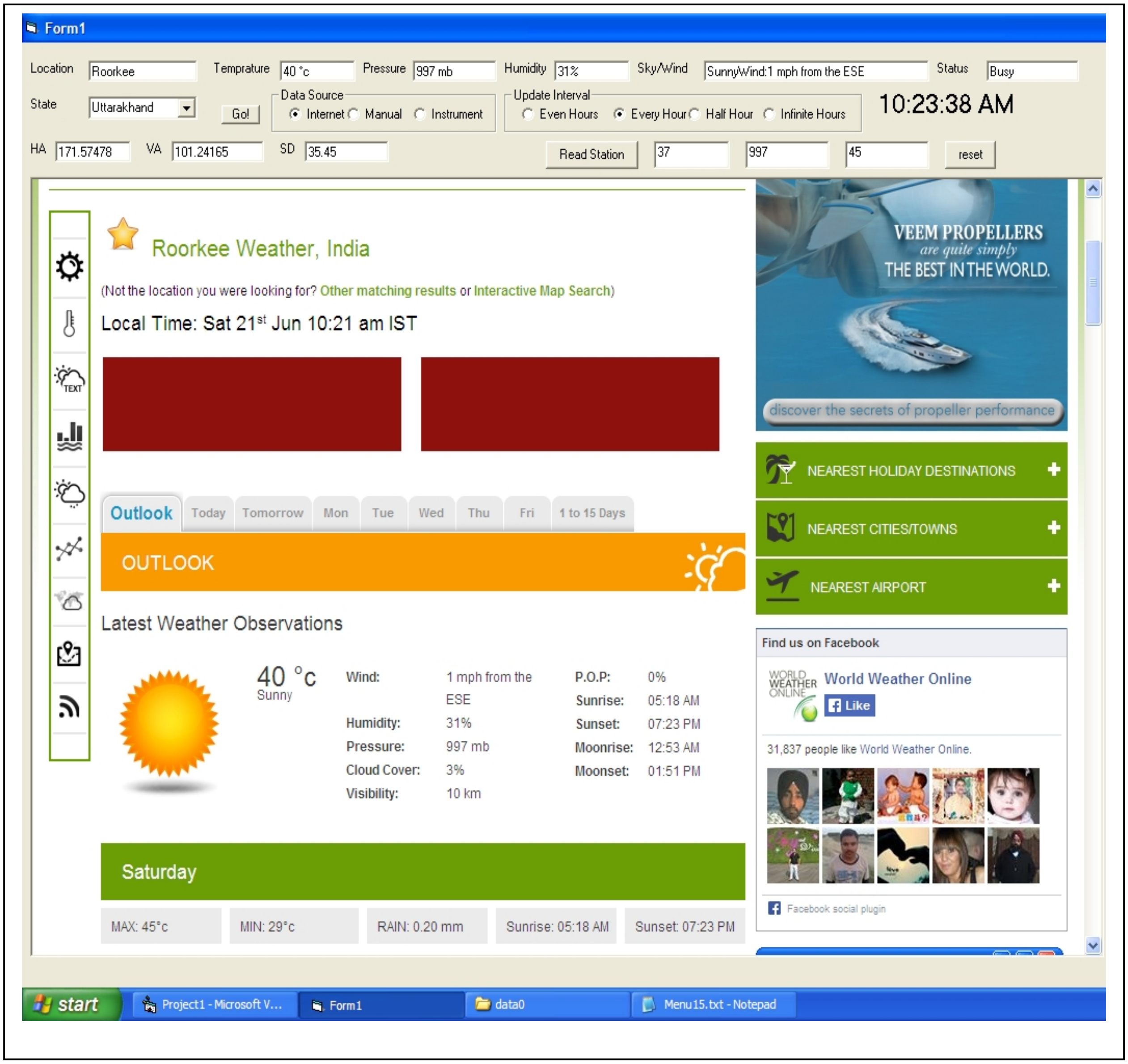


Fig.7.6 Online Parameters Entry with Data Source as 'Internet'

(*Web source of parameters: "http://www.worldweatheronline.com/")

In case of data source 'Instrument' only temperature measuring instrument was deployed. Pressure and humidity have to be entered manually.

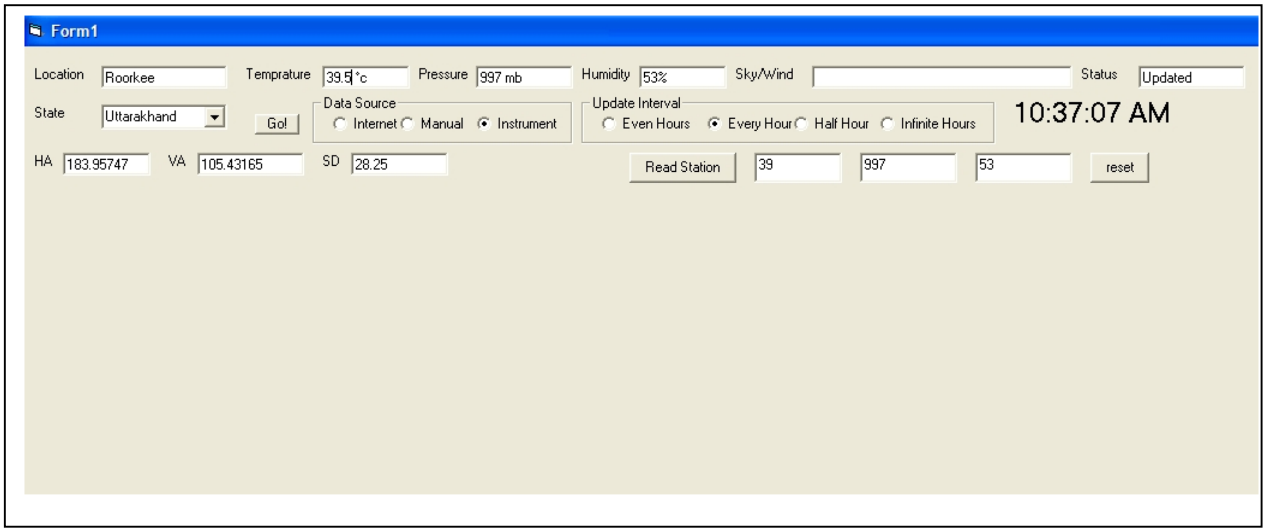


Fig.7.7 Online Parameters Entry with Data Source as 'Instrument'

7.9 Observations and Results

Table 7.1 Observations with fixed TS parameters: Temperature=20^{0}C, Humidity=50%, Pressure=100.7kpa (Dated: 15-05-2014, Roorkee, Uttarakhand, India)

Time	Temperature (^{0}C)	Pressure (kpa)	Humidity (%)	HA (grade)	VA (grade)	SD (meters)
6:00	23	100.7	83	200.0871	100.0008	20.00983
7:00	24	100.7	74	200.0873	100.0010	20.00978
8:00	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
9:00	28	100.8	51	200.0881	100.0020	20.00960
10:00	30	100.8	46	200.0885	100.0024	20.00951
11:00	31	100.8	43	200.0887	100.0027	20.00947
12:00	32	100.8	38	200.0889	100.0029	20.00943
13:00	33	100.7	36	200.0891	100.0031	20.00939
14:00	34	100.6	32	200.0893	100.0034	20.00935
15:00	34	100.6	32	200.0893	100.0033	20.00935
16:00	35	100.5	27	200.0895	100.0036	20.00932

Table 7.1 shows observations taken with fixed TS parameters and in Table 7.2 observation are shown with online TS parameters update. A variation of approximately 34ppm in Slope Distance

(SD), 6.5" in degree of horizontal angle and 7.5" in degree of vertical angle was observed at 4:00p.m. on 15-05-2014 as shown in Table 7.1 with reference of Table 7.2.

