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GPS Positioning of Some Objectives Which are Situated at Great Distances from the Roads by Means of a "Mobile Slide Monitor – MSM"

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Additional information is available at the end of the chapter

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1. Introduction

This chapter presents a Mobile Slide Monitor (MSM) which can be used for fast geographic positioning of some objectives or of some of their components that are situated at great distances from the roadways, (buildings, terrain markings) or are inaccessible in a direct mode, (dams, bridges, heaps of debris). The system assures an accurate geo-referencing of the off-road objective characteristics, an important problem for the infrastructure management at the level of public works administration.

The main applications of this MSM equipment are to estimate and alert, in due time, the occurrence of great proportion accidents caused by breaking down of civil constructions (buildings, bridges, tunnels, dams). These accidents are due to natural causes such as landslides and floods, in the areas with a high risk, or due to some human interventions such as the erroneous emplacement of some new constructions, the erroneous designing or even due to the oldness of some constructions.

Moreover, the bridges are part of a country's transportation infrastructure and are typically assessed and maintained by the authorities responsible for the appropriate transportation sector (road or rail). Nowadays, the deterioration of bridge structures is a serious problem due to issues related to modern society; reliance on the automobile, the increased bridge traffic, the environmental pollution, and the use of potentially corrosive substances (e.g. cleaning and de-icing). Bridge monitoring is necessary to ensure the safety of those who either use, or are affected by the structure itself, and the maintenance of the sector is usually part of the legislature governing.

Therefore the main objective of the present chapter is to describe a mobile laboratory for the monitoring of constructions deformations in the incipient phases, deformations that are due

to terrain sliding from natural or human causes. As opposed to the systems which achieve in static regime the stability monitoring of the constructions by using some precision optical systems or GPS equipments with differential regime functioning but to which the follower receiver is attached in a fixed montage on the surveyed construction, the proposed mobile monitoring system permits that the measurements be rapidly performed, at a preset time interval, with a reduced cost on a multitude of objectives and with a minimum delay between the moment of some defection apparition and the moment of its identification and alarming.

2. Importance and relevance of the technical content

Monitoring of situations and territories with hydro-geological risk represent an institutional task of the Public Administrations. Therefore, in some areas, it becomes necessary to achieve systems for real-time survey, which are able to record the alarm signs of a potential risk for the population. An early-warning system provides, also, the foundation for an effective risk mitigation plan, given the uncertainties related to the mathematical prediction of the natural phenomena and the strong public demand for protection against natural hazards.

The World Bank promotes a proactive and strategic approach to managing natural hazard risk, by taking into account a comprehensive framework, based on the following five pillars:

Risk assessment - includes application of the hazard, exposure, vulnerability, and loss analyses and provides projections of the average annual expected loss and the probable maximum loss from a single catastrophic event;

Emergency preparedness. Citizens and government agencies need to be prepared for breakdowns în essential services, to develop plans for contingencies, and to implement the plans. They should be encouraged to make resources available for facilities and equipment, they need to provide emergency personnel, they need training, sponsor exercises, and get information available for the public;

Investments in risk mitigation. This may include inexpensive investments in increasing institutional capacity, strengthen enforcement of building codes, provide training, and involve communities, including mapping, monitoring and warning systems. As investments in physical infrastructure (flood protection, landslides prevention and retrofitting of housing and/or public buildings for seismic resistance) are very expensive, the selection of the most suitable of them should be carried out by applying cost-benefit or cost-effectiveness analysis;

Institutional capacity building. The efficiency and effectiveness of a comprehensive hazard risk management system depends on the knowledge, awareness, and capacity of the stakeholders involved. For that purpose, the following aspects are recommended:

• to create decentralized emergency management systems;
• to ensure community involvement and participation;
• to develop an efficient legal framework, and
• to provide training, education, and knowledge sharing.

It is also important to integrate hazard risk management into the economic development process. Emergency planning and risk mitigation need to be an integral part of the rural and urban development process, with the participation of all the stakeholders.

Develop a catastrophe risk financing strategy. Countries need to develop and introduce targeted risk financing strategies for dealing with catastrophic events that can have a severe impact on their economies. The strategy would address the funding gap caused by the need to recover economic losses and meet social obligations and other responsibilities, following a catastrophic event. Developing a risk financing strategy is particularly important for countries exposed to catastrophic earthquakes.

Therefore, the Regional Public Administrations from a country, which has more or less accentuated risk for the natural disasters, may have at their disposal the possibility to verify, at pre-established time intervals, the real state of the geological formations or of the building, which is suspected to be in danger.

The main application of the MSM equipment presented here, is the estimation and the alerting in due time regarding the risk of great proportion accidents, by break down of civil constructions due to some natural causes, such as landslides and floods, in areas with high risk of accidents.

The final result will be the achievement of a Geographic Informational System (GIS), which will have to integrate all the information and the all types of data, which are needed for the natural disasters management, from the prognosis to the post-factum measurements. Moreover, besides the hazard maps which must be elaborated for the all regions of the respective country, the local authorities must, also, draw up risk maps which refer to the most exposed areas to the natural calamities.

3. State of the art

Usually, the measurement of superficial displacement is the simplest way to observe the history of a landslide and to analyze the kinematics of the movement, so the investigation of the terrains sliding movements permits, also, the detection of possible precursor elements of the mass movements.

3.1. Existing fixed mapping equipments

In the past, a various surveying techniques were used to detect the superficial movements of unstable area. For examples, tapes and wire devices were used to measure changes in distance, between terrain points or crack walls. Levels, theodolites, Electronic Distance Measurement (EDM), and total station measurements provide both the coordinates and changes of target, control points and landslide features. In addition, aerial or terrestrial photogrammetry provides point coordinates, contour maps and cross-section of the landslides.

3.1.1. Leica Smart Station (Scott A., 2006)

A classical example of such optical measurement equipment for observing different targets with displacement probability is the "Leica Smart Station", a Total Station with integrated GPS offered on the market by the "Leica Geosystems AG" company. The introduction of SydNET, a network of Continuously Operating Reference Station (CORS), allows surveyors to perform Differential GPS without having to purchase a reference receiver. For distances of up to tens of kilometres away from the network reference stations, centimetre accuracy can be achieved, with the RTK-GPS Network.

This equipment involves the optical observation of the proposed object from different static locations of the operator, locations which are precisely determined by means of the highly performing GPS receiver. In these conditions, the determination of the geographic coordinates of a single distant objective involves multiple complex operations and in consequence, can be considered time consuming.

3.1.2. SEPA's system (Caporali A., 2008)

Another totally different technical solution for this problem, solution which aims to reduce the length of the measurement times involved by the use of the optical total stations, is represented by the "Fixed Satellitary Monitoring System of the Territory and Civil Infrastructures" (or SAMOS for short) achieved by SEPA company ("Sistemi Elettronici Per Automazione S.p.A.") from Torino (Italy).

The SEPA's system represents a solution for cost effective applications targeting the real time monitoring and diagnosis of ground deformation; for instance, landslides and the subsidence, or the infrastructure deformations affecting buildings, bridges, viaducts and dams, or even both simultaneously.

Based on measurements from a GPS L1-only carrier phase employing commercial receivers and using the basic principles of interferometric surveying, SAMOS provides continuous real-time monitoring of the area of interest, reporting the millimetric displacement of each sensor relative to a reference sensor.

Measurements are taken at a rate of 1 Hz and the processed results are updated using the same frequency. The system performance is equivalent, on short baselines up to a few km in length.

This Satellitary Monitoring System, in fact like other this kind of systems, is composed of two subsystems, namely:

- a number of Field Sensors, (Fig. 2), deployed to collect the satellite data and which are fix mounted on different parts of the objective of interest (bridge, dam, building). These field sensors are continuously relayed by means of a radio connection to
- a Base Station, (Fig. 3), for real-time processing of the data collected from the field sensors.

For its protection this Base Station is introduced in a Waterproof box (Fig. 4).

Figure 1. Fixed Satellitary Monitoring System of the Territory and Civil Infrastructures achieved by "SEPA Sistemi Elettronici Per Automazione S.p.A." from Torino (Italy).

Figure 2. GNSS receiver

The Field Sensor uses a single frequency GPS receiver to measure the carrier phase on the L1 GPS signal and an RF Modem for point-to-point communication with the base station via radio link. A microcontroller supervises the communication and the exchange of data

between the GPS receiver and the radio modem, and in addition, it supplies diagnostic data related to the sensor itself.

Figure 3. Base station

Figure 4. Waterproof box of the Base Station

It is also important to mention that, for this SAMOS system, it is necessary that, on the surveyed objectives, to be assured permanent electrical energy supplies (which can be constituted from photovoltaic panels or, if this is available, from the mains power supply of the area). In both cases, a backup battery is included. Moreover, we must notice that the receivers and the system GPS components remains in field in the majority of cases, without any surveillance from the operators.

The Base Station includes the network controller, used to receive the GPS data collected via radio links from sensors deployed in the field, and a computer running the software to process the data and display the results in real-time. The raw measurement data as well as the results are stored in a database for possible further processing, if required, or simply archiving. (Caporali A., 2008)

3.1.3. Conclusions referring to the fixed monitoring systems

In addition to collecting the measurement data, the base station can retrieve status information from the sensors, such as the accumulator supply voltage, RF link signal strength and temperature.

