Theoretical and Empirical Researches in Urban Management
Volume 6, Issue 4 / November 2011

MOBILE LASER SCANNING TO SPATIALLY UPDATE THE CITY INFRASTRUCTURE NETWORKS

Mahmoud AL-HADER
Limitless, Dubai, United Arab Emirates
mahmoud.hader@gmail.com

Ahmad RODZI
Faculty of Engineering, University Putra Malaysia
arm@eng.upm.edu.my

Abdul Rashid SHARIF
Faculty of Engineering, University Putra Malaysia
rashid@eng.upm.edu.my

Noordin AHMAD
Faculty of Engineering, University Putra Malaysia
noordin@geoinfo.com.my

Abstract
The city infrastructure daily development in any city/community is very huge; the huge development in the city infrastructure networks is reflected in the daily number of new installations, replacements, enforcements, etc. The daily city infrastructure utility updates are subject to maintenance and operation on frequent basis. The efficiency of the maintenance and operation workflow is strongly related to the geographical location of these city infrastructure networks. Due to the huge daily updates of the city infrastructure networks, the ability of collecting the updates locations using the current geospatial monitoring techniques is very difficult. This research is discussing a more efficient geospatial monitoring technique for the city infrastructure networks. The research will concentrate on the polyethylene city infrastructure materials, where power, water and communication networks are covered or protected by polyethylene materials. The research conducted a technical comparison between the current geospatial monitoring techniques and developed an overall performance evaluation.

The mobile laser scanning technology achieved the best performance evaluation, where a detailed data analysis, data collection, mobile laser missions, modelling and interpretation, system geometrical corrections for the location and orientation also have been conducted. Prior conducting the performance evaluation, the research investigates the mobile laser behaviour and recognition capabilities with respect to polyethylene city infrastructure materials. After analyzing the mobile laser pulses behavior and its correlations with the mission ground speed and exposed scanned surface, the mobile laser pulses response constant for the polyethylene city infrastructure materials has been concluded. The concluded mobile laser pulses constant utilized to develop a mathematical model for re-planning the mobile laser scanning missions to obtain the best model for monitoring the polyethylene city infrastructure networks.

Keywords:Spatial Thinking, Smart Cities, GIS, City Infrastructure Development

1. INTRODUCTION

The sustainable urban development is a subject of interest for regional policy makers and it needs appropriate assessment based on futile instruments for research, and for practical reasonsl (planning and decision making). Even if the sustainability's attainment is a research topic field for academia and urban planners and managers and, as well, an ambitious goal for any resource administrator, yet there is no precise way of defining and measuring it. The intelligent spatial update of the city infrastructure network is part of sustainability architecture. Hernández-Moreno and De Hoyos-Martínez (2010) debates some of initiatives working on indicators and frameworks for sustainable development.

Over the past few years, several research and development authorities across the world have been started the development and support of intelligent city platforms in terms of monitoring and controlling. The city infrastructure network is one of the primary city subsystems, where the intelligence is very efficient and would significantly improve the overall performance. The research discusses the intelligent city infrastructure monitoring platform in the sense of geospatial monitoring. The geospatial monitoring highlights the update of the geographical location (XYZ) represented in 3D surface model of the area of interest. The adopted research methodology for monitoring the city infrastructure networks is mobile laser-based survey equipment.