Table 7.2 Observation with Online Parameter Update

(Dated: 15-05-2014, Roorkee, Uttarakhand, India)

Time	**Temperature (^{0}C)**	**Pressure (kpa)**	**Humidity (%)**	**HA (grade)**	**VA (grade)**	**SD (meters)**
6:00	23	100.7	83	200.08653	100.00014	20.01
7:00	24	100.7	74	200.08652	100.00012	20.01
8:00	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
9:00	28	100.8	51	200.08652	100.00012	20.01
10:00	30	100.8	46	200.08653	100.00013	20.01
11:00	31	100.8	43	200.08653	100.00012	20.01
12:00	32	100.8	38	200.08652	100.00014	20.01
13:00	33	100.7	36	200.08653	100.00012	20.01
14:00	34	100.6	32	200.08654	100.00013	20.01
15:00	34	100.6	32	200.08652	100.00012	20.01
16:00	35	100.5	27	200.08652	100.00012	20.01

These observations were taken for a fixed station position. Online TS parameter update was done with a frequency of half an hour. The measurements were done in prismatic mode of TS. The distance of prism from station position was fixed to 20 meters.

7.10 Conclusion

Subroutines were developed and deployed with satisfactory results. With a regular half hourly update of parameters and with variations in station parameters throughout the day, all the measurements give the same results. It demonstrates successful implementation of concept of online parameters update for precise measurements.

Chapter 8

COPING WITH TIME COMPLEXITY

8.1 Introduction

System failures twice or thrice in a week had guided to do a separate study for it. Certain time critical operations were found responsible for it. This chapter deals with safe execution of such operations. The problem is not only related to high speed operations performed in PMTS but also describe and treat parallel execution of slower devices in asynchronous mode. The various components of PMTS are independent one. Their communication with the computer system is asynchronous at present. DC is a high speed device (more than 115200 bps, depends on frame size and camera type) and rest components communicate at a slower speed (9600 bps). Evaluation of expressions, instruction execution and other dead lock situation are also discussed here.

8.2 Objective

Provisions for safe execution of time critical operations is a major objective in this chapter

8.3 Major Causes of System Failure

Major causes of system failure in PMTS are as under:

8.3.1 Time Critical Situation

When two or more devices communicate with the computer system in parallel asynchronous mode and have a predefined frequency of data packets as shown in the diagram given below:

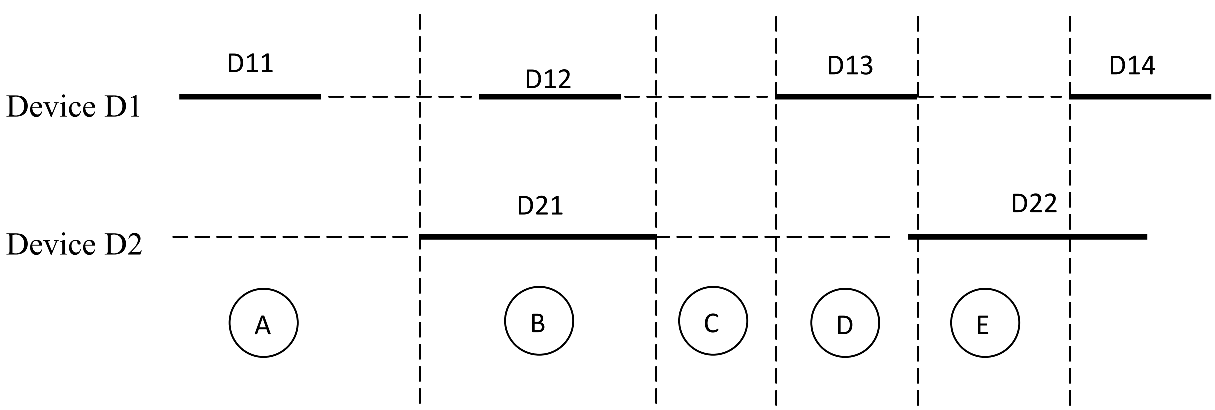


Fig.8.1 Timing diagram of Data Packets from device D1 and device D2

In time slot "A" Data Packet (DP) D11 will be safely received from D1(as shown in Fig.8.1). For time slot "B" D21 from D2 is in a safe state. But D12 from D1 is in critical situation. If the data buffer of communication port1 can hold it, then it will be delivered to computer system later on otherwise D12 can get corrupted or lost. In slot "C" there is no work load from communication ports. In time slot "D", D13 from D1 is in safe start and safe end, but D22 from D2 may or may not be in a safe state depending on affordability of data at buffer of communication port2. Similarly D14 from D1 is in critical situation.

Safe data packets: D11, D21 and D13
Time Critical data packets: D12, D22 and D14

8.3.2 Absurd point

During distance measurement if target object does not reflect sufficient energy back to EDM then distance measuring operation gets failed. It happened when large amount of energy transmitted by EDM is absorbed by the target. In this case reflected energy will not be able to energize the sensor of EDM and EDM retry for distance measure by transmitting the energy again and again. The system fails to proceed further. These absurd points create big problems during run time of scan function. Surface profile contains thousands of points and chances of multiple absurd point are always there.

8.3.3 Subroutines for communicating with slower devices

A subroutine when start its execution will engage the system with it. Small chunk of codes in it may not affect the system but larger size of it will degrade the performance of parallel environment. Subroutines communicating with a slower device if contain large number of instructions then these will bring the system in worst situation.

We discuss this with example:
Let a subroutine contains following set of requests to slower device and in reply device send a response:

Thread	**Device**
Request1	
	Response1
Request2	
	Response2

Request3

Response3

|

|

|

RequestN

ResponseN

Stop

When this subroutine is called then it will consume a lot of time because of slower responses. Its communication with other devices gets suspended. In PMTS, DC works in hand shaking mode and other devices interact in asynchronous mode. Thus important data packets may be lost.

8.3.4 HD Camera

HD camera is the only device which work in hand shaking mode with computer system and consume maximum time of CPU. All normal processes can execute in parallel mode with it. Only HD camera creates problems with lengthy processes.

For example, observe the following sequence of operation:

Initialization of PMTS:

a) Start Software application of PMTS
b) Start live video
c) Start RB

In every case RB fails to initialize. Its reason is that at the time of RB initialization volume of requests to RB and responses from RB is very large. Mean time large amount of video data is coming from camera. RB initialization is a time critical operation and fails to initialize.

A successful initialization is always observed for following sequence of operation:

a) Start Software application of PMTS
b) Start RB
c) Start Live video

At the time of system initialization this problem was fixed, but what should be done during system execution if same situation is faced.

8.3.5 Time consuming real time expression

PMTS contains multiple time complex expressions. One solution for them is that these can be delayed for offline processing. To fulfill real time requirements these expressions cannot be ignored or delayed.

