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RESEARCH ARTICLE

THE PROBLEM OF SYNCHRONIZATION OF MANY MEASURING DEVICES INSTALLED ON THE CAR FOR THE PURPOSE OF ACQUIRING GEOSPATIAL DATA

PROBLEMATYKA SYNCHRONIZACJI WIELU URZĄDZEŃ POMIAROWYCH ZAINSTALOWANYCH NA SAMOCHODZIE DO CELÓW POZYSKIWANIA DANYCH GEOPRZESTRZENNYCH

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KEY WORDS: geospatial data, synchronization, mobile laser scanning, measurement of clearance gauge, photogrammetry, database

ABSTRACT: The article presents the analysis of mobile scanning systems for geospatial measurement and synchronization problems of many devices used for this purpose. The aim of the research was to acquire innovative knowledge and skills regarding the operation of the platform for automation in obtaining road data and using them in the eDIOM system. The work focuses on the greatest possible simplification of procedures for acquiring data from a video detour, laser scanning and vectorization of road objects. The system is to be operated by one person, without much knowledge of GIS systems or IT and geodetic knowledge. The authors focused on the eIDIOM system, which is dedicated to such tasks. The development of the system focused on economic issues, i.e., reducing the cost of using a geospatial measurement system and facilitating the use of such systems. The overriding goal of the project was to ensure its comprehensiveness in measurements. The authors also discussed the issues of innovation, ecology, and the impact of the studied system on the sectors of the economy, i.e., local and public administration, infrastructure and geodesy. As a result of the conducted research, it was possible to develop several modules for the acquisition of geospatial data.

1. INTRODUCTION

Mobile scanning systems are always composed of two elements: sensors and navigation devices. The most frequently used sensors are digital cameras and laser or radar scanners. Measurements allow collecting data on the spatial position of points in relation to the scanning platform, by calibrating the measurement systems in relation to georeferential systems and/or in an external reference point. For scanners, this is based on direct measurement. When using a vision system, it ends with the analysis and measurement of image properties. In turn, the vehicle navigation system is built of a GNSS receiver and an INS inertial navigation module. This module constantly monitors the position and orientation of the vehicle. The GNSS receiver is a basic device that measures the position of the vehicle and uses a network of satellites called the Global Satellite Navigation System. The limitation of the use of GNSS navigation is the possibility of blocking the satellite signal and the low frequency of determining the orientation of the vehicle. The relative position and orientation of the sensors included in the measurement system are obtained by integrating the signals from the INS module. These readings must be corrected by input from an external source. For this purpose, the necessary data is provided by GNSS. The system may also include other sensors such as odometry sensors, inclinometers and barometers. Present standard mobile systems consist of laser scanners and digital cameras which, when connected, create colored point clouds, enabling automatic identification of objects. Classic photogrammetry is also used, and automation is possible owing to the latest algorithms for matching (feature matching), detection and identification of objects in digital images. The measurements are based on the following algorithms: LSM (Least Squares Method) and the latest: BRIEF, SIFT, SURF, and FAST. Scanning systems are used for mapping 3D cities, creating 3D models of architectural objects, positioning and testing deformation of road infrastructure, automatic recognition of road signs, measuring railway infrastructure, including gauge measurements, etc.

Modern operating systems are based on three groups of methods:

1. A method based on measurement with a laser rangefinder and a laser scanner (LiDAR),
2. Photogrammetry using the image stream,
3. A method involving light profiles projected by a light laser and recorded by a high-speed digital camera (Mikrut *et al*., 2016)

The most advanced systems are a combination of the above-mentioned measurement methods. As an example, you can give mobile ones based on laser scanning, i.e. (Briese *et al*., 2012); Chen e*t al*., 2012; Kukko *et al*., 2012; Zoller+ Fröhlich, 2020; Blug *et al.*, 2012; L-Kopia, 2020; Street-Mapper, 2020).