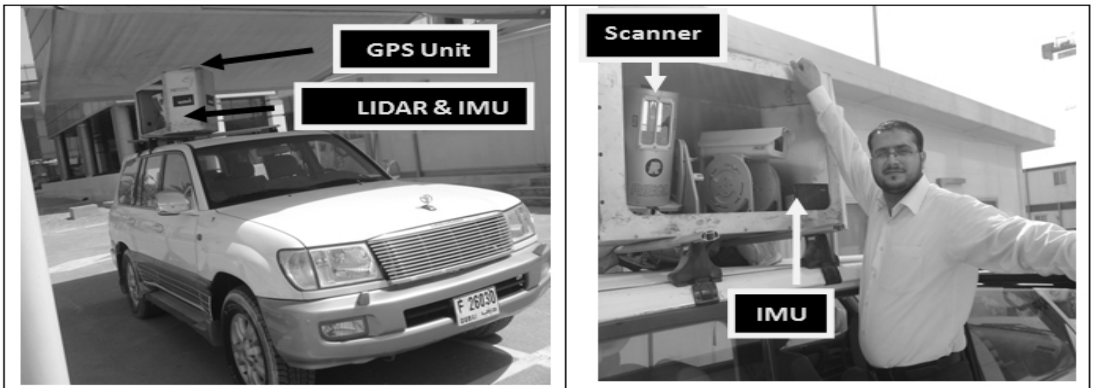
The research analyzes the collected mobile laser scanning observations, navigational GPS data, system ground speed, GNSS reference station corrections and IMU observations. These field data sets are not directly related to each other. The preliminary analysis showing that the location and time can be used to correlate these data sets, where the analysis will be valuable. The aim of the mobile laser scanning analysis is to identify the best practice methodology of utilizing the new mobile laser scanning technology in the city infrastructure monitoring (not only in the volumetric computations for the excavated surfaces). The research discussed an extraction mathematical model for identifying the best system ground speed to be conducted during the mobile laser scanning missions for any kind of polyethylene pipelines/cables. The research is debating only the polyethylene infrastructure materials due to the conducted detailed analysis for identifying the mobile laser beam intensity constant. Other materials might be subject to other studies where the system ground speed is subject to be changed due to material surface reflectivity factor for the mobile laser scanning pulses.

The detailed analysis of mobile laser scanning pulses behavior with respect to polyethylene city infrastructure networks (cables and pipelines) resulted a new planning of the mobile laser missions. The resulted new planning is forming a more intelligent city infrastructure geospatial monitoring platform. The new intelligent geospatial platform will develop new smart city concept.

There are several technologies, strategies and methodologies that can be utilized for spatial data collection for surveying and mapping production including monitoring the city infrastructure progress. These technologies are including common data collection methodologies using conventional terrestrial surveying techniques, photogrammetry and varies types of remote sensing techniques including laser scanning. The research is discussing a technical comparison between most of available geospatial monitoring. The goal of conducting this comparison is to validate the performance of the mobile laser scanning technology versus the other geospatial technologies.

The laser scanning technology is based on laser scanning of a structured laser line over the surface of an object in order to collect 3-dimensional data. The surface data is captured by a receiver/rangefinder sensor mounted in the laser scanner on top of vehicle which records accurate dense 3D points in space. The philosophy of geo-referenced dynamic spatial data of the collected point cloud data is based on the integration with the ground positioning using either GPS or GNSS technology observations, and the integrated inertial instrument unit, which is capable of taking both type of measurements is often referred as a LIDAR system.

The utilized dynamic laser scanning surveying equipment and the surveyed area is owned by Limitless LLC, Dubai government. Figure 1 (A) is showing the outside system representation mounted on top of the car explaining the two main components (GPS & LIDAR).



A. Limitless LLC laser scanning system | B. Limitless LLC dynamic laser scanner and IMU units

FIGURE 1. LIMITLESS LLC LASER SCANNING SYSTEM UNITS AND COMPONENTS

Figure 1 (B) is representing the utilized dynamic laser scanning system units; the system has two main units, the scanner and the IMU unit. The system is supported with smart georeferenced camera where it is not investigated in this research. The correlation between the three main components has been well calibrated in the sense of orientation using IMU, position using GPS and data laser beam pulses emitted from the mobile scanner.