8.4. Solutions for System Failure

Following recovery solution for system failure were implemented successfully.

8.4.1 Solution for Time Critical Situation

The portions of application software which contained instructions responsible for time critical operations were replaced with event driven codes. Whenever a device tries to send data packet an event is generated by corresponding communication port. On listening the event, system send a pause command to other components to delay their data packets. On completion, pause is withdrawn from all of them. The codes were tested and implemented successfully.

8.4.2 Solution for Absurd points

"Wait and terminate" method was successfully implemented to skip absurd points. In this method, before its implementation, longest time 'L' taken by EDM in measuring slope distance was calculated using following steps:

Step1. An additional attribute TT (time taken in one measurement) was added in surface profile capturing function.

Step2. Surface profile capturing function was executed

Step3. Step2 was repeated for different field and different environmental conditions.

Step4. From observed data set, longest time taken in measuring a target was founded out (maximum value of TT), Let it is L.

Step5. Stop

After calculation of 'L', an extra time 'ET' is added to it get wait time 'WT'.

WT= L + ET

Older distance measuring method dist( ) was replaced by new method dist1( ).

```
dist1( )
{
          Send_request_ to_ measure_distance
           While ( time < WT)
            {
              If ( is_response_from_RB )
              {
                   return (Read_response)
              }

              doevents

            }
Send_request_to_teriminate
  return ( ABSURD_POINT)
}
```

Where:

Send_request_ to_ measure_distance is control command to RB to initiate slope distance measurement. 'time' is current running duration of method dist1( ). Is_response_from_RB will be true if EDM has finished distance measurement. Read_response will return slope distance measured by EDM. Doevents is a listener to events generated by other devices. If there is some event generated by some device then current process i.e. dist1( ) is suspended temporarily. On completion of event control is passed back to dist1( ). If while loop get completed then the target under observation is an absurd point. Send_request_to_teriminate is a request to RB to terminate measuring slope distance.

Value of constant ABSURD_POINT is kept equal to zero. Any observation with slope distance equal to zero will not considered for further processing.

8.4.3 Solution for subroutines for communicating with slower devices

By executing one instruction at a time and pass the control back to calling program will solve the problem. To achieve it, extra parameter say 'N' was passed to it. Each time when the subroutine is called then its “Nth” instruction was executed, on success ‘N’ was incremented by ‘1’ and control was transferred back to calling program.

For example:

```
Subroutine1( original parameter list, by_reference N)

{

        Switch case(N)
                Case 1: request1
                N=N+1
                Return
        Cases 2: if (response1) then
                        N=N+1
                        Return (read_response)
                Else  return
                        |
                        |
        Case M-1:       requestM-1
                N=N+1
                Return
        Cases M: if (responseM) then
                        N=N+1
                        Return (read_response)
                Else  return
}
```

In PMTS, various programs for robotic application are written in computer system. Computer system sends one command to RB at a time. On execution of the command RB sends status of execution. There may be observable time gap between command and response. This time gap was utilized for handling other devices.

8.4.4 Solution for HD Camera

A simple solution was used for this problem. Before starting a critical operation, the video was paused. On completion of the operation, the video was resumed.

For example:

Normal operation1

Normal operation2

Pause the video.

Critical operation

Resume the video

Normal operatioN-1

Normal operationN

8.4.5 Solutions for time complex real time expression

Following solutions were implemented for complex real time expressions.

8.4.5.1 Simplification of expressions

Certain complex expressions were simplified to remove time complexities from them.

For example:

Equation of three dimension polygon plane (PP3D) was obtained by measuring three points on it with the help of TS. Later this plane was transformed into photo coordinate system. The transformation expression is time complex. Observe the following statements in reference of coordinate systems:

- Rotation in Cartesian coordinate system is time complex.
- Translation in polar coordinate system is time complex.

To avoid complexities following statements were used:

- Rotation in polar coordinate system is not complex.
- Translation in Cartesian coordinate system is not complex

These statements convey a message that if rotation has to performed then make use of polar coordinate system and for translation purpose make use of Cartesian coordinate system.

Coming back to the problem of polygon plane, let three point measured by TS are A(r1, ha1, va1), B(r2, ha2, va2), and C(r3, ha3, va3). Let PHA and PVA are camera's horizontal and vertical angles when photo of plane was taken. Assume all angular orientation between telescope and camera are zero. Let telescope coordinate system at the time of photo is exposed is an intermediate coordinate system having PHA, PVA rotational angles with TS coordinates. The three points in intermediate coordinate system will be:

A'(r1, ha1-PHA, va1-PVA), B'(r2, ha2-PHA, va2-PVA), and C'(r3, ha3-PHA, va3-PVA) i.e. rotation in polar coordinate.

Translate photo coordinate system to intermediate coordinate system with following translation parameters: Tx = Xoffset, Ty = Yoffset, Tz = Zoffset. Thus three dimensional polygon plane and photo-coordinates are transformed to intermediate coordinate system. Perform photo-coordinate mapping in this intermediate coordinate system online. Offline processing will transform coordinates from intermediate to TS coordinate system.

8.4.5.2 Break up complex expressions into smaller expression

The expressions, for which above mentioned solution was not suitable, were broken into smaller expression. These smaller expressions were evaluated into time sharing mode with activities from other devices. Break up of a time complex expression 'E' is as under:

E = E1 + E2

E1 = E11 + E12

E2= E21 + E22

Thus E is broken into four parts. Timing of its execution with activity of other devices is shown below:

E11
Device 1 activity
Device 2 activity

E12

Device 1 activity

Device 2 activity

E1

Device 1 activity

Device 2 activity

E21

Device 1 activity

Device 2 activity

E22

Device 1 activity

Device 2 activity

E2

Device 1 activity

Device 2 activity

E

Device 1 activity

Device 2 activity

8.5 Factual Precedence of Brackets in BODMAS

This research work is a byproduct of this chapter. It has proved that the brackets have lowest precedence among various operators used in expressions.

BODMAS (Brackets, Order, Division, Multiplication, Addition, and Subtraction) has defined precedence for various operators in Mathematical expressions. According to it brackets have highest precedence, followed by Order, Division, Multiplication, Addition, and finally subtraction has lowest precedence.

Experimental evidences have shown lowest precedence for brackets in BODMAS. This factual precedence of brackets has great role in simplifying Parallel Interpreters/Compilers, Parallel Architectures and parallel executions of inorder expressions. This new fixing not only presents the reality, but also reduces computational complexities.

For more details, refer to Annexure-I.

8.6 Conclusion

Time complex processes, device activities and expressions were analysed and necessary solution for them were developed and deployed. Various solutions implemented in this chapter have converted PMTS into a reliable system.

Chapter 9

CONCLUSION

9.1 Introduction

This chapter summarizes research work carried out in development of Photogrammetric Mapping with Total Station for the purpose of integrating a powerful processing component with robotic base. For realizing the concept of "Make in India", developed an indeginous technology to provide a cost effective solution for precise measurement of 3D point cloud data even in inaccessible locations.