The Graphic User Interface (GUI) shows the real-time status of the network (satellites available and being tracked, nominal antenna locations and network geometry, status of each sensor) and the results of the data analysis as northing, easting and vertical

displacements of each antenna with respect to the reference antenna, using diagrams and tables. The GUI can be tailored to the customer's requirements, and it will alert the operator when preset thresholds are exceeded.

The main disadvantage of the SEPA types fixed systems is that this equipment must be mounted in a fixed position on every point of interest, meaning that for an objective or an area suspected to present landslides, a great number of equipments of this kind is necessary, and, in consequence, high total costs.

Taking account of the newest improvements of the GNSS systems regarding the real-time positioning accuracy, (A. Stoica et al., 2008), the authors of this chapter present the achievement of a mobile equipment for the monitoring of the field stability as opposed to the most used in present, static optical total stations, "Leica" or "SEPA" type systems, which are based on GPS receivers with differential regime functioning but which are fixed mounted on the surveyed objectives.

3.2. Existing mobile mapping equipments

But one must specify that also for this mobile alternative, which is proposed here for the monitoring of some objective position, there are various mobile equipments for mapping and, respectively, for monitoring, introduced on international level, equipments which are described in the following subsections.

3.2.1. "GPSVision™" achieved by the "LAMBDA TECH International" company (Guangping He, 1996)

The Mobile Mapping Equipment "GPSVision™" (fig. 5) achieved by the "LAMBDA TECH International" company from Fort Wayne (USA), which is equipped with a positioning module composed of a GPS receiver with double frequency, an Inertial Navigation System (INS) and a linear Distance of running Measuring Instrument (DMI), in combination with four digital video cameras of high resolution. The digital video cameras are mounted above the vehicle and they can be oriented forward, to each side or backward in correspondence with the application needs, so that due to the fact that the video cameras pairs see, at a certain moment, the same field area from different positions, by using some triangulation algorithms, it is possible to calculate the locations relative to the lab vehicle of the sighted targets.

The main characteristics of the system are:

- The images are taken according to an operator-defined distance interval to provide full coverage of the route and its surroundings. By applying a sophisticated photogrammetric triangulation technology, any point that appears in any set of two images can be located in a global coordinate system during digitization with Lambda Tech's Feature Extraction software;
- Stereo imaging allows for determining absolute positions of features such as signs in latitude and longitude to sub-meter accuracy and it also allows very accurate relative measurements of all visible roadside attributes, such as the width, height and offset of a

sign. Stereo imagery allows for multiple views of the same object with 3D capabilities and the ability to recreate image views where the original cameras never took a picture;

- GPSVision™ specified absolute accuracy for terrestrial data positions is **one meter or less** depending on the distance bewtween the feature to be extracted and the camera lens. Depending on the image spacing this accuracy can be increased. The GPSVision™ system was designed to deliver sub-meter RMS positions when visible features are within the camera field of view of both image pairs and **no farther than 30 meters** in front of the camera lenses;

- From a photogrammetric perspective, GPSVision™ is a fix-based stereovision system with known position and attitude provided by the GPS/INS component. Just as a person uses two eyes to determine the distance of an object, every infrastructure feature that is "seen" by the cameras can be triangulated into a three-dimensional coordinate and then transferred into a global coordinate system (e.g., latitude, longitude, height);

- GPSVision™ Feature Extraction software is executable on Microsoft Windows operating systems. It is driven by an external rule base and is language neutral. The user interacts with the software by pointing at features of interest seen in the stereo image pairs with the mouse or stylus. Then, the software triangulates the relative position of the selected feature and transfers it into the global coordinate system and positioned to within one meter or less of their actual location;

- From an application perspective, the GPSVision™ system is used to collect digital images along highways, state roads, residential streets, alleys, and railroads while traveling at posted speed limits. These geo-referenced digital images are used for video log applications but most importantly, the software is used to position visible physical features, such as poles, curb lines, traffic signs, manholes, pedestals and building locations. In addition, the GPS/INS positioning component creates base maps of the route network for Geographic Information Systems (GIS) base map and Computer Aided Drafting and Design (CADD) applications.

Figure 5. GPSVision™ - with four video cameras achieved by the "LAMBDA TECH INTERNATIONAL" Company (USA) for objectives that are closed to the road arteries

3.2.2. "GPSVan™" achieved by the "Mapping Center" from the Ohio State University (Brzezinska et al., 2004)

A similar example of a mobile system for mapping and data collection, which can map railroads, thoroughfares and transport infrastructures (as for example, roads, circulation signs and bridges) during its displacement at posted road speeds is represented by "GPSVan™" system achieved by the Mapping Center from the Ohio State University and which is also composed of two main components: a positioning module and an imagery module. This imagery module includes, also, in this case, a stereo metric system with two video cameras which record the stereo images of the roads during the displacement on the respective arteries of the lab vehicle. Each video frame is time marked with the GPS signal and the geodesic coordinates (latitude, longitude and ellipsoidal height, respectively) are attributed to each image.

From the above presented aspects, it results that both the GPSVision™ and GPSVan™ equipments represent, in their essence, a fix-based stereovision system with known position and attitude, provided by the GPS/INS component and, respectively, by the GPS/DRS component. This fixed base is represented by the distance, on the hood width of the lab vehicle, between the optical distances of the two video cameras, mounting distance which in the case of both GPSVision™ and GPSVan™ equipments is approximately of 1.2 meters. As a consequence of the fixed base reduced value, the difference between the angles of sighting directions of the two video cameras is under the minimum value it can be measured by the optical system when the sighted targets are situated at a distance, greater then approximately 40 meters, in respect to lab vehicle. This limitation of the observing distance, at a quite reduced value, represents in its essence the main disadvantage of the stereo metric systems, which are based on the use of a pair of video cameras, mounted on the same lab vehicle.

4. Originality of the proposed Mobile Slide Monitor (MSM)

The static regime systems, previously described, achieve the stability monitoring of the constructions by using precision optical systems or GPS equipment with differential regime functioning, but to which the follower receiver is attached in a fixed montage on the surveyed construction. As opposed to these systems the monitoring system presented here has the advantage that it permits measurements to be rapidly performed, at preset time interval, with a reduced cost on a multitude of objectives and with a minimum delay between the moment of some defection occurence and the moment of its identification and alarming.

Taking account of the above-mentioned characteristics of the bi-cameral stereo-metric systems, the INOE 2000 Institute from Bucharest elaborated the Invention Patent RO 126294 A2/2009 whose main objective was to increase up to U200 – 300 metersU, the distance up to which the sighted targets from the terrain can be positioned.

Conceptually this Mobile Slide Monitor - MSM involves:

- The acquisition of **successive images** achieved from a **moving vehicle** by means of a single **CMOS video camera** mounted above this vehicle (Fig.6);


Figure 6. Moving vehicle and the CMOS video Camera

- **The determination** with a sub-metric accuracy of the **vehicle position,** by means of a GPS device at the time of taking the picture (Fig. 7);

**Figure 7.** Multi-Frequency GPS receiver

- The use of an **innovative mathematical** algorithm based on a triangulation method for the **geographic position** computing of every object which appears in two different images.
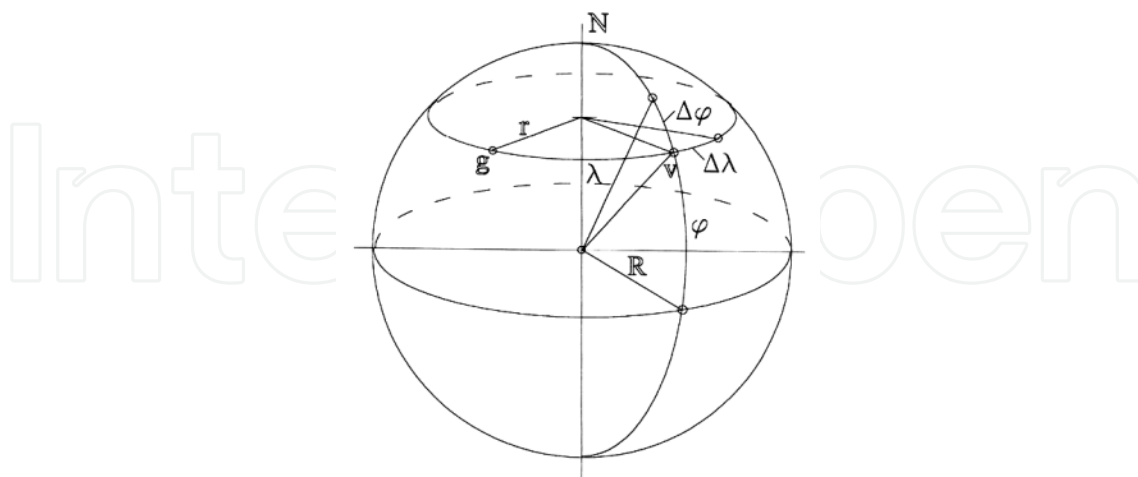
Figure 8. Geographic positioning of the sighted object.