2. MOBILE MAPPING SYSTEM

The mobile mapping concept refers to a means of measuring spatial data using mapping technologies and sensors that are mounted on a mobile platform. Schwarz et al, (2007) debate a process which was mainly driven by the need of highway infrastructure mapping and transportation corridor inventories. Cameras, along with navigation and positioning sensors, e.g., GPS, and inertial devices such as IMU, were integrated and mounted on a mobile vehicle for mapping purposes. Objects can be directly measured and mapped from images that have been georeferenced using navigation and positioning sensors. In the early days, the research community had used various terms to characterize this exiting research area. Terms like kinematic surveying, dynamic mapping, and vehicle based mapping.

Schwarz et al, (2007) mention that the current stage is the mapping, which is a well established engineering subject, has become increasingly influential to people's lives and business processes. It has long been recognized that geospatial data is at the heart of any geospatial application. Consequently, collecting and updating map and image information in a timely, accurate fashion has become more important than ever.

Zhang et al, (2003) discuss the latest development and evolution of surveying and mobile mapping technologies that opens new avenues for the acquisition, update, fast and online processing of data. Zhang et al, (2003) debate the currently advanced technologies that support the mobile mapping systems, including GPS and Inertial Navigation Systems (INS), imaging sensors of high-resolution, multispectral and hyper spectral sensors, portable computers and highly intelligent processing/automation algorithms. The definition and history of the Mobile Mapping System (MMS) is reviewed and briefly outlined. Advancements in low-cost, micro-GPS technologies; where some new advancements of the current MMS had recently developed and integrated to demonstrate current progress and expected future trends of development.

Multi-platform and mult-sensor integrated mapping technology has clearly established a trend towards fast geospatial data acquisition. Schwarz et al, (2007) discuss some sensors that can be mounted on a variety of platforms, such as satellites, aircraft, helicopters, terrestrial vehicles, water based vessels, and even people. The increasing use of internet and wireless communication networks and the recent advances in sensor networks further enable us to transfer and process data in a more efficient manner. As a result, mapping has become mobile and dynamic.

Jeong et al, (2006) provide an effective base for the management of information on construction and repair of highway and its auxiliary facilities. The photograph data is collected with a mobile mapping

Theoretical and Empirical Researches in Urban Management
Volume 6, Issue 4 / November 2011

system composed of the Charge-Coupled Device (CCD) cameras, the GPS, and the Inertial Navigation System (INS). The research also provides methodology for data management with the data collected on a pilot section of highway. The proto-type of the highway facility management system can improve the cognitive power, and enables the extraction of qualitative information on the attributes and the positions of the interested objects.