This research is mainly focused on photogrammetric mapping with total station, during this research eight objectives are achieved i.e. a) integration of computer system, photogrammetric system and RTS, b) overall control over the functioning of RTS using online command and data transfer between computer system and RTS, c) photo-coordinate mapping to TS coordinate system and vice versa, d) real time parameter updates, e) reflector less, no optical marks/bar/symbols based measurement, f) image assisted precise object targeting, g) skipping absurd points and h) customizable environment for development of robotic applications.

9.2 Summary

Foundation of this research work is laid in chapter 3 and 4, in these chapters overall control of robotic base was handed over to computer system by performing reverse engineering on total station, which concludes with a sufficient set of parameters, variables and instruction set helping in realization of PMTS. The second objective i.e. the overall control over the functioning of robotic base using online commands and data transfer with computer system, powerful processing and controller is developed and deployed through interfacing. Integration of photogrammetric system with robotic base is carried out to fulfill the first objective of PMTS and a new approach of modeling lens distortion is introduced in chapter 5. In which optical integration and lens distortion model helped in realizing third objective of mapping photocoordinates with satisfactory results.

After developing the base model of PMTS, methods of controlling movements of robotic base by clicking on target in the image are developed. The developed system reduces the complexity in setting a target, which becomes easier as compared with narrow field of view of telescope. A novel approach is developed for targeting the objects in precision which concludes the objectives of image assisted precise object targeting and reflector less, no optical marks/bar/symbols based measurement. It is not feasible to update station parameters manually at run time of scan function, therefore an automatic system is developed for parameter update to maintain precision in measurement (this fulfills the fourth objective of PMTS). Frequent PMTS system failures suggested to perform a seprate study for cause and cure of failures. Various causes of system failure in PMTS and their solutions are presented in chapter 8 to make PMTS a reliable system, this concludes the last objective - skipping absurd points inclusively.

A work plan presents an outline of a set of goals and detailed description of processes by which objectives of the thesis are accomplished, offering a better understanding of the scope of Photogrammetric Mapping with Total Station. Throughout the thesis, work plan helped to stay organized well working on a wider and complex research domain of robotic total station. PMTS architecture, represents its components and their inter-relationship, is developed and tested.

Hence, integration of photogrammetric system with total station is successfully completed with desired results. Camera used in the system can be metric or non-metric camera. Over all precision of measurement is dependent on Total Station used. It can be used for capturing surface, recording temporal data, monitoring critical surfaces and targets. The developed system has a facility to develop applications in high level language and can be customized.

9.3 Major Contributions of the Research

Through this study following points emerged:

- This research address the gaps in present 3D surveying technologies
- This research integrates the advance technologies like photogrammetry systems with total stations
- The developed photogrammetric mapping with total station shows real time photcoordinates mapping to total station coordinates system.
- Given a cost effective solution for precise measurements
- Reduces the burden of creating and managing optical marks/reflectors/symbols/bars based measurements

- The present study also specifies the associated problems rising in developing programs for robotic applications at user end
- Replacement of functions of telescope with camera
- Presented a new approach of modeling lens distortions
- Online station parameters update for precise measurement
- Fixation of factual precedence of brackets in BODMAS (a byproduct of research work)

9.4 Future Scope and Recommendations

Full fledged Controller can be developed in future for complete functionalities and marketing purpose. Presently photogrammetry system is mounted outside the robotic base. In future it can be mounted inside to make it more robust. PMTS has its use in capturing field profiles, temporal surface data and in monitoring systems. Further the system can be extended to be operated remotely through internet connection.

REFERENCES

Alyilmaz, C., Yakar, M. and Yilmaz, H.M. (2010). *Drawing of Petroglyphs in Mongolia by Close Range Photogrammetry.* Scientific Research And Essays, 5/11, pp. 1216-1222.

Anai, T. and Chikatsu, H. (2000). *Dynamic Analysis Of Human Motion Using Hybrid Video Theodolite.* IAPRS, Vol. XXXIII; Amsterdam.

Atkinson, K.B. (1996). *Close Range Photogrammetry and Machine Vision.* Whittles Publishing, Scotland.

Balsa-Barreiro, J. and Lerma, J.L. (2014). *A New Methodology to Estimate the Discrete-return Point Density on Airborne Lidar Surveys*. International Journal of Remote Sensing, 35(4), pp. 1496-1510. DOI:10.1080/01431161.2013.878063

Bhatla, A., Choe, S., Fierro, O., & Leite, F. (2012). *Evaluation of Accuracy of as-built 3D Modeling from Photos Taken by Handheld Digital Cameras*. Automation in construction, 28, pp. 116–127.

Brandstätter, G. (1989). *Das analytische Modell der videogestützten räumlichen Zielerfassung mit panfokalem Fernrohr*. Proceedings of first Conference on Optical 3-D Measurement Techniques Congress in Vienna/Austria. Eds Grün/Kahmen. Wichmann Verlag.

Buchmann, P. (1996). *Entwicklung eines Messsystems zur automatischen polaren Objekterfassung am Beispiel der Bauaufnahme*. DGK Reihe C / 456, München, Dissertation, Ruhr-Universität Bochum.

Bucksch, A., Lindenbergh, R. and Van-Ree, J. (2007). *Error Budget of Terrestrial Laser Scanning: Influence of the Intensity Remission on the Scan Quality*. In: Proceedings GeoSiberia - 2007, Novosibirsk.

Carbonell, M. (1989). *Arquitectural Photogrammetry, in Karara HM, editor, Non-topographic photogrammetry.* Falls Church, Virginia: ASPRS.

Chitade, A. and Katiyar, S.K. (2011). *Stream Network Change Analysis Using Edge Detection Techniques*. International Journal of Advances in Sciences and Technology, 2(3).

Deren, L. and Zheng, Z. (1992). *Analytical Photogrammetry*. Publishing House of Surveying and Mapping, pp. 400.

Dwivedi, R.J. and Dikshit, O. (2013). *A Comparison of Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) in Second Order Design (SOD) of GPS Networks*. Journal of Applied Geodesy, 7, pp. 135–145.

El-Hakim, S. F., Beraldin, J.A. , and Blais., F. (1995). *A Comparative Evaluation of the Performance of Passive and Active 3-D Vision Systems.* St. Petersburg Conference on Digital Photogrammetry, St. Petersburg, Russia, SPIE, NRC 39160

El-Omari, S. and Mosehi, O. (2008). *Integrating 3D Laser Scanning and Photogrammetry for Progress Measurement of Construction Work.* Automation in Construction Journal, 18(1), pp. 1-9.

Fabiankowitsch, J. (1990). *Automatische Richtungsmessung mit digitalen Differenzbildern*. Dissertation, TU Wien. 2805 Series, Operating Instructions. Edition 24.08.2000.

Fathi, H. and Brilakis, I. (2013). *A Videogrammetric as-built Data Collection Method for Digital Fabrication of Sheet Metal Roof Panel.* Addvanced Engineering Informatics, 4(4), pp. 466-476.

Fekete, K. and Schrott, P. (2008). *Qualification of Close Range Photogrammetry Cameras by Average Image Coordinates RMS Errors vs. Object Distance Function.* The International Archieves of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Beijing, Vol. XXXVII, Part B5, pp. 149-152.

Finsterwalder, R. and Hofmann, W. (1968). *Photogrammetrie. 3rd edition*. Walter de Gruyter & Co, Berlin 1968.164 Bibliography.