One of the mobile geospatial scanning systems is the Trimble® GEDO GX50 by Geotronics, which, in cooperation with Trimble GEDO systems, is designed to collect information about the track, trackside facilities and perform gauge analyzes. It is based on innovative Trimble-designed profiling scanners for highly accurate data acquisition. It is available in single-head and dual-head configurations depending on project requirements. The system works with the existing Trimble GEDO railroad measurement and scanning software package. The system facilitates quick and accurate capture of high-resolution 3D data for gauge verification and as-built data collection. Data provides an excellent basis for modeling in the BIM (Geotronics, 2020) -compliant design and construction process.

This can be replaced as a similar DEPHOS system. The mobile mapping system is a highly efficient data collection method to manage and monitor pavement and roadside assets; The DEPHOS Group implements compact and portable systems that can be moved between any car or truck. As mobile mapping vehicles travel at highway speed, there is no need for the cost and inconvenience of road closures. Routine monitoring tasks, such as checking road stability, usually involve stopping and placing survey transects at intervals along the network. The mobile mapping system allows for an operation in which, after collecting a continuous cloud of points along the network, the cross-sections can be analyzed in the office. In addition, once a continuous mobile mapping dataset is collected, it serves as a base reference dataset that can be archived and re-viewed without the need to visit the site again (Dephos, 2020).

Another mobile scanning system is StreetMapper, the first mobile laser scanning system developed by IGI and 3D Laser Mapping. It is used for the rapid mapping of highways, infrastructure and buildings. It uses the latest navigation technology, high-precision laser scanners and advanced data processing combined with an innovative system designed to ensure the StreetMapper IV. The accuracy of the system was proven under the toughest conditions (StreetMapper, 2020).

The German company RIEGL has systems for mobile scanning: VMY-2, VMY-1, VMX - 2HA, VMX-RAIL, VMQ-1HA, VMZ (Riegl, 2020). The company's systems enable the recording of scanning data obtained from mobile platforms such as boats, trains, road and off-road vehicles. The work of the laser scanner is complemented by position sensors, for example GPS (Global Positioning System) and IMU (Inertial Measurement Unit). The products can be completely or partially portable. Their operation is tested for reliable operation even in very demanding environmental conditions.

TPI has developed a mobile system for measuring railway tracks. It is a mobile measuring trolley - GG-05, which enables one-person measurement of track geometry. The trolley is equipped with a transverse tilt sensor, spacing sensor, odometer, tachymetric prism and a Bluetooth communication module with a range of up to 500m, for data transmission with a Topcon motorized total station. The trolley automatically informs with a sound signal about the place of measurement according to the adopted measurement interval. Both the railway cart and Topcon Total Station use the same type of power supply (batteries and chargers). The company has also developed the LiAIR V70 system. It is a UAV or sUAS-mounted lightweight LiDAR measuring instrument designed and manufactured by GreenValley International (GVI). This system is equipped with the Livox AVIA laser scanner and is one of the most economical LiDAR systems in the LiAir series by GVI. The LiAir V70 (TPI, 2020) is capable of providing highly accurate 3D point cloud data and is well-suited for applications in a wide variety of industries, including forestry. It is also possible to equip with a high-resolution digital camera that can be used to generate photogrammetric products and 3D true color point clouds.

Another similar system is an autonomous mobile robot and AIS 3D laser scanner. The ARIADNE robot is an industrial robot. The mobile platform can carry a load of 200 kg at speeds up to 0.8 m / s. The 3D laser scanner is built on the basis of a 2D laser rangefinder with a mounting and a servomotor (Robotik, 2020).

The autonomous mobile robot should also be mentioned with a 3D laser rangefinder for 3D exploration and digitization of indoor environments (Surmann, 2003). It can be used in rescue and inspection robotics, facilities management and architecture. It consists of an autonomous mobile robot, a reliable 3D laser rangefinder and three developed software modules. The 3D laser rangefinder obtains a 3D scan in this pose. The proposed method allows for quick and reliable digitization of large indoor environments without any intervention and solves the SLAM problem (Slam, 2020).