3. TECHNICAL COMPARISON BETWEEN THE GEOSPATIAL MONITORING TECHNOLOGIES

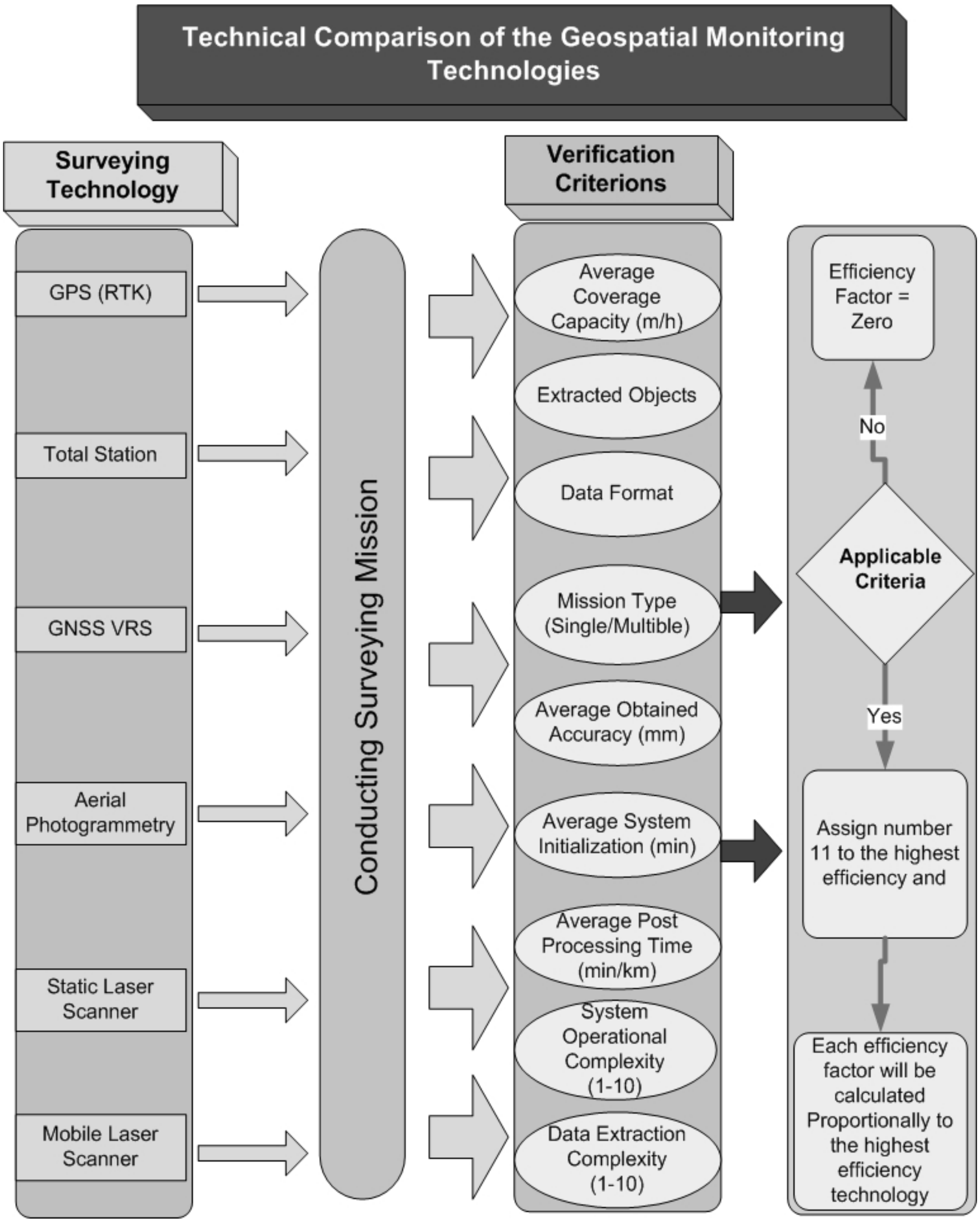


FIGURE 2. TECHNICAL COMPARISON OF THE GEOSPATIAL MONITORING TECHNOLOGIES

The research conducted a technical comparison between the common geospatial monitoring technologies in order to evaluate efficiency factor for each geospatial monitoring technology. The technical comparison methodology has been designed based on identifying most of functionalities and capabilities adopted in each technology. The average coverage capacity, extracted objects, data format, mission type, average obtained accuracy, average system initialization, average post processing time, system operational complexity, data extraction complexity are the investigated functionalities, where each function has an efficiency factor. Each surveying technology will be subject to mission data collection and data extraction, where some of surveying technologies are not applicable with all efficiency factors. Taking into consideration that some of criterions cannot be precisely measured like measuring the system complexity, accordingly these criterions will be estimated.

The overall efficiency factors evaluation concluded by gathering and averaging all efficiency factors for each surveying technology. The overall efficiency factors are measuring the each surveying technology from general perspective considering the nine technical factors. Figure 3 is showing the overall efficiency factor for the six surveying technologies. The highest efficiency factor achieved using dynamic laser scanning; where the efficiency factor is equal 7.6. The lowest overall efficiency factor achieved using total station technique; where the efficiency factor is equal 4.8. However, GNSS VRS, static laser scanning, aerial photogrammetry efficiency factors provide good overall efficiency factors.