4.1. The functioning and the use of the Mobile Slide Monitor

The general assembly of the proposed Mobile Slide Monitor is presented in Figure 9.
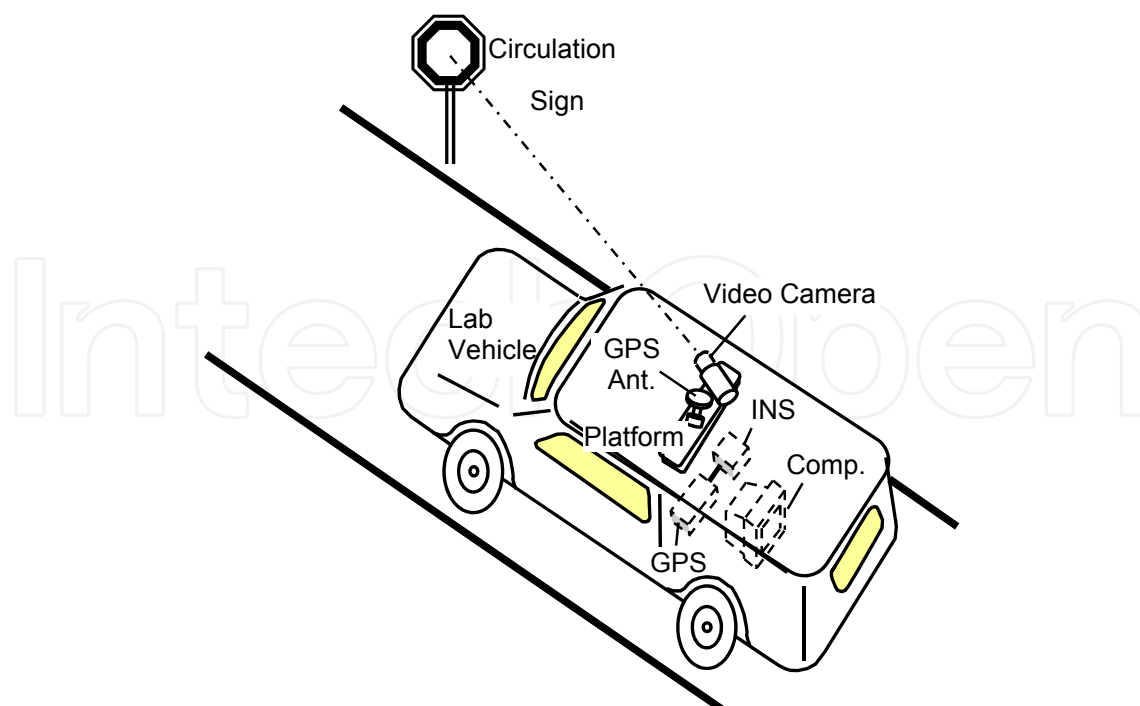
Figure 9. The equipment assembly during a normal functioning on a tested route

More precisely, the mobile positioning system achieved in conformity with the invention patent proposes itself to obviate the limits which affect the functioning of the above-mentioned equipments by introducing the following series of combined measures:

- In order to increase up to 200 – 300 meters, the distance up to which the sighted targets from the terrain can be positioned, the proposed MSM equipment resorts to the use of a single digital camera of high resolution in a fixed montage on a lab vehicle. This way, the measurement of the applied stereo-metric method is based not on the width of the lab vehicle, which uses the bi-cameral method, but on the distance of 20 – 30 meters between the positions resulted from the lab vehicle displacement and from which the camera sights the same objective (fig. 10). This single video camera has a telemetric type objective and a reduced angle of view;

On the basis of the notations entered in the figure 10, it is possible to compute the geographic position coordinates of the sighted target: λ_T, ϕ_T, h_T - longitude, latitude and height, respectively:

- Ψ_{T1} and Ψ_{T2}, azimuth angles of the sighted target in rapport with two positions of the Lab Vehicle, angles which are determinated from the two target preloaded images with the Video Camera;
- λ_1, ϕ_1, h_1 and λ_2, ϕ_2, h_2, the vehicle geographic coordinates determined for the two positions of the Lab Vehicle by means of its GPS receiver;
- Ψ_1, Θ_1, Φ_1 and Ψ_2, Θ_2, Φ_2, the vehicle orientation angles determined for the two positions of the Lab Vehicle by means of its Inertial Navigation System (INS);
- M.B. – Measuring Base, namely the distance between the two positions, Pos.1 and Pos.2 of the Lab Vehicle,
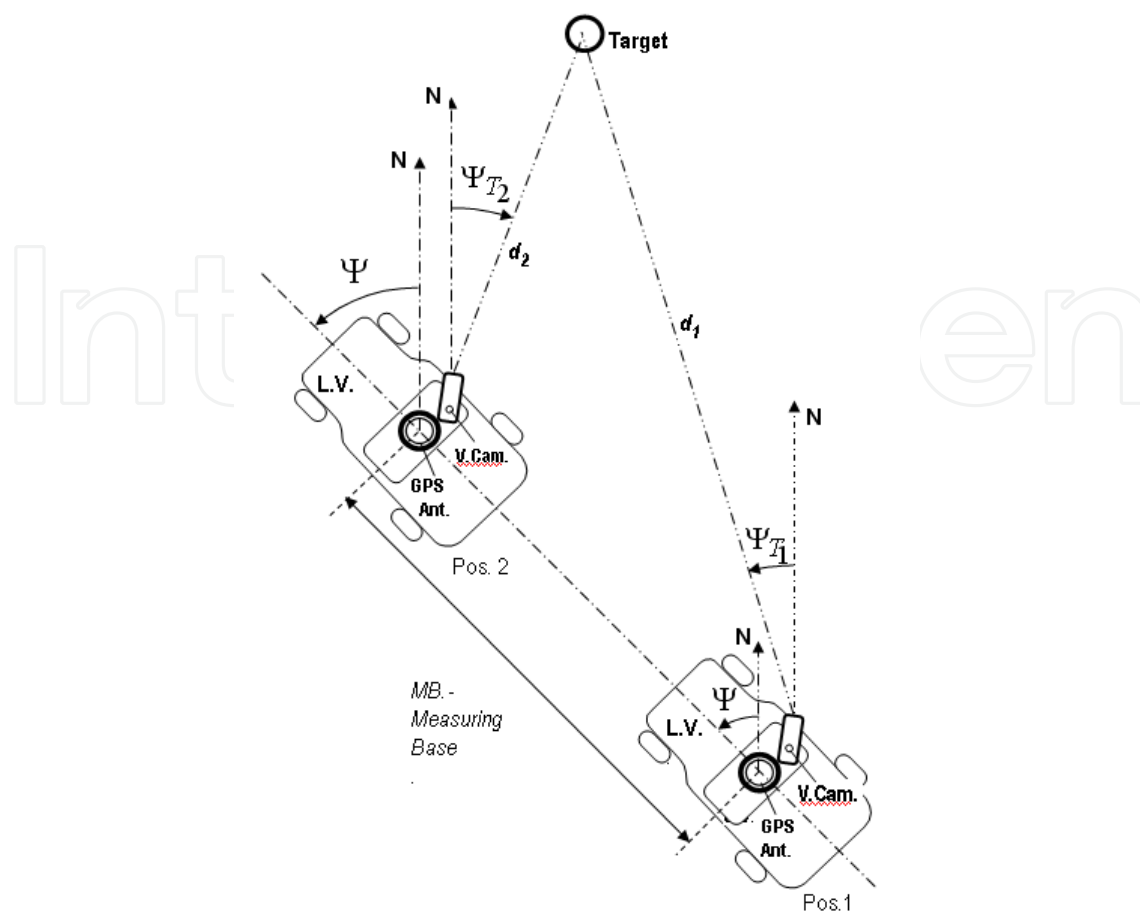
Figure 10. Fig.10 The Sighting of the same target from two different positions between which the Measuring Base - MB is forming.

The geographic positioning of a far away target (200 – 300 meters) involves in a first phase the use of the video camera which is triggered by the PPS (Pulse Per Second) signal furnished by the GPS receiver for taking photo images of the respective target from two different positions of the lab vehicle (about 20 – 30 meters) (Fig.11).
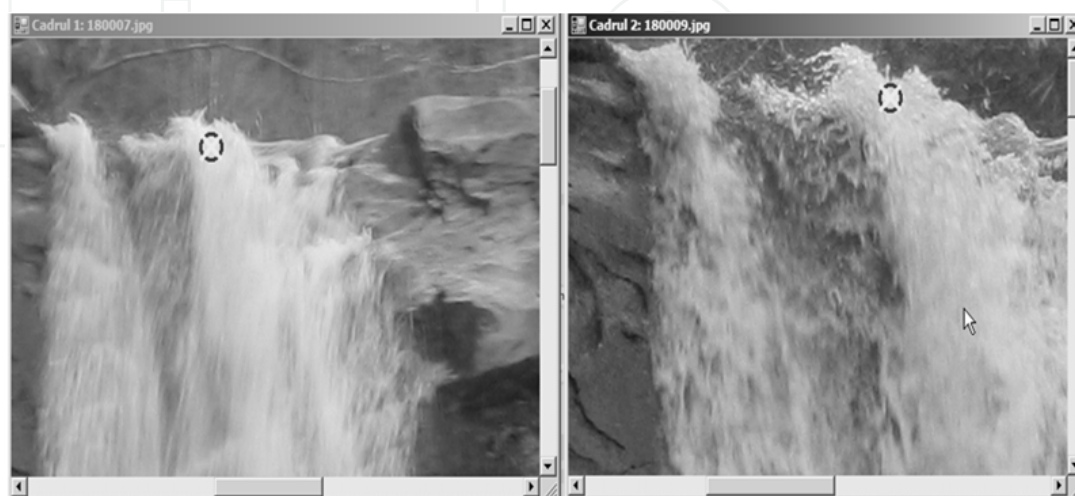
Figure 11. The sighting of a far away objective from two positions of the mobile monitoring system.