When writing about monotonous geospatial scanning systems, the Leica Pegasus: Backpack by Leica Geosystems is a system for kinematic scanning both indoors and outdoors. Leica Pegasus is a new solution using field and underground data acquisition technology (Leica, 2020). This mobile kinematic scanning technology offers the proven ergonomics of a trekking backpack, the Pegasus is lightweight and durable, and extremely easy to transport.

Another use of mobile scanning technology is a manual, mobile 3D scanning system for hard-to-reach places developed by Australian scientists from CSIRO (Commonwealth Scientific and Industrial Research Organization). It's called the Zebedee and it consists of a lightweight laser scanner mounted on a spring to a handle held by an operator and connected to a laptop. While sensors and software determine the trajectory of the device's movement, the scanner generates a cloud of points from the path traveled. The power supply is provided by a battery pack that allows you to work in the field for min. 13 hours. The greatest advantage of the system is its mobility and lightweight. This makes it easier to work, especially in hard-to-reach terrain, such as narrow corridors or caves. Another advantage of the system is that it allows you to obtain a finished product in a relatively short time.

There is also a robot system, Irma3D, which automates the work of a terrestrial laser scanner operator. The constructed system enables work without the use of special targets or markers, and thus allows surveyors to save more than 75% of the time spent in the field. The robot is able to explore remote places or hazardous areas such as plants, underground mines, tunnels, caves or channels. The result is precise, multi-modal 3D digital maps.

3D modelling of real objects with a 3D laser scanner has become popular in many applications, such as reverse engineering of petrochemical plants, civil and construction engineering, and digital preservation of cultural assets. Despite the development of light and fast laser scanners, the complicated measurement procedure and the long measurement times are still a heavy burden for the widespread use of laser scanning. To solve these problems, a robotic 3D scanning system using multiple robots has been proposed. The system, named CPS-SLAM, consists of a host robot with a 3D laser scanner and slave robots with target marks. The large-scale 3D model is acquired by an on-board 3D laser scanner on the host robot from several positions precisely determined by a locating technique called Cooperative Positioning System (CPS), which uses multiple robots. Therefore, this system can build a 3D model without complicated post-processing procedures such as ICP (Iterative Closest Point) (ICP, 2020). Moreover, this system is an open-loop SLAM system, and a very precise 3D model can be obtained without closed loops.

Another system for mobile space scanning is ROBIN, recognized as one of the most flexible mobile mapping systems in the world. Thanks to several mounting options, ROBIN can be used on multiple platforms, providing the ability to map areas by walking, driving and flying. Lightweight and portable, ROBIN is designed for one-man operation, enabling rapid on-site deployment even in remote and hard-to-reach locations, making it suitable for a wide variety of applications and environments. It can be used to measure road and rail infrastructure, mining and tunnels, utilities, telecommunications and energy, mapping, environmental research, geohazards and disaster response, defense, military and security issues. When combined with WINGS, it allows the same system to be mounted on an aerial test helicopter.

Work on mobile scanning systems has been going on continuously for over two decades. As a result, more and more perfect and precise measurement systems are created, which are used more and more widely, both in scientific research and in practical applications.

2. CONCEPT

The scientific aim of the research was to propose a complete mobile platform that would be able to perform the most tedious tasks in the road lane inventory with minimal operator involvement. The platform will do this work in a much shorter time and with much fewer errors. The intention of the research was also to indicate methods of synchronizing many devices used to measure geospatial data (Mikrut *et al*, 2016). In addition, automated surveys will be able to be compared with the eDIOM database. The research was carried out based on reading existing methods and testing selected solutions.

In order to achieve the set goal, the following tasks had to be performed: literature review, selection of appropriate test systems, selection of appropriate test sections, preparation of test fields and performance, analysis of measurements within test experiments.