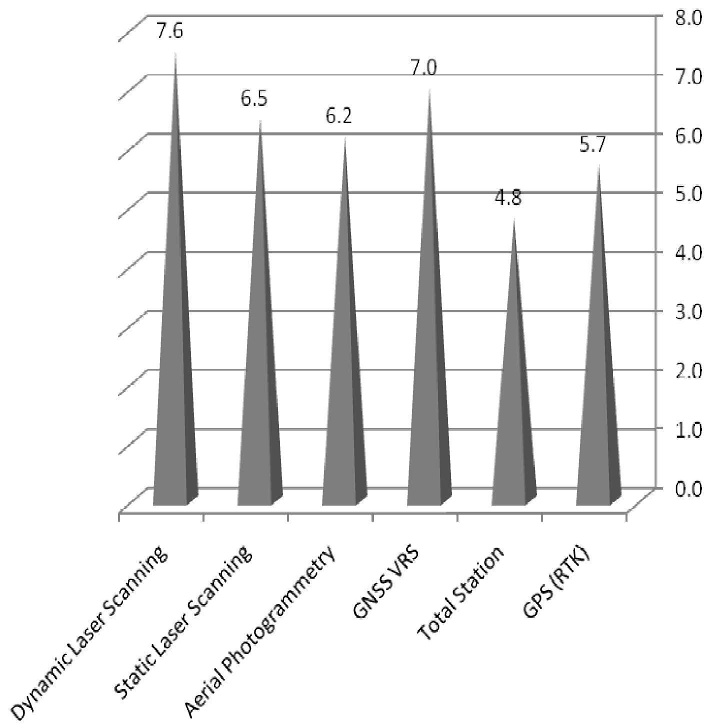


FIGURE 3 OVERALL EFFICIENCY FACTORS EVALUATION

Theoretical and Empirical Researches in Urban Management
Volume 6, Issue 4 / November 2011

Theoretical and Empirical Researches in Urban Management
Volume 6, Issue 4 / November 2011

4. ANALYTICAL ANALYSIS FRAMEWORK

The analytical analysis developed to interpret the mobile laser scanning behavior with respect to polyethylene city infrastructure networks and accordingly to identify the mobile laser response constant and to develop an extraction mathematical model. The extraction mathematical model will be the base for mobile laser scanning mission planning. Prior conducting the mobile laser mission, a site investigation is needed to measure the exposed portion of the pipeline/cable using measuring tape. The exposed portion of the feature pipeline/cable (exposed perimeter) will be the only input for the mathematical model, where the high laser response and the material constant are known. The calculated value will be the best practice of the mobile laser scanning mission speed.

The adopted analytical analysis methodology has been divided into four main aspects. The first aspect is to analyze the IMU observation. The analysis of IMU observations is mainly related to interpret the mobile laser beam pulses intensity at each point of time. The time series is considered the primary link to correlate the mobile laser pulses, location (latitudes and longitudes) and system ground speed. These three coefficients are recorded with respect to time; on the other hand, the desired correlation needs to be between laser pulse response and the system ground speed. The location (latitudes and longitudes) will define the exact location of the investigated polyethylene pipeline; where the time interval will be identified accordingly. The identified time interval will be used to identify the system ground and accordingly the laser response at each point of time and ground speed unite. The expected correlation between the system ground speed and the mobile laser response is to conclude the highest mobile laser response constant for scanning the polyethylene city infrastructure networks. Taking into consideration that the pipeline exposed perimeter and the material is known, a mathematical model to extract the best speed practice for any exposed polyethylene city infrastructure feature will be developed.

The mobile laser system sends and receives 200 pulses per second in positive and negative directions; where the system records the frame ground speed every 0.02 second. Accordingly there is a gap between the recorded mobile laser pulses (record every 0.005 second) and the frame ground speed (record every 0.02). The mobile laser pulses have been resembled from 0.005 to 0.02 seconds in order to compare the frame ground speed with the mobile laser pulses response at the same point of time. The positivity (+) and negativity (-) of the received mobile laser beam pulses are only representing the laser beam direction; accordingly all negative values have been transferred to absolute values prior to conduct the analytical analysis.