Afterwards, in a post processing regime, the pixel coordinates of the point, representing the target in each of the two images are determined, and, thus, it is possible to establish in each case the target angular position, relative to the video camera axis (Fig. 12).

$$d_x = \frac{n_x}{N_a} \cdot a \quad ; \quad d_y = \frac{n_y}{N_b} \cdot b$$

a , b – linear dimension of the "*a*" and respectively "*b*" sides of the CMOS sensor;

N_a, N_b - pixel number from the "*a*" side and respectively "*b*" side of the CMOS sensor;

n_x, n_y - pixel coordinates of the point T which is marking the target on the CMOS sensor surface;

d_x, d_y - linear coordinates of the point T which is marking the target on the CMOS sensor surface;
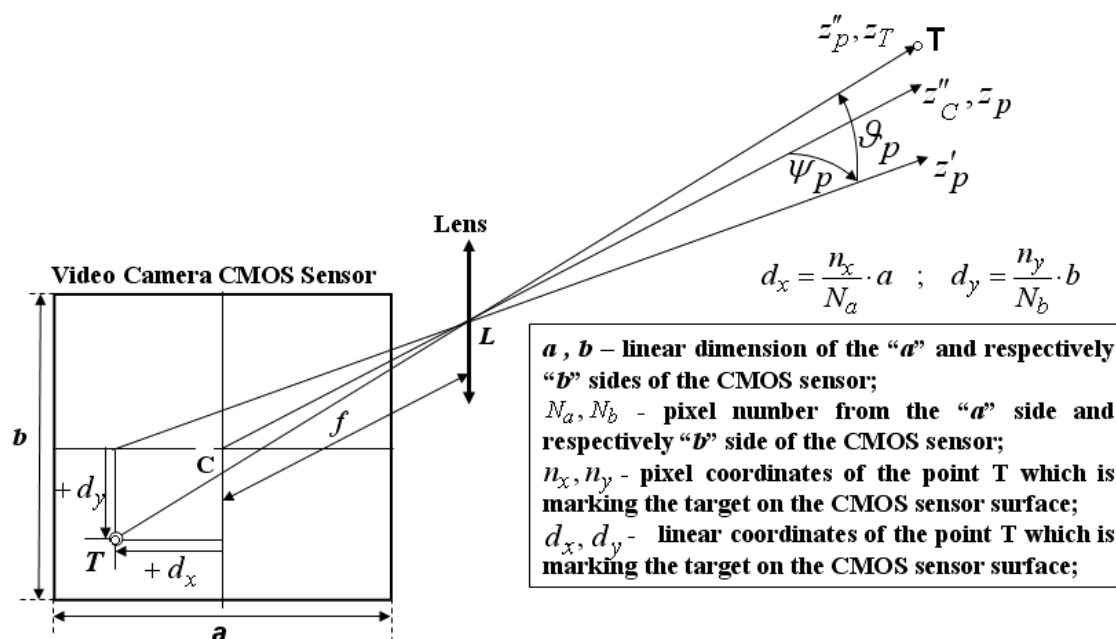
Figure 12. The definition of the deviation angles ψ_p and θ_p of the target direction relative to the central axis of the viewing field of the video camera

- To assure the positioning of the sighted objectives in the frame of the global terrestrial system of coordinates and their registering in files of GIS (Geographic Information System) type, at the operator returning at the computing centre, from the obtained images, series of two images are selected. In these series of two images the same sighted objective is evidenced in a corresponding mode, which will allow the selection of this objective in an electronic modality and the determination of the pixel coordinates which achieves the objective displaying on the monitor screen. These coordinates together with other data which accompany the two selected images, permit to compute the geographic and elevation coordinates of the sighted objective with the use of using triangulation proceedings as well as methods to report to the spherical system of the terrestrial coordinates.

So, as it is presented in figure 12, in the post processing regime, the pixel coordinates of the point representing the target in each of the two images are determined, and, on this basis, it is possible to establish in each case the target angular position relative to the video camera axis.

- To achieve, in real time, the precise positioning of the lab vehicle, with errors that can be included between few millimetres and some centimetres, it resorts to the use of a GPS positioning system with multiple frequencies and with differential RTK (Real Time Kinematic) regime functioning capability. This means that it has the possibility to be

connected through the Internet network, to a reference GPS station, at which it is subscribed and from which it can take the differential corrections. In relation to this, it is mentioned that the National Romanian Service ROMPOS – DGNSS provides corrections for the real time kinematic applications with a positioning accuracy evaluated at the interval between 3.0 and 0.5 meters for the receiver with a single frequency. The ROMPOS – RTK service delivers corrections for the real time kinematic applications with a positioning accuracy value situated between 0.5 and 2.0 cm for the receivers with two frequencies (Stoica, 2008);

-    To increase the time marking accuracy of the obtained video images, the video cameras triggering is achieved from exterior by the PPS signal (Pulse Per Second) received from the GPS satellite system, which, also, contains in its message, besides of the positioning data, the data regarding the Universal Time – UTC;

4.2. Tightly coupled GPS/INS

-    In order to continuously maintain the achieved positioning precision, the GPS system is tight coupled with an IMU (Inertial Measuring Unit) unit, the data of these systems being distributed through a filtering element of Kalman type. By integrating GPS and INS, the accurate GPS position is used to update the INS, and the latter then produces the high rate of accurate position and attitude data of mobile mapping system. The INS is needed for continuously measure the camera location and orientation. Combining GPS, INS and Distance Measurement Indicator (DMI) data is a very efficient and accurate method to determine the position (lat/long/height), azimuth, pitch and roll angles of the system cameras. The measurements of the INS come from two sensor triads, an accelerometer block and a gyro block. They are defined as three components of the specific force vector and three components of the body rotation rate. Integrated with GPS data, the system geometry data are calculated using the Kalman method. (Moafipoor S. et al., 2004)

The integrated GPS/INS solution produces continuous, smooth position and orientation of the system even when the GPS signals are lost due to obstructions such as bridges, trees, tunnels, mountains, high-rise buildings or limited and sporadic satellite coverage.

Taking into account of the functioning details described here, the figure 13 presents the complete set of devices which compose our Mobile Slide Monitor.

4.3. SPAN (Synchronized Position Attitude Navigation) technology: Bidirectional INS/GPS coupling to obtain the objectives positioning with an improved accuracy and continuity

Inertial Measuring Systems – INS are used on land, at sea and in the air as well as in space to determine the dynamic properties and trajectory of a moving object. They are, also, used for navigation, guidance and control or stabilisation of objects.

Video Camera - DALSA **Pantera TF 6M8**	Camera Link Frame Grabber **PIXCI E4**

GPS Receiver **ProPak – V3**	Inertial Navigation System **SPAN–IMU - FSAS**	GPS – Antenna **NovAtel**

| Desktop Computer and LCD monitor	Auto Supplimentary Battery	Invertor – 700W **TS-700-212B**

Figure 13. The components of the Mobile Slide Monitor

In general, an INS system uses forces and rotations measured by an IMU (Inertial Measuring Unit) to calculate position, velocity and attitude. Forces are measured by accelerometers in three perpendicular axes within the IMU and the gyros measure angular rotation rates around those axes. Over short periods of time, inertial navigation gives very accurate acceleration, velocity and attitude output. The INS must have prior knowledge of its initial position, initial velocity, initial attitude, Earth rotation rate and gravity field. Since the IMU

measures changes in orientation and acceleration, the INS determines changes in position and attitude, but the initial values for these parameters must be provided from an external source. Once these parameters are known, an INS is capable provide an autonomous solution with no external inputs. However, because of errors in the IMU measurements that accumulate over time, an inertial-only solution degrades in time unless external updates such as position, velocity or attitude are supplied.

The GPS receiver provides auxiliary information for the INS, and it is reciprocally aided by feedback from the INS to improve signal tracking. The feedback from the INS to the GPS engine is the deeply coupled aspect of the system (Fig. 14).
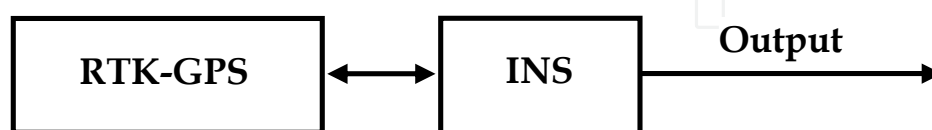
Figure 14. Bidirectional INS/GPS Coupling

The combined GPS/INS solution of the SPAN (Synchronized Position Attitude Navigation) integrates the raw inertial measurements with all available GPS information to provide the optimum solution possible in any situation. By using the high accuracy GPS solution, the IMU errors can be modelled and mitigated. Conversely, the continuity and the relative accuracy of the INS solution enable faster GPS signal reacquisition and RTK solution convergence.