Golparvar-Fard, M., Peña-Mora, F. and Savarese, S. (2009). *D4AR- A 4-Dimensional Augmented Reality Model for Automating Construction Progress Data Collection,* *Processing and Communication*. Journal of information technology in construction, 14, pp. 129–153.

Gottwald, R. (1987). *Kern E2-SE – Ein neues Instrument nicht nur für die Industrievermessung?* AVN, 4, pp. 147 – 153.

Gravel, C., Larouche, C. and Gagnon, P.A. (1999). *Integration of Total Station and Digital Camera*. Surveying with Images, *Geomatics Info Magazine*, 13(9), pp. 6-7.

Group, G. (2000). *Motion Controller, 4-Quadrant PWM for DC-Micromotor.* MCDC.

Gruen, A., Huang, X., Qin, R. and Du, T., W. (2013a). *Integration of Mobile Laser Scanning Data with UAV Imagery For Very High-Resolution 3D City Modeling*. Proceedings MMT2013, International Symposium on Mobile Mapping Technology, Taiwan.

Gruen, A., Huang, X., Qin, R., Du, T., Fang, W., Boavida, J. and Oliveira, A. (2013b). *Joint Processing of UAV Imagery and Terrestrial Mobile Mapping System Data for Very High Resolution City Modeling.* Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Science, Rostock.

Haddad, N., and Ishakat, F. (2007). *3D Laser Scanner and Reflectorless Total Station: A Comparative Study of the Slots of El-Khazneh at Petra in Jordan*. XXI International CIPA Symposium, 01-06 October 2007, Athens, Greece.

Hernández-López, D. and Lerma, J.L. (2012). *Analysis of the Ground Sample Distance on Large Photogrammetric Surveys Beatriz Felipe-García*. Applied Geomatics, 4(4), pp. 231-244. DOI:10.10 07 /s12518-012-0084-2

Huang, Y. D. (1992). *3-D Measuring System Based on Theodolite-CCD Cameras.* XVIIth ISPRS-Congress. Volume XXIX. Commission V. Part B5. Washington D.C. pp. 541-544. Bibliography 165.

Huep, W. (1988). *Konzeption und Einsatzmöglichkeiten eines Automatisierten Theodolitsystems*. X. Internationaler Kurs für Ingenieurvermessung, September 1988, München, S. A13/1-A13/13.ISO 17123-3, 2001. Optics and optical instruments − Field

Procedures for Testing Geodetic and Surveying Instruments − Part 3: Theodolites. First edition, 2001-12-01. ISO copyright office.

Ikeda, S., Sato, T. and Yokoya, N. (2003). *A Calibration Method For An Omnidirectional Multi-Camera System*. IS&T/SPIE's 15th Annual Symposium on Electronic Imaging, Santa Clara, California, USA

Imura, M. (2001). *Digital Archiving of Kamegata-Ishi (Turtle Shape Stone) using Data Fusion of Heterogeneous Measurements*. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXIV(5/W1), Proceedings of International Workshop on Recreating the Past, pp. 75-80.

Jeong, J.H. and Takagi, M. (2007). *Crack Monitoring Using A Digital Camera And An Image Total Station*. Kochi University of Technology, Japan.

Kahmen, H. and Roic, M. (1995). *A New Generation of Measurement Robots for Object Reconstruction without Targeting*. Proceedings of 3rd Conference on Optical 3-D Measurement Techniques, Vienna/Austria. Eds. Grün/Kahmen, Wichmann Verlag, pp. 251–262.

Kamat, V.R., Martinez, J.C., Fischer, M., Golparvar-Fard, M., Peña-Mora, F. and Savarese, S. (2011). *Research in Visualization Techniques for Field Construction*. Journal of construction engineering and management, 137(10), pp. 853–862.

Katiyar, S.K. (2010). *Accuracy Aspects in the use of GPS Technology for Geoinformation System*. Journal of Disaster and Development, published by National Institute of Disaster Management (NIDM), New Delhi.

Katiyar, S.K. , Dikshit, O. and Kumar, A. (2003). *Geocoding Using GPS in Autonomous Mode. "GIM International"*. University of Delft, The Netherlands, No. 6(17).

Katiyar, S.K. and Dikshit, O. (2011). *GCP Database Development Methodology for Remote Sensing and GIS, using GPS and SOI Topographic Maps.* Journal of Indian Society of Geomatics, Space Application Centre Ahmedabad, No.2(5), pp. 101-106.

Katiyar, S.K. and Chitade, A.Z. (2011). *Stream Network Change Analysis using Edge Detection Technique.* International Journal of Advances in Science and Technology, No. 3(2).

Kavanagh, B.K. (2009). *Surveying with Construction Applications (7th ed.).* Prentice Hall.

Khalid L.A. and Khalid, E.A. (2015). *A comparison Between Analytical Aerial Photogrammetry,Laser Scanning, Total Station and Global Positioning System Surveys for Generation of Digital Terrain Model*, Geocarto International, 30(2), pp. 154-162.

Khalid, L. A. and Khalid, E.A. (2014). *Accuracy, Time Cost and Terrain Independence Comparisons of Levelling Techniques.* Geodesy and Cartography, 40(3), pp. 133-141.

King, B.A. (1997). *Some Considerations for the Statistical Testing of Least Squares Adjustments of Photogrammetric Bundles.* The photogrammetric record, 15(90), pp. 929–935.

Kraus, K. (1992a). *Photogrammetry, Advanced Methods and Applications*. Foutrh Ed., Vol. II, Dümmler, Bonn.

Kraus, K. (1992b). *Photogrammetry, Fundamentals and Standard Processes*. Vol. I, Fourth Revised and Enlarged Ed., Dümmler, Bonn.

Kraus, K. (2007). *Fotogrametri, Fotogrametri ve Lazer Tarama verilerinden eometrik Bilgiler, Cilt 1,Nobel Yayınevi*, 1. Baskı, _stanbul (Translation by Altan et al.).

Kumar, K., Prasad, P.S., Goyal, N. and Mathur, S. (2007). *Large – Scale -Mapping and Monitoring of the Patalganga Landslide*. Disaster and Development, Journal of the national Institute of Disaster Management, 1(2), pp. 187 – 196.

Kumar, K., Panigrahi, R.K. (1998). *Instrumentation, Monitoring and Analysis of a Landslide – A Case Study.* Fourth International Conference on Case Histories in Geotechnical Engineering, St. Luis, Missouri.

Kumar, K., Prasad, P.S., Kathait, A. and Negi, I. (2014). *Monitoring of Critical Landslides and Design of Preventive measures.* Proceedings of World Landslide Forum 3, Beijing.

Lichti, D.D., Gordon, S.J., Stewart, M.P., Franke, J. and Tsakiri, M. (2002). *Comparison of Digital Photogrammetry and Laser Scanning*. Proc. of the CIPA WG6 Int. Workshop on Scanning for Cultural Heritage Recording.
http://www.isprs.org/commission5/workshop/.

Lichti, D.D., Stewart M.P., Tsakiri, M., Snow, A.J. (2000). *Calibration and Testing of a Terrestrial Laser Scanner.* Int. Arch. of Photogrammetry and Remote Sensing, XXXIII, Part B5, pp. 485-492.