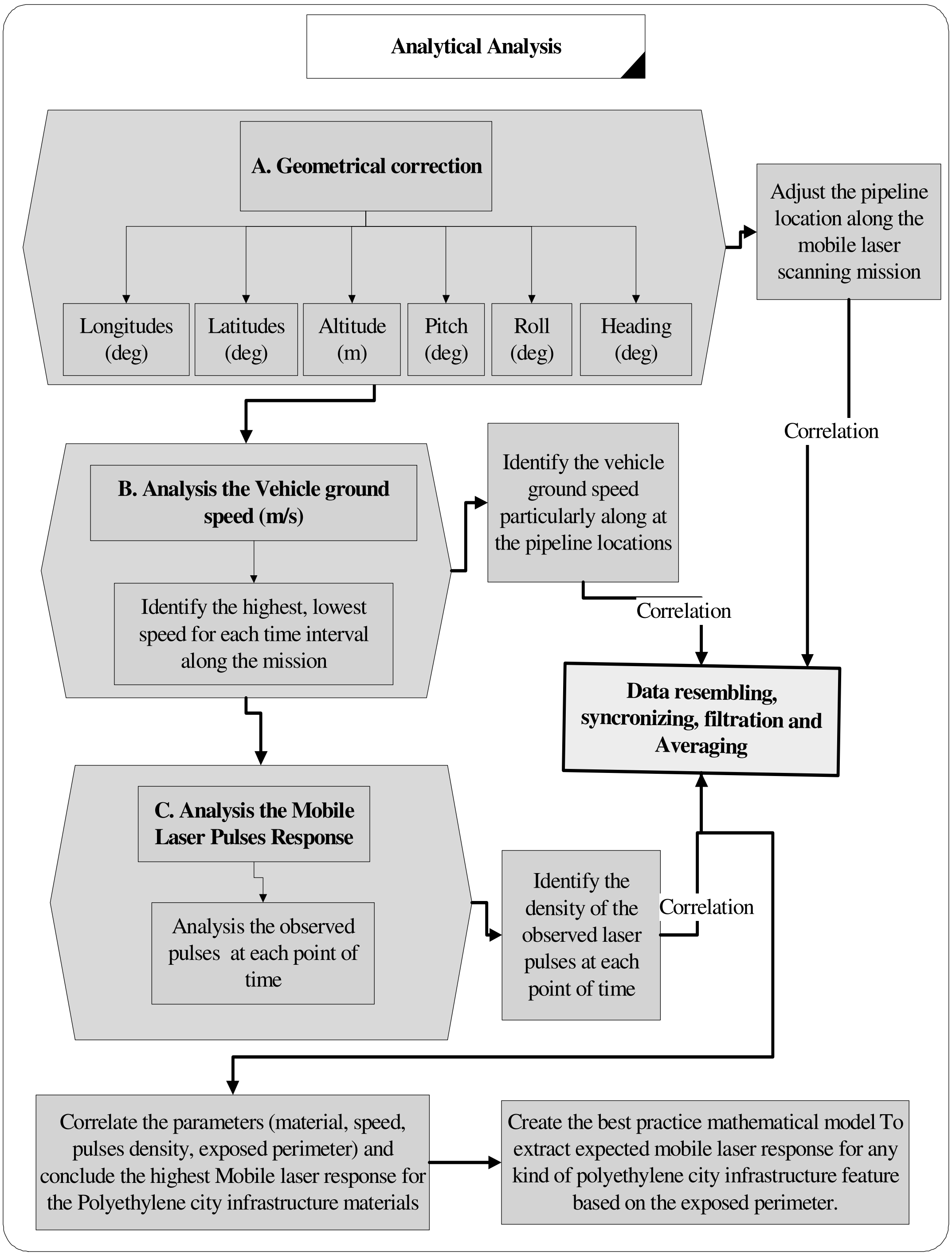


FIGURE 4. ANALYTICAL ANALYSIS FRAMEWORK

Prior to synchronize the mobile laser pulse response with the system ground speed, the time series need to identify in very high accuracy level. The accurate time series identification is significantly related to the accuracy of identifying the polyethylene location (latitudes and longitudes). The location accuracy is mainly related to the geometrical correction for field mission locations (XYZ) and the IMU orientation angles (Roll, Pitch and Heading). The geometrical correction of the IMU orientation angles are also

Theoretical and Empirical Researches in Urban Management
Volume 6, Issue 4 / November 2011

related to the geometrical correction of the system reference frame. The system reference frame will be geometrically corrected using the input correction combined from the GNSS reference station. After correcting the reference frame and the GPS observations using the GNSS reference station corrections, the IMU orientation angles will be corrected as well. The geometrical correction of the reference frame, GPS observations and IMU orientation angles are conducted using least square adjustment embedded in the POSPac Mobile Mapping Suite V.5.2.

The mission reference frame, GPS observations and IMU observations analysis have been conducted initially for the complete mission. The reason of analyzing the complete mobile lasers scanning mission is to filter out and delete anomalies and all unwanted records from the collected observations. Normally the laser pulses field observations including unwanted observations due to high sensitivity of the system. Very small objects like dust or objects around the desired features will be captured. The overview mission data analysis is important to fine tune the collected observed mobile laser beam pulses with respect to mission speed unites. Figure 4 presenting the schematic workflow for the conducted research analytical analysis.

5. RESULTED COLOUR CODED 3D SURFACE

The dynamic laser scanning mission covered most of the study area. The uncovered areas are represented in black colour where the laser beam either totally absorbed or dose not reflected to scanner sensor plats. The black colour also might not been covered during the scanning due to the area accessibility. The other possibility that the area is out of scope which will be close to the area of interest where part of it might be observed by the scanner the other is not.