GPS signal reacquisition is dramatically improved when running SPAN. This is a key performance feature in restricted coverage environments, such as urban canyons, where the user may have only a few seconds of satellite visibility before another blockage occurs. With SPAN technology, the user will be able to get GPS measurements in that small window of visibility. That means the INS will have shorter periods of free navigation and smaller errors, since the GPS is available more often for aiding (Kennedy and Rossi, 2005).

4.3.1. The IMU unit montage conditions

It is necessary to mount the IMU unit in a fixed location where the distance from the IMU to the GPS antenna phase center is constant. Also, the use must ensure that the orientation, with respect to the vehicle and antenna, is also constant. For the attitude output to be meaningful, the IMU should be mounted such that the positive Z-axis marked on the IMU enclosure points up and the Y-axis points forward through the front of the vehicle, in the direction of track and X pointing to right. (IMAR-iTraceRT-F200, 2008).

The body coordinate system is defined as given in figure 15:

4.3.2. GPS antenna montage conditions

Mount the GPS antenna close to the IMU housing. It is recommended to mount the antenna in top of the IMU if the system is mounted on a car, truck, ship or aircraft. In the

cases in which the geographic positioning of some objectives which are at some distance from the surveying vehicle, an optimal variant in the case of an aircraft can be constituted by IMU unit mounting above the video camera in the mode presented in the following schema:
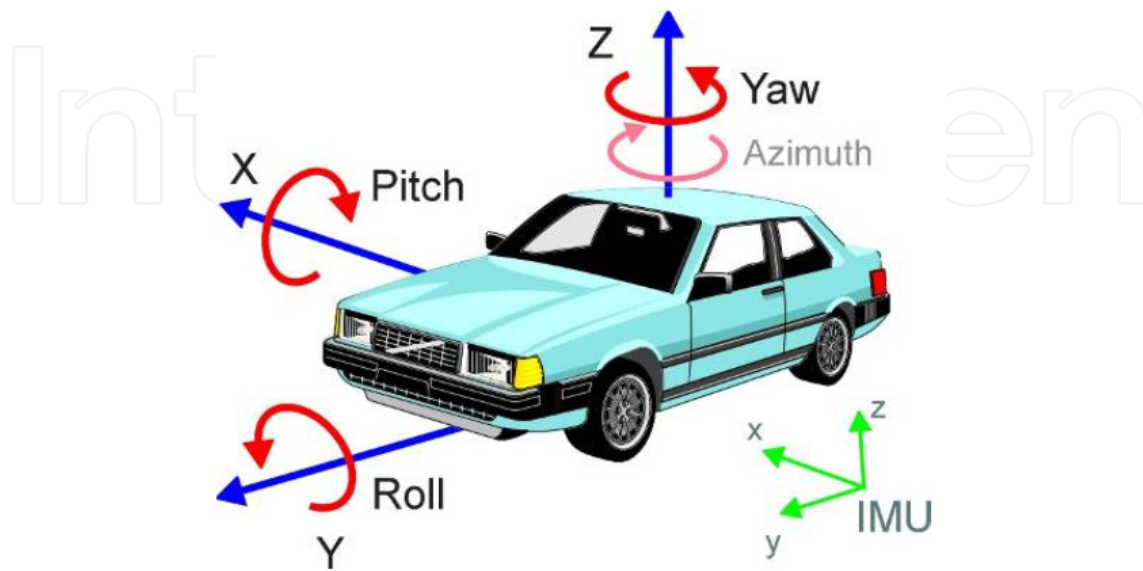

Figure 15. The reciprocal orientation of the IMU unit and the carrying vehicle.
(IMAR - iTraceRT-F200, 2008)
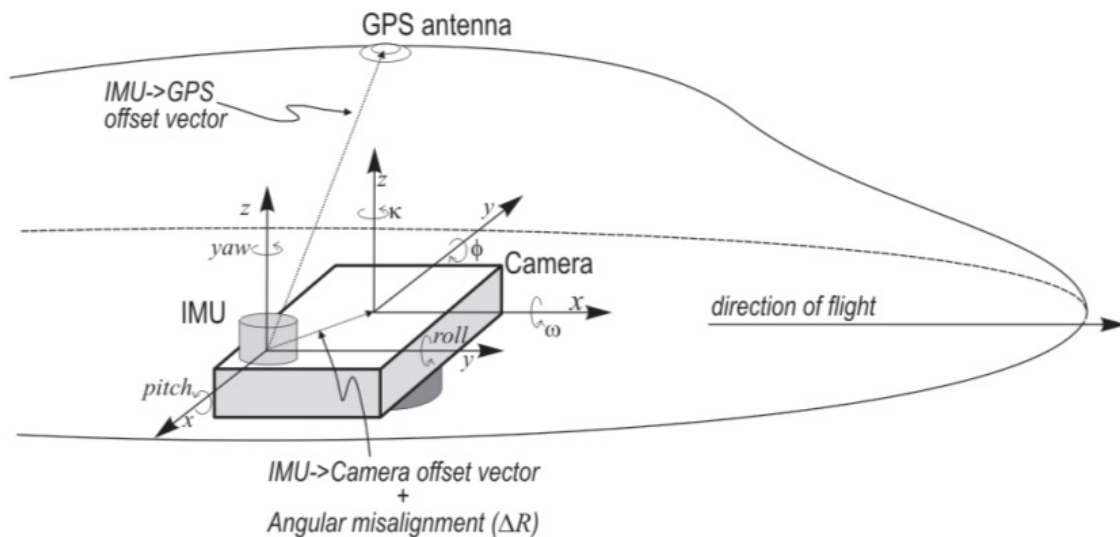
Figure 16. The mounting variant of the IMU unit in a surveying aircraft. (Novatel, Inertial Explorer, 2009)

The lever arm (offset) between IMU and GPS antenna has to be measured in the IMU coordinate system and with an accuracy better than 1 centimeter. Even slight deviations in the measurement of the lever arm may lead to significant position errors and will degrade the total system performance (Fig.17).
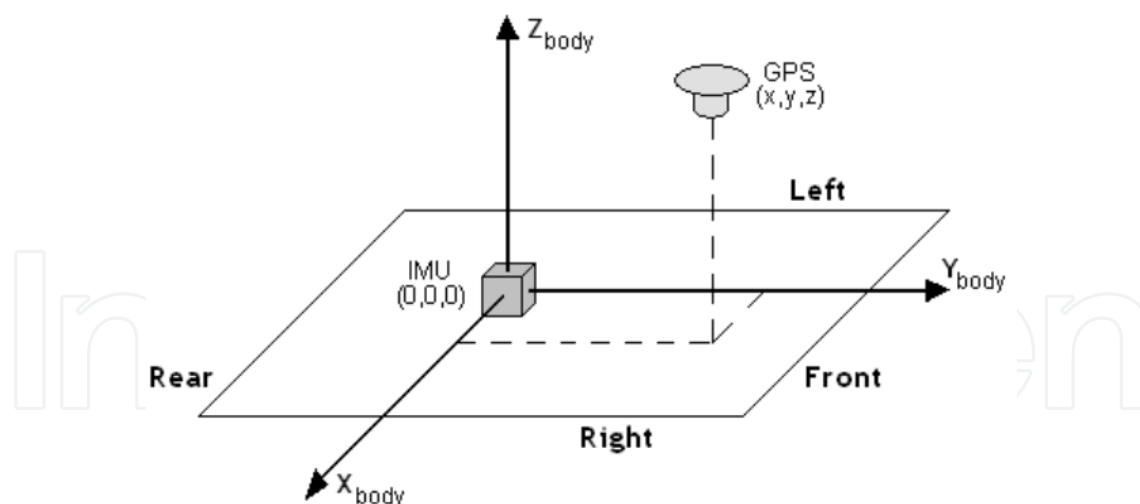
Figure 17. Fig.17 Body Frame Definition for Lever Arm Offset (Novatel Inertial Explorer 8.20, 2009)
The IMU is the local origin of the system and the measurements are defined as follows:
X: The measured lateral distance in the vehicle body frame from the IMU to the GNSS antenna;
Y: The measured distance along the longitudinal axis of the vehicle from the IMU to the GNSS antenna.
Z: The measured height change from the IMU to the GNSS antenna (Fig.18).
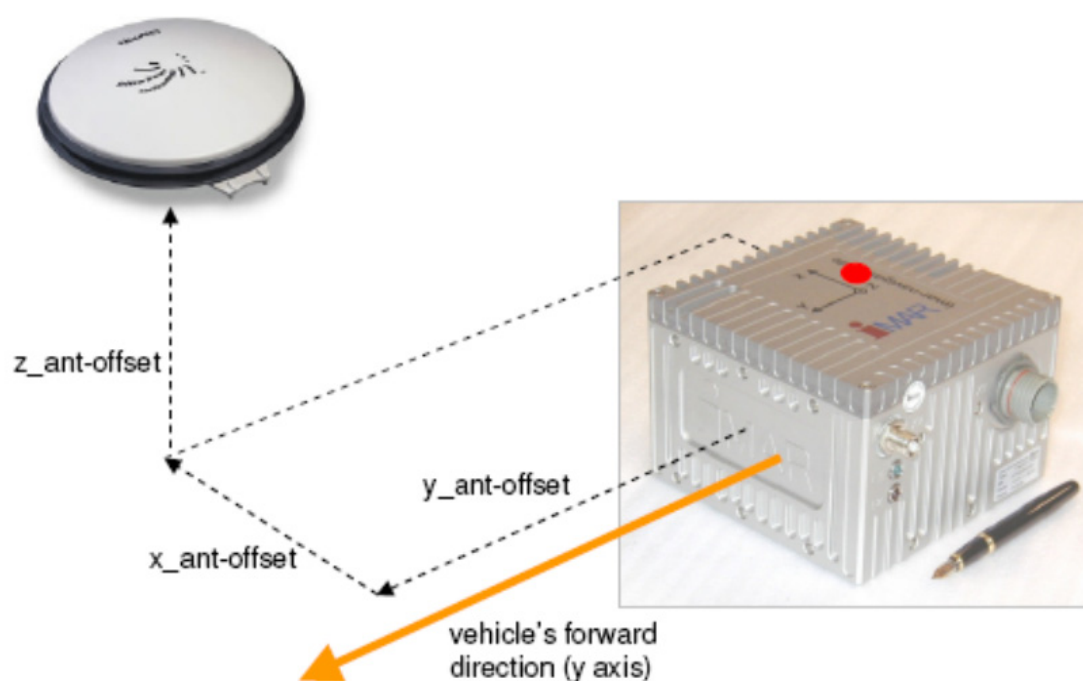
Figure 18. The definition of the offsets between the IMU unit and the GPS antenna
(IMAR iTrace-F200, 2008)