Lohani, B. and Dashora, A. (2013). *Turning Mechanisms for Airborne LiDAR and Photographic Data Acquisition*. Journal of Applied Remote Sensing, 7(1).

Lohani, B., Yadav, M., Goel, S., and Singh., A.K. (2014). *Developing Basic Design and Mathematical Framework for a Mobile Mapping System—A Case Study Using Available Sensors.* Journal of the Indian Society of Remote Sensing, doi: 10.1007/s12524-013-0340-x.

Lotfy, D.K. and Khalid, E.A. (2007). *Effect of Control Distances Constraint on the Accuracy of Block Adjustment*. Engineering Research Journal. Issue 109, pp. C1–C15.

Luhmann, T., Robson, S., Kyle, S. and Harley, I. (2006). *Close Range Photogrammetry*. Whittles Publishing, ISBN 1-870325-50-8, pp. 4-5.

Manorathna, P., Ogun, P., Marimutha, S., Justhan, L., and Jackson, M. (2014). *Performance Evaluation of a Three Dimensional Laser Scanner for Industrial Applications.*Information and Automation for Sustainability (ICIAfS), 7th International Conference, IEEE.

Matthias, H. (1982). *Der Topomat*. Vermessung, Photogrammetrie, Kulturtechnik, Switzerland, Jg. 80, H. 4, S. 123-125. Product Information: handouts/folders of instrument manufacturers Leica Geosystems, Topcon, Trimble, Sokkia, Zeiss from the years 2001 to 2007 (Portions © 2008 Trimble Navigation Limited. All Rights Reserved; Copyright Leica Geosystems;

Mischke, A. and Wieser, A. (1995). *Automatic Target-Area-Collimation with Video-Theodlites*. Proceedings of 3rd Conference on Optical 3-D Measurement Techniques, Vienna/ Austria. Eds. Grün/Kahmen, Wichmann Verlag, pp. 263 – 271.

Mischke, A. (1996). *Distanzmessung mittels Autofokusfunktion einer CCD-Kamera*. AVN, 1, pp. 31 – 39.

Mischke, A. (2000). *Entwicklung eines Videotheodolit-Messsystems zur automatischen Richtungsmessung von nicht signalisierten Objektpunkten*. Geowissenschaftliche Mitteilungen, 54. Wien.

Mischke, A. and Kahmen, H. (1997). *A New Kind of Measurement Robot System for Surveying on Non Signalized Targets*. Proceedings of 4th Conference on Optical 3-D Measurement Techniques, Zurich/Switzerland. Eds. Grün/Kahmen, Wichmann Verlag, pp. 311–318.

Murai, S. (2002). *Yesterday, Today and Tomorrow of System for Spatial Data Processing, Analysis and Representation*. ISPRS Commission II, Symposium 2002, Proceedings of Integrated System for Spatial Data Production, Custodian and Decision Support, Xi'an, China

Murai, S., Otani, S., and Ito, T. (2004). *Digital Photogrammetric System Using Total Station with the Scanning Function*. International Workshop on "Processing and Visualization using High-Resolution Images" Pitsanulok, Thailand.

Pflipsen, B. (2006). *A Comparison of Total Station versus Laser Scanner and Different Software.* Department of technology and Built Environment, University of GAVLE.

Qin, R. and Gruen, A. (2014). *3D Change Detection At Street Level Using Mobile Laser Scanning Point Clouds And Terrestrial Images.* ISPRS Journal of Photogrammetry and Remote Sensing 02/2014; 90(2014), pp. 23-35. DOI:10.1016/j.isprsjprs.2014.01.006

Rao, P.J., Kumar, K., Babu, G.L.S. and Panigrahi, R.K. (1998). *Investigation, Instrumentation and Monitoring of Landslides at Powari, Kinnaur District (H.P) - A Case Study.* Journal of Indian Roads Congress, New Delhi, 16.

Riechmann, W. (1992). *The Accuracy of the Réseau-Scanning Camera (RSC) in Comparison with Theodolite- and Photogrammetric Systems.* ISPRS-Congress, Washington D.C. 29(B5), pp. 852−586.

Roic, M. (1996). *Erfassung Von Nicht Signalisierten 3D-Strukturen Mit Ideotheodoliten*. Geowissenschaftliche Mitteilungen, Heft 43. Wien. Bibliography 167

Scherer, M. (1995). *Ein Expertensystem zur Architektur-aufnahme – Bausteine auf dem Weg dorthin*. Zeitschrift für Vermessungswesen, pp. 134-142.

Scherer, M. (2002). *Advantages of the Integration of Image Processing and Direct Coordinate Measurement for Architectural Surveying-Development of the System TOTAL*. XXII FIG International Congress, ACSM/ASPRS Annual Conference, Washington DC.

Scherer, M. (2003). *Kostenersparnis durch Integration verschiedenartiger Aufnahmemethoden und unterschiedlicher Attribute in einem konsistenten System*. Jahrestagung der VdL , Hannover

Scherer, M. (2004). *How to Optimise the Recording of Geometrical Data and Image Data for the Purpose of Architectural Surveying*. XXth ISPRS Congress Istanbul, Turkey

Scherer, M., and Lerma, J. (2009). *From the Conventional Total Station to the Prospective Image Assisted Photogrammetric Scanning Total Station: Comprehensive Review*. Journal Surveying Engineering., 135(4), pp. 173–178.

Seatovic, D. (2000). *Integration eines motorisierten Videotheodoliten TM3000V in das Karlsruher Industriemesssystems*. Diplomarbeit, Karlsruhe.

Shashi, M. and Jain, K. (2007). *Use of Photogrammetry in 3D Modeling and Visualization of buildings.* Journal of Engineering and Applied sciences, 2(2), pp. 37-41.

Shashi, M., Heera, N., and Jain, K. (2007). *Application of Total station in Modern Arena of Sports.* Journal of Indian Surveyor, 61(1), pp. 51-56.

Shashi, M., Jain, K. and Patil, A. (2008). *Recognition of Model Shape after Deformation using Close range Photogrammetry.* Journal of Indian Surveyor, 62(1), pp. 43-45.

Shen, X.S., Lu, M. and Chen, W. (2011). *Tunnel-boring Machine Positioning During Microtunneling Operations through Integrating Automated Data Collection with Real Time Computing*. Journal of Construction Engineering and Management, 137(1), pp. 72–85.

Uffenkamp, V. (1993). *Conception of a Digital Turning and Tilting Camera.* Proceedings of 2nd Conference on Optical 3-D Measurement Techniques, Zurich/Switzerland. Eds. Grün/Kahmen, Wichmann Verlag, pp. 72–80.

Uffenkamp, V. (1995). *Konzeption, experimentelle Realisierung und Kalibrierung einer optoelektronischen Schwenk-Neige-Kamera mit langer Brennweite.* Dissertation, TU München.

Walser, B.H.. (2004). *Development and Calibration of an Image Assisted Total Station*. A Dissertation Submitted to the Swiss Federal Institute Of Technology Zurich.

Wang, Z. (1979). *Principles of Photogrammetry*. Publishing House of Surveying and Mapping, pp. 575.

Wasmeier, P. (2002). *Potential der Objekterkennung mit dem Videotheodolit TCA2003*. Diplomarbeit, TU München.