The collected field observations are subject to the post processing in the sense of positional accuracy and filtration in terms of removing the unwanted point clouds such dusts. The post processing and LAS file generation is conducted using the Applanix POSPac software, where the colour coded 3D surface generation is conducted using Quick Terrain software.

The colours reflecting the features elevations where cyan is reflecting the ground surface then green, yellow, orange and red. The black objects are either invisible features or it is non-reflective surface such water or asphalt pavement. The figure also showing the importance of the accessibility of the concerned city features in order to avoid any dark areas and to reflect the physical conditions. The high brightness along the road is generated due to the high reflectivity of the features which also reflects the shape resolution of the features. The system depends on the following factors that affect the features resolution/brightness (intensity of the points to represent the feature):

- Speed of the vehicle
- The location of the vehicle with respect to the road
- The range of the observed features

The vehicle speed depends on the purpose of surveying, in the sense of monitoring the city infrastructure networks, the most practical speed was between 0 to 20 km/h. within this range, the intensity of the features points would be sufficient to reflect the shape and location of the network observable items. However, slowing down the vehicle speed would give slightly enhanced point cloud intensity.

The location of the vehicle is also need to be considered while dynamically scanning/driving. Due to the height of the system and the inclination of the scanner; the vehicle should be located 4 m away from the first feature. The observed features are strongly discovered between 200 to 300 m away from the vehicle. The features materials are the basis of reflecting the laser beam and accordingly forming the feature shape. The system can recognize metallic objects in more than 500 m where these objects located in space or similar regular surfaces such above water or desert flat surface. One of the research objectives is to verify the practicality of implementing the mobile laser scanning technology on the city scale. The research is intended to verify the performance of the system, time consuming, data processing and the accuracy of the measured features. The transmission district cooling pipe network shown in the figure below has been tested using the mobile laser scanning system.