### 4.3.3. Complex positioning equipment for the slide monitoring

In the same time it is very important to mention that the necessary accuracies of some centimetres can be obtained due to the capability of a device such as Novatel GPS which is to function in a differential RTK (Real Time Kinematic) regime. (Kennedy S. et al., 2007). This type of operation is obtained by connecting the Novatel GPS receiver via Internet to a

network of fixed reference base stations as it is the **ROMPOS network** in Romania, which is able to transmit to its customers differential correction data.

4.4. Determination of the offset values between the GPS positioning point of the Inertial Measuring Unit and the central reference point "L" of the video camera

4.4.1. The offset linear components in relation to the reference system (x_V, y_V, z_V) of the lab vehicle

- The geographic coordinates (longitude, latitude) for the vehicle positioning are provided by the GPS system, more precisely, for the IMU point in which the Inertial Measuring Unit is placed (Fig.19);
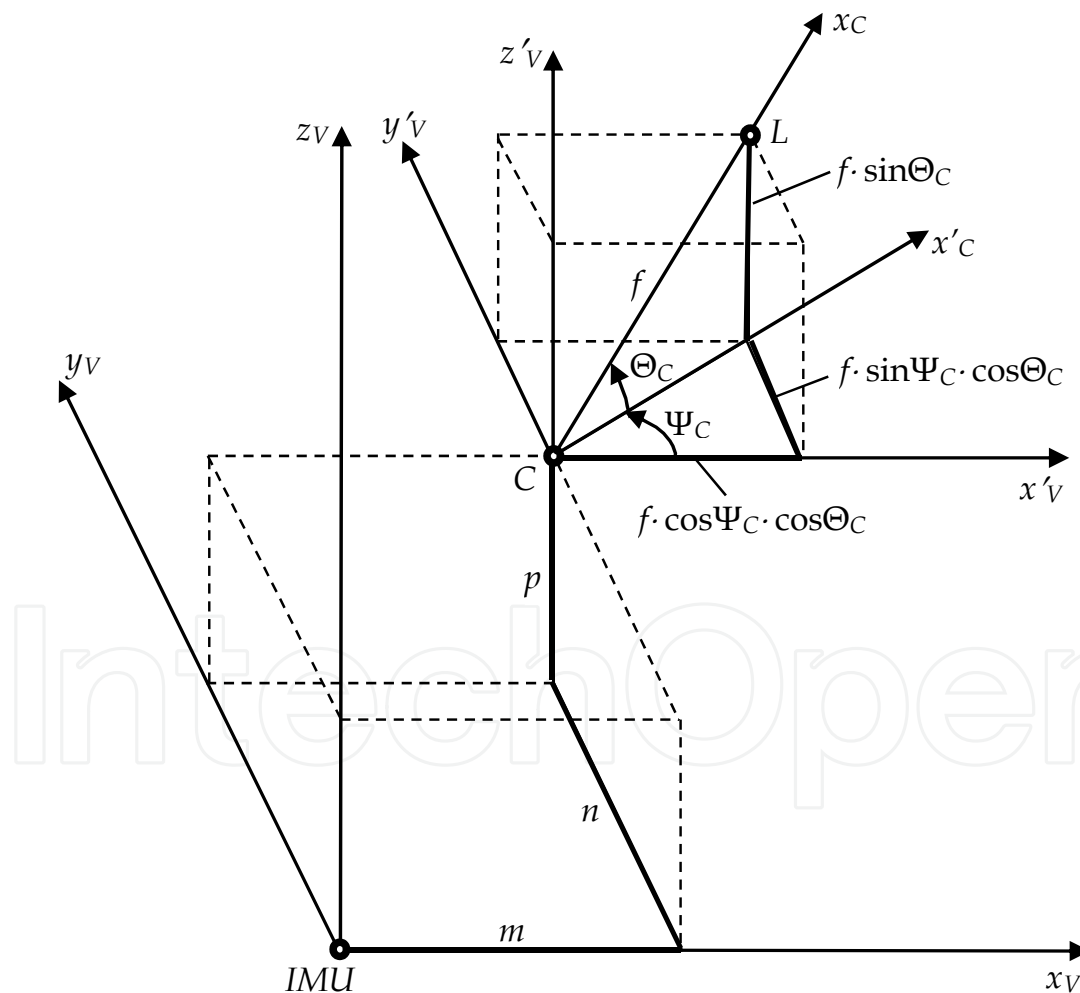
Figure 19. The relative positioning between the Inertial Measuring Unit (IMU) and the Video Camera coordinate systems

- The reference point relatively to which the positioning measurements of the sighted target are achieved, is constituted by the central point L of the video camera lens, which is placed at the focal distance f from the video camera matrix sensor;
- It arises the problem to establish the geographic coordinates for the reference point L on the basis of the same type of coordinates of the point IMU;
- The distance between the points IMU and L presents the following components:
a. On the x'_V axis of the vehicle coordinate system:

$$D_{x'_V} = m + f \cdot \cos \Psi_C \cdot \cos \Theta_C;$$ (1)

b. On the y'_V axis of the vehicle coordinate system:

$$D_{y'_V} = n + f \cdot \sin \Psi_C \cdot \cos \Theta_C;$$ (2)

c. On the z'_V axis of the vehicle coordinate system:

$$D_{z'_V} = p + f \cdot \sin \Theta_C.$$ (3)

In the above-mentioned relations, by m, n and p were noted the components, on the axis x_V, y_V, z_V, of the distance between the point IMU and the central point C of the video camera sensor.

By Ψ_C and Θ_C were noted the video camera montage (fixed) angles in relation with the vehicle coordinate system.

$$D_{x_V}, D_{y_V}, D_{z_V}$$

- In order to compute the offset components, in relation with the reference system x_V, y_V, z_V, with IMU point as origin, the following group (2) of relations is used:

$$D_{x_V} = D_{x'_V} \cdot \left(\cos \Psi \cdot \cos \Phi - \sin \Theta \cdot \sin \Phi \cdot \sin \Psi \right) - D_{y'_V} \cdot \cos \Theta \cdot \sin \Psi + D_{z'_V} \cdot \left(\cos \Phi \cdot \sin \Psi \cdot \sin \Theta + \sin \Phi \cdot \cos \Psi \right)$$

$$D_{y_V} = D_{x'_V} \cdot \left(\cos \Phi \cdot \sin \Psi + \sin \Theta \cdot \sin \Phi \cdot \cos \Psi \right) + D_{y'_V} \cdot \cos \Theta \cdot \cos \Psi + D_{z'_V} \cdot \left(\sin \Phi \cdot \sin \Psi - \sin \Theta \cdot \cos \Phi \cdot \cos \Psi \right)$$

$$D_{z_V} = -D_{x'_V} \cdot \cos \Theta \cdot \sin \Phi + D_{y'_V} \cdot \sin \Theta + D_{z'_V} \cdot \cos \Theta \cdot \cos \Phi$$

In these relations by Ψ, Θ and Φ, were noted the rotational angles of the lab vehicle, angles which were measured by the Inertial Unite IMU in relation with the reference system (x, y and z) of the current location.