In the described system, the focus was on developing methods and procedures for synchronizing all system components, i.e., using the PPS signal with GPS (Fig. 1).

Including the development of the model and the determination of fixed time shifts enabling the perfect synchronization of all devices. The focus was also on developing methods and procedures for calibrating the measurement platform using camera triggering in random mode and encoder emulation in speed change mode.

Figure 1. View of the system installed on the car

3. RESEARCH

The research was focused on developing methods and procedures for correcting location read errors in order to obtain 1 cm accuracy for mobile RTK, with no requirement to connect to a base station. Methods and algorithms have also been developed and data processing procedures to apply GPS corrections to IMU data and aligning them with DMI and calculating the point where the photo was taken. An advanced Kalman filter was used for equalization. Finding the camera trigger points asynchronously on the path is a novelty with DMI. The most important problem to be solved is the determination of methods and ways of synchronization between devices and the development of ways to combine the procedures of obtaining maximum data accuracy with other devices in order to improve data quality. The system also focused on developing methods and algorithms and procedures for IMU implementation and noise compensation procedures and for correcting GPS measurement errors by means of shift and drift parameters, using the advanced Kalman filter. Another issue was the development of methods, algorithms and execution procedures and the use of photo analysis methods and the OpenCV library to recognize objects in photos (markings, advertisements, damage). The focus was also on the development of methods, algorithms and procedures for detecting rut or fault damage, using devices that can be mounted on a measurement platform, such as an IMU or a laser. The possibility of using the roll signal analysis was also carried out and pitched to determine the distortion of the road and the use of a line laser and/or a camera capable of reading a monochrome image with a laser line invisible to the human eye. Methods, algorithms and procedures for the elimination of vibrations of the mechanical platform were also developed in order to verify the effectiveness of passive and active methods of elimination of vibrations and the selection of the optimal solution. The ways of using known techniques of vibration compensation with the use of advanced CAD / CAM tools with dynamic calculations were indicated.

An attempt was also made to develop methods, algorithms and procedures for sharing data on WMS / WFS / DPC websites and DPC format. There was also an attempt to develop a pyramid of points, indexing and compression rules, determining the necessary amount of data depending on the distance from the camera and speed of work comparable to WMS systems supporting large rasters. The possibility of using NVIDIA graphics cards and CUDA mechanisms, multiplying the speed of 3D operations, was verified. One of the highlights of the research was the development of a point cloud storage format that included RGB, XYZ, intensity, classification and DeltaZ colors. This format meets several important aspects, such as: lossless format, no data redundancy, pyramidal access depending on the scale, data compression to optimize file size, access speed and spatial indexing, and the possibility of implementing file and database versions.

Omnidirectional lasers with 80,000 measurement points were used in the research. A program for the acquisition of points directly from the Ethernet port was made, along with the procedures for reading their input parameters and programming them, min. rotational speed, data packets, time. Scanners were attached to the car to obtain the first results of field tests. The research was aimed at determining the size of the packets, how they were written and the methods of recording. The enormous amount of data made it necessary to divide the sets at intervals of 15 minutes.

4. RESULTS

The main result of the activities undertaken is the developed system of automated visual analysis of road markings. The system was implemented with the C ++ programming language, MS Visual Studio development environment, as well as generally available libraries of functions supporting the processes of processing and analyzing graphic images, machine learning, and extensions of standard C ++ language functions: OpenCV (Open

Source Computer Vision library), TensorFlow, Caffe, Dlib, Boost (Fig. 2.). The implemented solutions enable the recognition of vertical and horizontal markings used on Polish roads, as well as the detection of other objects, including selected damage to one (e.g., cracks). A wide range of recognizable objects has been achieved by introducing process hierarchy. In this solution, in the first phase, general groups of objects are recognized, characterized by similar features related to both shape and color. The next step is to refine the diagnosis with the use of classifiers trained to assign objects from selected groups to specific classes representing road signs. The effectiveness of the recognition processes depends to a large extent on the examples that were used in the process of training the implemented detection and classification mechanisms.