Wasmeier, P. (2003). *The Potential of Object Recognition Using a Servo-tacheometer TCA2003.* In: Optical 3-D Measurement Techniques VI, Gruen / Kahmen (eds.), II, pp. 48-54, ETH Zurich,

Wenhao, F. (2001). *Close-range Photogrammetry*. Wuha n University Publishing House.

Wester-Ebbinghaus, W. (1985). *Bündeltriangulation mit gemeinsamer Ausgleichung photogrammetrischer und geodätischer Beobachtungen*. Zeitschrift für Vermessungswesen, 110 (3), pp. 101-111.

Wester-Ebbinghaus, W. (1988a). *High Resolution Object Recording by Video-Theodolite*. ISPRS-Congress, Com. V, Kyoto 1988, 27(B10), pp. 219−223.

Wester-Ebbinghaus, W. (1988b). *Analytics in Non-topographic Photogrammetry.* ISPRSCongress, Com. V, Kyoto 1988, 27(B11), pp. 380−390.

Wieser, A. (1995). Ingenieurgeodätische Überwachungsmessung mit Videotheodoliten. Diplomarbeit, TU Wien.

Yadav, M., Goel, S., Singh, A. K. and Lohani, B. (2013). *Mobile Mapping System using Laser Scanner, GPS and IMU.* ISRS Journal, DOI 10.1007/s12524-013-0340-x.

Yakar, M. (2009). *Usıng Close Range Photogrammetry to Measure the Posıtıon of Inaccessıble Geologıcal Features.* Experımental Technıques, doi: 10.1111/j.1747-1567.2009.00583.

Yakar, M. (2009). *Digital Elevation Model Generation By Robotic Total Station Instrument.* Experimental Techniques, 33(2), pp. 52-59, doi: 10.1111/j.1747-1567.2008.00375.x

Yakar, M. (2011). *Using Close Range Photogrammetry to Measure the Position of Inaccessible Geological Features*. Experimental Techniques, 35(1), pp. 54-59.

Yilmaz, H.M., and Yakar, M. (2008). *Computıng of Volume of Excavatıon Areas by Dıgıtal Close Range Photogrammetry*. Arabian J. Sci. Eng., 33(1A), pp. 63-78.

Yilmaz, H.M., Yakar, M., Yildiz, F., Karabork, H., Kavurmaci, M.M., Mutluoglu, O., and Goktepe, A. (2009). *Monitoring of Corrosion in Fairy Chimney by Terrestrial Laser Scanning.* J. Int. Environ. Appl. Sci., 4(1), pp. 86-91.

Zhang, A.Z., Zheng, A.,S. and Zhan, A. Z. (2004). *Digital Terrestrial Photogrammetry with Photo Total Station*. International Society for Photogrammetry and Remote Sensing.

Zhang, L. (2009). *Study on Applications of Three-Dimensional Laser Scanning Technology in Forestry Resources Inventory.* IEEE, International Conference on Automation and Logistics Shenyang, China.

Zhang, Z., Zheng, S. and Zhan, Z. (2003). *Photo Total Station System an Integration of Metric Digital Camera and Total Station*. Proceedings of 6th Conference on Optical 3-D Measurement Techniques, Zürich. Eds. Grün/Kahmen, I, pp. 176 – 182.

Zhanga, Z., Zhenga, S., and Zhana, Z. (2005). *Digital Terrestrial Photogrammetry with Photo Total Station*. School of Remote Sensing Information Engineering, Wuhan University, 129 Luoyu Road, Wuhan 430079, China.

ANNEXURE-I

Factual Precedence of Brackets in BODMAS

1. Introduction

BODMAS (Brackets, Order, Division, Multiplication, Addition, and Subtraction) has defined precedence of various operators in Mathematics. According to it brackets have highest precedence followed by Order, Division, Multiplication, Addition, and finally subtraction has lowest precedence.

Experimental evidences have shown lowest precedence for brackets in BODMAS. This factual precedence of brackets has great role in simplifying Parallel Interpreters/Compilers, Parallel Architecture and parallel inorder expressions. This new fixing not only presents the reality, but also reduces computational complexities.

2. Definitions

2.1 Full form of BODMAS is:

Brackets: ( ) , [ ] , { }

Order: Exponential, Roots, OF etc.

Division: / or ÷

Multiplication:* or ×

Addition: +

Subtraction: -

2.2 Precedence in reference of BODMAS

Brackets 1, **O**rder 2, **D**ivision 3, **M**ultiplication 4, **A**ddition 5, **S**ubtraction 6

Associativity: Left to Right

3. Objective

To prove precedence of Brackets is lower than other operators

4. Proof

Before proceeding towards proofs, one have to wash out the already defined precedence of brackets. One has to start a fresh like a child of nursery class.

Rule:

For nested brackets the precedence value of inner bracket will be added to outer bracket.

4.1 Relational Proof

By definition a "Bracket" is used to increase precedence of other operators' e.g. to perform addition before multiplication in equation X=A + B * C it will be written as:

X = (A + B) * C

In the equation shown above original precedence allotted to '+' and '*' remain unchanged.

Question arises that how to increase precedence without modifying it. This is analogous to asking "How to increase length of a line segment without enlarging it". There exists a solution for second statement. Simply draw a smaller line parallel to it as shown below:

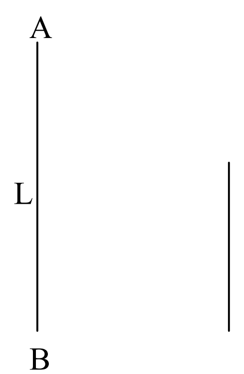


Fig.1. Line segment AB of fixed length L look larger.

In the absence of extra line the line segment AB only seems to have a length L. But in the presence of extra line segment it will look like a larger line without any change in its length.

If extra line segment is larger than given line segment then it will look smaller in size. This is the example from where idea about precedence of bracket came in mind.

If same concept is applied on precedence of operators then it can be concluded for above equation that precedence of '+' seems larger due to presence of lower precedence brackets.

4.2 Analytical proof

Let us replace precedence by distance of operand from its operator as given in table 1.

Table 1 Various operators in BODMAS and their precedence

Sr. No.	Operator	Precedence	Distance
1	( ), { }, [ ] - brackets	6	6
2	O - ORDER	1	1
3	/ - Division	2	2
4	* - Multiply	3	3
5	+ - Addition	4	4
6	- - Subtraction	5	5

Assume that an operand is attracted by an operator at smaller distance from it.

For example, in expression A+B/C:

$A\ {}_4{+}_4\ B\ {}_2/_2\ C$

Or

A _ _ _ _ + _ _ _ _ B _ _ / _ _ C

Or

A   +   B / C

Where: a subscripted digit / underscore represents distance of an operand from its operator. Here operand B is at distance 4 from ‘+’ operator and is at distance 2 from operator ‘/’. It will be attracted by ‘/’, the operator at smaller distance.

Now insert brackets in given expression to make it (A+B)/C. Its representation in distance form will be:

${}_6(_6\ A\ {}_4{+}_4\ B\ {}_6)_6\ {}_2/_2\ C$

Or

_ _ _ _ _ _ (_ _ _ _ _ _ A _ _ _ _ + _ _ _ _ B _ _ _ _ _ _) _ _ _ _ _ _ _ _ _ / _ _ C

Or

(A   +   B   )   /   C

On removing brackets

A   +   B   /   C

Clearly B is more close to ‘+’ as compared with ‘/’. Thus addition will take place first as compared to division.