4.4.2. Transformation of the linear offset distances, D_{x_V} and D_{y_V}, in circular arcs corresponding to the angular coordinate segments: $\Delta\lambda$ and respectively $\Delta\varphi$

$$\Delta\lambda\left[\text{min.}\right] = \left(360 \times 60 \times D_{x_V}\right) \Big/ \left(2 \cdot \pi \cdot R \cdot \cos\varphi\right) \left[meters\right] \tag{5}$$

- for the distances on the longitude λ direction ;

$$\Delta\phi\left[\text{min.}\right] = \left(360 \times 60 \times D_{y_V}\right) \Big/ \left(2 \cdot \pi \cdot R\right) \left[meters\right] \tag{6}$$

- for the distances on the latitude φ direction.

It is also adopted the notation:

$$D_z = \Delta h. \tag{7}$$

On this basis, the geographical coordinates, λ_L, φ_L, h_L, of the reference point L which is constituted from the video camera objective centre, are obtained as follows:

$$\lambda_L = \lambda + \Delta\lambda; \; \varphi_L = \varphi + \Delta\varphi; \; h_L = h + \Delta h. \tag{8}$$

where λ, φ, h, represent the geographical coordinates supplied by the IMU for the point in which this is situated.

5. The computing relations group with which it is achieved the determination of the target T geographic position in the horizontal plane of the referential ellipsoid

At the computing of the linear distances, on the longitude and, respectively, on the latitude direction, between the video camera successive positions and, respectively, between the camera positions and the sighted target, it, also, takes account from the fact that this mono-cameral stereo-fotogrammetric system, permits the sighting of some objectives which are situated at distances of up to 200 – 300 meters from the lab vehicles. This way, it is possible to adopt the hypothesis consisting in the approximation of the terrestrial globe with an equivalent sphere with a radius R = 6.367.472 km., as it is presented in the Fig. 20.

The geographic position of the target T in the horizontal plane of the referential ellipsoid is achieved, by combining the determinations of the absolute angular coordinates, $\Psi_{T_1}, \Theta_{T_1}, \Phi_{T_1}$ and respectively, $\Psi_{T_2}, \Theta_{T_2}, \Phi_{T_2}$, of the sighted target, for two different positions, L_1 and, respectively, L_2, of the video camera, positions which are obtained as a result of the lab vehicle displacement with a distance in limits of which the target T is maintained in the video camera viewing field.

In the positioning scheme presented in Figure 20, the following notations were introduced:

Figure 20. The Lab Vehicle and the sighted target positioning on the equivalent sphere of the terrestrial globe.

λ_1, φ_1 and λ_2, φ_2 - the geographic coordinates of longitude and, respectively, of latitude, which are deduced for two sighting successive positions, L_1 and respectively L_2, of the video camera from the determinations performed by the GPS-INS group, by introducing the offset corrections, which correspond to the distances between the emplacement location of this group in the lab vehicle and the camera objective:

λ_T, φ_T - the target geographic coordinates of longitude and, respectively, latitude;

$\Delta\lambda_{1,T} = \lambda_T - \lambda_1$; $\Delta\lambda_{1,2} = \lambda_1 - \lambda_2$; - the angular differences of longitude;

$\Delta\varphi_{1,2} = \varphi_2 - \varphi_1$; $\Delta\varphi_{2,T} = \varphi_T - \varphi_2$; - the angular differences of latitude, between the target and, respectively, the two positions of the lab vehicle.

Between two circular arcs on latitude, $\Delta\hat{\lambda}$ and $\Delta\hat{\lambda}_{\varphi_T}$, which are delimited by two meridian circles and which are situated, the first at the latitude 0, and the other at the latitude φ_T, the following relation exists:

$$\Delta\hat{\lambda}_{\varphi_T} = \Delta\hat{\lambda} \cdot \cos\varphi_T \tag{9}$$

Also on the basis of the scheme from the figure 20 which presents the positioning mode of a target on an equivalent sphere of the terrestrial globe, the linear distances can be calculated on the basis of angular coordinate differences by means of an equation set, with the following form:

$$a[meters] = \frac{\Delta\hat{\lambda}[min.]}{360 \times 60} \cdot 2\pi \cdot r[meters] - \text{for the distances on the longitude } \lambda \text{ direction;} \tag{10}$$

$$b[meters] = \frac{\Delta\hat{\varphi}[min.]}{360 \times 60} \cdot 2\pi \cdot R[meters] - \text{for the distances on the latitude } \varphi \text{ direction;} \tag{11}$$

where: $r = R \cdot \cos\varphi$.

For the establishment, on this basis, of the computing relations for the geographic position absolute coordinates of the target T, it resorts to the positioning scheme presented in figure 21, taking account of the fact that due to the relative reduced dimensions of the sighting field, its spherical curved surface is approximated by in plan projection of this field.

By this, in plane projection of the sighting field, the circle arcs are replaced by linear segments, as follows:

$$a_1 = \frac{\Delta\hat{\lambda}_{1,T}}{360 \times 60} \cdot 2\pi \cdot R \cdot \cos\varphi_T = \frac{\Delta\hat{\lambda}_{1,T}}{360 x 60} \cdot 2\pi \cdot R \cdot \cos(\varphi_2 + \Delta\varphi_{2,T}); \tag{12}$$

$$a_2 = \frac{\Delta\hat{\lambda}_{1,2}}{360 \times 60} \cdot 2\pi \cdot R \cdot \cos\varphi_T = \frac{\Delta\hat{\lambda}_{1,2}}{360 \times 60} \cdot 2\pi \cdot R \cdot \cos(\varphi_2 + \Delta\varphi_{2,T}); \tag{13}$$

$$b_1 = \frac{\Delta\hat{\varphi}_{1,2}}{360 \times 60} \cdot 2\pi \cdot R; \tag{14}$$

$$b_2 = \frac{\Delta\hat{\varphi}_{2,T}}{360 \times 60} \cdot 2\pi \cdot R; \tag{15}$$

These result in the following expressions for the azimuth angles:

$$\tan\Psi_{T_1} = \frac{b_1 + b_2}{a_1} = \frac{\Delta\varphi_{1,2} + \Delta\varphi_{2,T}}{\Delta\lambda_{1,T} \cdot \cos(\varphi_2 + \Delta\varphi_{2,T})}; \tag{16}$$

$$\tan \Psi_{T_2} = \frac{b_2}{a_1 + a_2} = \frac{\Delta \varphi_{2,T}}{\left(\Delta \lambda_{1,2} + \Delta \lambda_{1,T} \right) \cdot \cos \left(\varphi_2 + \Delta \varphi_{2,T} \right)}. \tag{17}$$

From the first expression, we obtain:

$$\Delta \lambda_{1,T} = \frac{\Delta \varphi_{1,2} + \Delta \varphi_{2,T}}{\tan \Psi_{T_1} \cdot \cos \left(\varphi_2 + \Delta \varphi_{2,T} \right)}; \tag{18}$$

and from the second expression it results that:

$$\Delta \lambda_{1,T} = \frac{\Delta \varphi_{2,T} - \Delta \lambda_{1,2} \cdot \cos \left(\varphi_2 + \Delta \varphi_{2,T} \right) \cdot \tan \Psi_{T_2}}{\cos \left(\varphi_2 + \Delta \varphi_{2,T} \right) \cdot \tan \Psi_{T_2}}; \tag{19}$$

So by elimianatig the $\Delta \lambda_{1,T}$ parameter, we obtain:

$$\frac{\Delta \varphi_{1,2} + \Delta \varphi_{2,T}}{\tan \Psi_{T_1}} = \frac{\Delta \varphi_{2,T} - \Delta \lambda_{1,2} \cdot \cos \left(\varphi_2 + \Delta \varphi_{2,T} \right) \cdot \tan \Psi_{T_2}}{\tan \Psi_{T_2}} \text{ and :}$$

$$\left(\Delta \varphi_{1,2} + \Delta \varphi_{2,T} \right) \cdot \tan \Psi_{T_2} = \Delta \varphi_{2,T} \cdot \tan \Psi_{T_1} - \Delta \lambda_{1,2} \cdot \cos \left(\varphi_2 + \Delta \varphi_{2,T} \right) \cdot \tan \Psi_{T_1} \cdot \tan \Psi_{T_2};$$

On this basis, the following implicit computing relation of the latitude angular difference $\Delta \varphi_{2,T}$ is obtained:

$$\Delta \varphi_{2,T} = \frac{\tan \Psi_{T_2}}{\tan \Psi_{T_1} - \tan \Psi_{T_2}} \cdot \left[\Delta \varphi_{1,2} + \Delta \lambda_{1,2} \cdot \cos \left(\varphi_2 + \Delta \varphi_{2,T} \right) \cdot \tan \Psi_{T_1} \right] \tag{20}$$

and in continuation:

$$\varphi_T = \varphi_2 + \Delta \varphi_{2,T} \tag{21}$$

With the determinated in this mode value of the angular difference $\Delta \varphi_{2,T}$, can be calculated in this phase and the value $\Delta \lambda_{1,T}$ of the longitude angular difference by means of one of the two explicit relations (7.1) or (7.2).