FIGURE 5: PERSPECTIVE IMAGE OF THE DISTRICT COOLING NETWORK, STUDY AREA

Figure 5 representing the physical view of the installed district cooling network located in DJA, zone 1; where Figure 6 is showing the resulted colour coded map for the district cooling pipeline. The resulted

Theoretical and Empirical Researches in Urban Management
Volume 6, Issue 4 / November 2011

map emphases the practicality of using the mobile laser scanning technology in the infrastructure city component monitoring. Below are the resulted colour coded maps for the exposed district cooling pipes. As for the deep services such as district cooling, the depth of the trench is making a real challenge of any laser scanning technologies due to the laser beam limitation accessibility. Considering that the system is portable and mostly these services needs road access to feed them out. Accordingly the system is very efficient in reflecting the deep services rather than the shallow services (distribution networks).

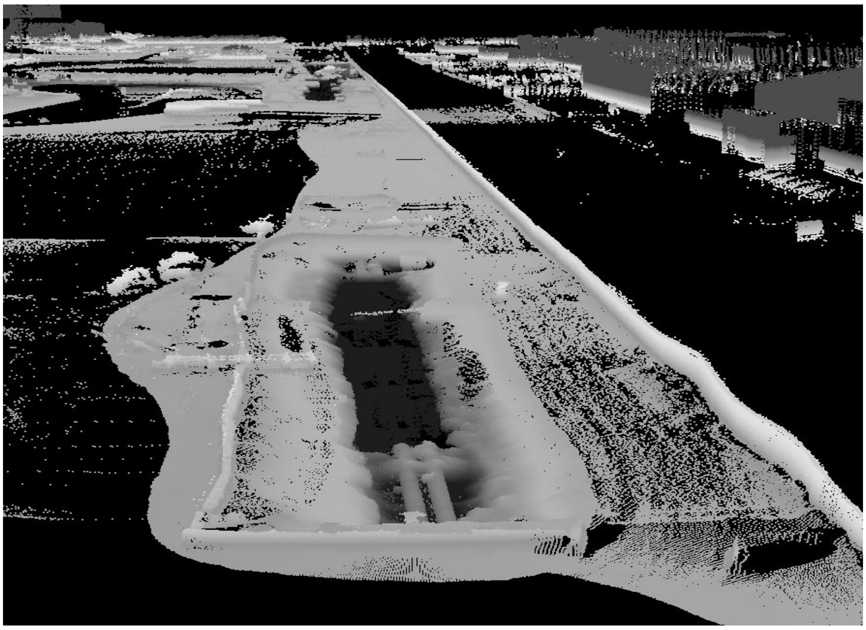


FIGURE 6: MOBILE LASER SCANNING COLOR CODED MAP FOR THE DISTRICT COOLING PIPES

The resulted colour coded map reflects the potential of mobile laser scanning technology usage in locating the exposed district cooling pipes along the other visible city objects.

REFERENCES

Hernández-Moreno, S. and De Hoyos-Martínez, J. (2010). Indicators Of Urban Sustainability In Mexico., *Theoretical and Empirical Researches in Urban Management*, 7(16), pp. 46-60

Jeong, H.K., Jeong, D.-H. and Kim, B.-G. (2006). Photograph Database for Highway Facility Management in Mobile Mapping System. Computational Science and Its Applications, *Computer Science*, Volume 3981/2006, pp. 996-1002

Schwarz, K.P. and El-Sheimy, N. (2007). *Smart mobile mapping systems-state of the art and future trends*. Advances in Mobile Mapping Technology- Taylor & Francis Group, London, ISBN 978-0-415-42723-4

Zhang, K-F. and Xiao B.-L. (2003). GPS and mobile multisensor mapping system. *Journal of Natural Sciences* - Volume 8, Number 2, pp. 557-56.