4.2.1 Complex Example

Solve following expression assuming that Brackets have lowest precedence

$2 * [9 / (8 – 5) + 6 \text{ OF } (3 * (7 + 4))] - 10$

Step1. Insert operand distances and on removing brackets to obtain following expression:

$2_3 * {}_{21}9_2 / {}_{8}8_5 - {}_{5}5_{10} + {}_{4}6_1 \text{ OF } {}_{13}3_3 * {}_{9}7_4 + {}_{4}4_{23} - 10$

Step2. Move operands towards shortest distance (Bold and enlarged characters)

$2_3 * {}_{21}9_2 / {}_{8}\mathbf{8_5} \mathbf{-} \mathbf{{}_{5}5}_{10} + {}_{4}6_1 \text{ OF } {}_{13}3_3 * {}_{9}\mathbf{7_4} \mathbf{+} \mathbf{{}_{4}4}_{23} - {}_{5}10$

$2_3 * {}_{21}9_2 / \mathbf{{}_{8}3_{10}} + {}_{4}6_1 \text{ OF } {}_{13}3_3 * \mathbf{{}_{9}11_{23}} - {}_{5}10$

In first attempt only two operations are performed

Step3. Repeat step2 on its resultant expression

$2_3 * {}_{21}9_2 / {}_{8}\mathbf{3_{10}} + {}_{4}6_1 \text{ OF } {}_{13}\mathbf{3_3} \mathbf{*} \mathbf{{}_{9}11_{23}} - {}_{5}10$

Again two operations are possible, giving following expression

$2_3 * {}_{21}\mathbf{3_{10}} + {}_{4}6_1 \text{ OF } {}_{13}\mathbf{33_{23}} - {}_{5}10$

Step4. Repeating again

$2_3 * {}_{21}3_{10} + {}_{4}\mathbf{6_1} \ \mathbf{OF} \ \mathbf{{}_{13}33}_{23} - {}_{5}10$

One operation is possible, giving following expression

$2_{10} * {}_{21}3_{10} + {}_{4}\mathbf{198_{23}} - {}_{5}10$

Step5. Repeat again

$2_{10} * {}_{21}\mathbf{3_{10}} \mathbf{+} \mathbf{{}_{4}198}_{23} - {}_{5}10$

Expression will become $2_{10} * {}_{21}\mathbf{201}_{23} - {}_{5}10$

Step6. Repeat again to obtain following expression

$\mathbf{402}_{23} - {}_{5}10$

and **392** is obtained as a final result which matches with result of traditional evaluation method.

Note: It seems that evaluation of above expression requires 7 steps, but using the cyclic result to operand conversion and operator removal the current clock will be halted till its completion, resulting in one step evaluation

5. Advantages of new findings

- **Operand oriented**

One of the biggest advantages is that expressions will become operand oriented. Directly go to an operand, compare its left and right operator distance. The comparison will guide to apply the operand to which operator.

- **Sequencing**

  In C language for logical operators like AND, OR etc. operands sequencing will result in faster execution of expression. Here they are automatically sequenced for all the operators, e.g. operand will be attracted by smaller distance operator.

- **Speed up for parallel computation**

  New concept will not require any type of scheduling for parallel computation. Once distances are inserted and brackets are removed the expression is ready for execution.

6. Conclusion

New assigned precedence to Brackets will reduce the evaluation complexity to a minimum level except the case in which there exist nested brackets in the expression. In that case complexity remains same as compared with older evaluation method.

ANNEXURE-II

Table2 List of subroutines in the library for PMTS

Sr.No.	Routine Name	Description	Parameters	Return value
1	Start( )	To switch ON and initialize robotic base; on success, returns a true value	nil	True/false
2	Set( )	It will assign a value to a station parameter; on success, returns a true value	Parameter ID and its value	True/false
3	Get( )	Return current value of a parameter	Parameter ID	Parameter value
4	movH( )	Move or set telescope of TS at a given horizontal angle	Horizontal angle in grades	True/False
5	movV( )	Move or set telescope of TS at a given vertical angle	Vertical angle in grades	True/False
6	movHV( )	Move or set telescope of TS at given horizontal and vertical angles	Horizontal and vertical angles in grades	True/False
7	Birdeye ( )	To capture panoramic view of the field delimited by horizontal angle	Horizontal angle in grades	Image of field
8	Image_cap_plane( )	Capture an image of field currently in view and places three bench marks on it	nil	Image of field
9	Image_cap( )	Capture an image of field	nil	Image of field

		currently in view without any bench marks on it		
10	AngularProfile	Record surface with equal angular division horizontally and vertically	HA1, HA2, VA1,VA2 i.e. horizontal and vertical range	Surface profile data
11	AngularProfileok	Same as AngularProfile function, but wait for user response before measurement such that user can perform fine setting through telescope	HA1, HA2, VA1,VA2 i.e. horizontal and vertical range	Surface profile data
12	mntr_Click()	Make measurement of a list of 3D point after equal interval of time i.e. monitoring a surface profile	Surface profile or list or 3D points	Surface profile data
13	Map( )	Draw map of point features currently present in program memory	nil	nil
14	prg1( )	Interpreter for robotic base, it translate high level language instructions into instructions for robotic base	Instruction to RB in HLL	nil
15	Zoombox( )	Enlarged view of a portion of image of field	X1,Y1,X2,Y2	nil
16	Timer1_Timer()	Check for availability of data at communication port, if available then read	nil	Data received from communication

		and interpret the data		port
17	Pic9line( )	Draw grid of lines on display for preparing distortion model of lens assembly	nil	nil
18	laserOFF	Turn OFF LASER pointer of robotic base	nil	nil
19	laserON	Turn ON LASER pointer of robotic base	nil	nil
20	Dist( )	Measure slope distance by issuing a command to robotic base	nil	Slope distance
21	Pdata( )	Mark a point on target image and calculate angles for movement	Image	Horizontal and vertical angles
22	Startcamera( )	Initializes the camera mounted on robotic base	nil	nil
23	Pausecamera( )	Pauses the camera mounted on robotic base	nil	nil
24	Stopcamera( )	Stop the camera mounted on robotic base	nil	nil
25	Vidformat( )	Display dialog box for setting parameters for video display	nil	nil
26	Pdraw( )	Draw a point on image	X, Y	nil
27	smooth( )	Balance the contrast in the image of the field	Image	Image
28	sharp()	For sharpening the image pixel data of the field	Image	Image
29	edgeD()	Detect and fix edges in the image of the field	Image	Image

30	RGB( )	Extract red, green and blue color bands from the image	Image	RGB data

ANNEXURE-III

List of Patents from This Thesis

1. "Interface for Robotic Total Station and Computer System with Embeddable Instruction Set", 161/DEL/2012, 19-01-2012.

List of Copyrights from This Thesis

1. **"**Precise Object Targeting in PMTS", 52090/2014-CO/SW, 24/07/2014
2. **"**Subroutines for Online Total Station Parameters Update for Precise Measurements", 50106/2014-CO/SW, 31/05/2014
3. **"**Factual Precedence of Brackets in BODMAS", 54018/2014-CO/L, 17/09/2014