In similar mode:

$$\lambda_T = \lambda_1 + \Delta \lambda_{1,T} \tag{22}$$

After obtaining, in the presented mode, of the target geographic coordinates, λ_T and φ_T, in continuation it is possible to calculate and the linear distances: a_1, a_2 and b_1, b_2, on the longitude and respectively latitude directions, between the video camera successive positions and, respectively, between these positions and the sighted target, with the relations:
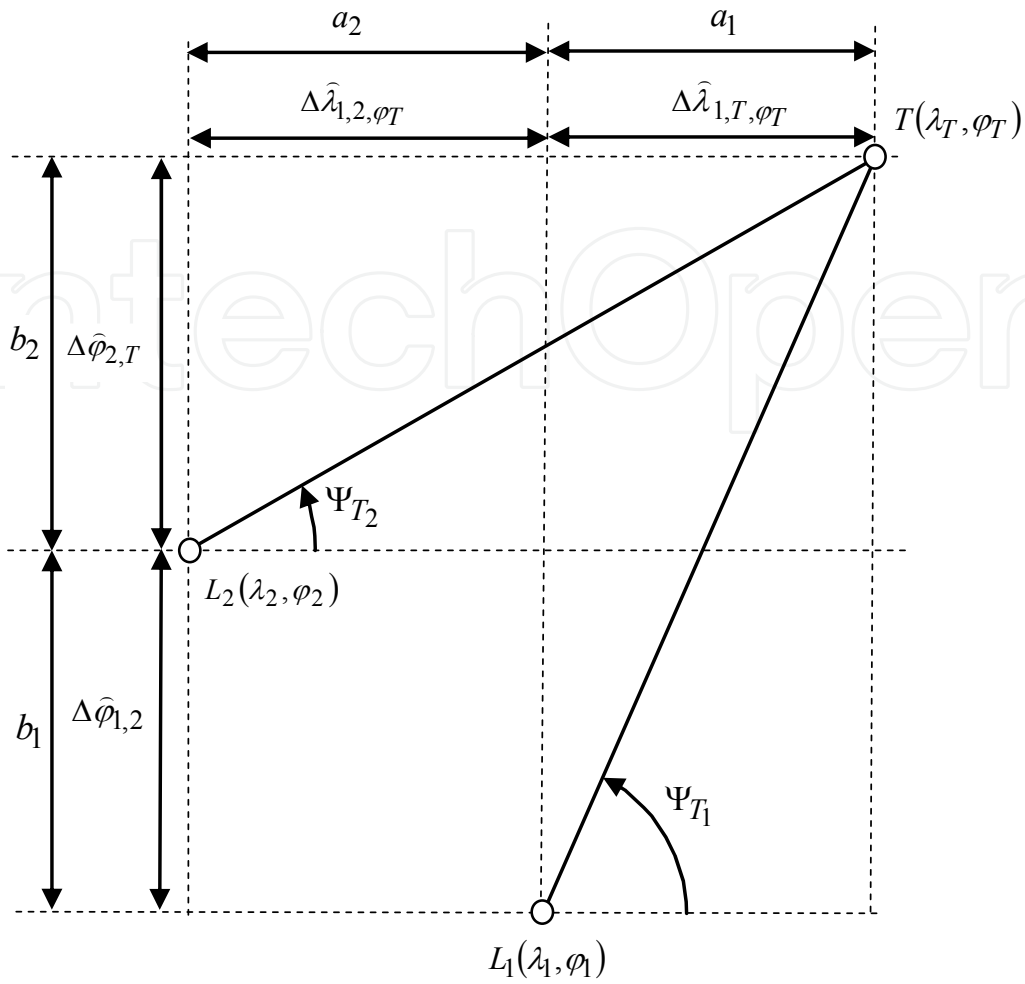
Figure 21. In plane projection of the target sighting field

$$a_1 = \frac{\Delta\lambda_{1T}\big[\text{min.}\big]}{360\times60}\cdot2\pi\cdot R\cdot\cos\varphi_T; \quad a_2 = \frac{\Delta\lambda_{1,2}\big[\text{min.}\big]}{360\times60}\cdot2\pi\cdot R\cdot\cos\varphi_T;$$

$$b_1 = \frac{\Delta\varphi_{1,2}\big[\text{min.}\big]}{360\times60}\cdot2\pi\cdot R; \quad b_2 = \frac{\Delta\varphi_{2,T}\big[\text{min.}\big]}{360\times60}\cdot2\pi\cdot R. \tag{23}$$

On this basis, it is, also, possible to calculate the direct distances between the target **T** and the positions, L_1 and L_2, of the two video cameras by means of the relations:

$$L_1T = \sqrt{a_1^2 + \big(b_1 + b_2\big)^2} \text{ and } L_2T = \sqrt{\big(a_1 + a_2\big)^2 + b_2^2} \tag{24}$$

Moreover, in conformity with the schema presented in figure 22, the height h_T of the target T in the horizontal plane O.P. of the reference ellipsoid can also be calculated with one of the relations:

$$h_T = h_{L_1} + L_1T\cdot\sin\Theta_{T_1} \text{ or}: h_T = h_{L_2} + L_2T\cdot\sin\Theta_{T_2} \tag{25}$$
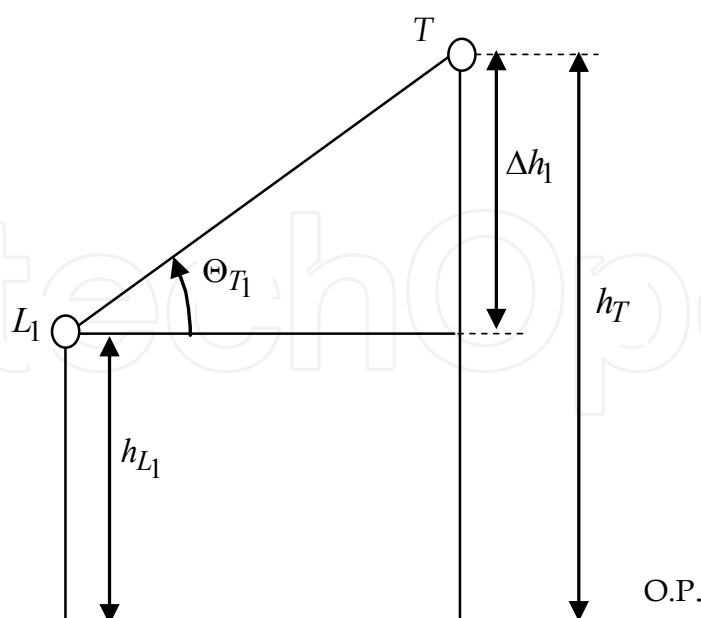
Figure 22. The diagram for the target height h_T computing.

6. Inertial Explorer post-processing software for the final perfection of the MSM accuracy data

Waypoint Products Group's **Inertial Explorer** post-processing software suite integrates rate data from six degrees of freedom IMU sensor arrays with GNSS information processed with an integrated GNSS post-processor (same as GrafNav's). Inertial Explorer use strapdown accelerometer (Δv) and angular rate ($\Delta \theta$) information to produce high rate coordinate and attitude information from a wide variety of IMUs. (Kennedy S. NovAtel Inc., Canada & Hinueber E., iMAR GmbH, 2005)

Inertial Explorer implements either a loose coupling of the GNSS and inertial data or tightly coupled (TC) processing that uses GPS carrier phase to limit error during periods where satellite tracking is limited or variable (even if only 2 or 3 satellites are visible). It is important to time-tag the inertial measurements to the GPS time frame during the data collection process. Proper synchronization is vital. Otherwise, the IMU data will not process. In NovAtel's SPAN system, IMU data is automatically synchronized and the Inertial Explorer's GNSS decoder automatically extracts the IMU data.

7. Conclusions

In order to increase up to 200 – 300 meters, the distance up to which the sighted targets from the terrain can be positioned, it resorts to the use of a single digital camera of high resolution in a fixed montage on a lab vehicle, instead of two cameras which usually are used in the case of classical stereo photogrammetric systems and for which the measurement basis is limited by the montage distance between the two cameras on the lab vehicle, respectively by

the dimensional width of the respective vehicle, which is around of 1.2 meters. Due to this fact, the two viewing lines are not intersected on the sighted target, but only with great errors and therefore the bi-cameral stereo photogrammetric systems cannot precisely identify the positions of the objectives that are at distances of more than approximatively 30 meters from the equipment.

So by using a single video camera, the measurement basis of the applied stereo metric method is constituted from the distance interval of 20 – 30 meters, between two triggerings of the camera during the lab vehicle displacement, distance from which the camera sights the same objective.

On this basis, at the returning at the computing center, it follows that from the obtained images to be selected by two images in which the interesting objective is evidenced in a corresponding mode, which will permit the selection of this objective in an electronic modality and the determination of the pixel coordinates, which achieves the objective displaying on the monitor screen. These coordinates together with the other data which accompany the two selected images, will permit to compute, using triangulation proceedings as well as methods for reporting to the spherical system of the terrestrial coordinates, the geographic and elevation coordinates of the sighted objective.

The immediate result of this equipment functioning is represented by the obtaining of a series of digital documents structured in GIS format, documents which contain the data registered in field, with the possibility to update them anytime.

Taking account of its conception, the "Slide Monitor" equipment can be installed not only on a terrestrial vehicle, but also on any kind of boats for the surveillance from an aquatic medium of some isolated objectives disposed on an inaccessible border.

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