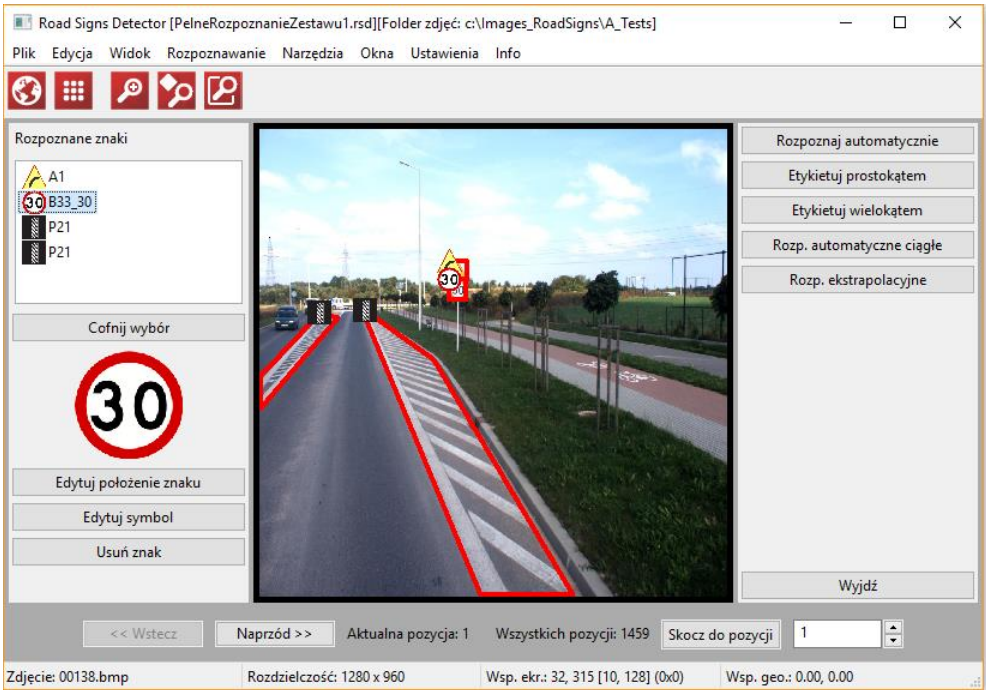

Figure 2. Window of the editing module of the automated visual analysis of road marking system

In the first version of the system, a recognition model based on the HOG method was proposed, where the training of the detector and the classifier were carried out with the use of synthetic patterns (generated artificially). This model had a disadvantage in the form of reduced effectiveness for photos with rotated characters, another disadvantage of this model was the extended time of photo analysis (more than 20 seconds for a single photo with a resolution of 2592 x 1458). The average detection/classification efficiency for this model was approx. 58%. Due to the above problems, an innovative optimized model for selecting the analytical structure used in the recognition process was proposed. The optimized detection/classification models are mostly system models based on deep learning convolutional neural networks (on a sample of 50 characters after teaching each character

3000 real objects). The average road marking detection efficiency for this model is 76%, while the classification efficiency of detected objects is 91%. The analysis speed is 0.48 seconds for images with a resolution of 2592 x 1458 pixels. The tests were carried out on a model data set including 1000 photos representing various parts of the road lane. The effectiveness of both detection and classification will increase with increasing training sets, which is a special feature of detectors/classifications based on artificial neural networks. Therefore, there is a need to carry out a wide range of acquisition of graphic data and indexing of characters in the photos. The system has the functionality of interfacing with the GPSCAM2 inspection platform and analyzing photos during the tour. Texts can be recognized for signs and road signs. An important feature of the developed solution is also the possibility of conducting a comparative analysis of the current state of the marking with the state of the marking in previous years on the indicated road sections based on historical data contained in the eDIOM database.

5. CONCLUSIONS

As a result of the work carried out, a working prototype of a mechanical-electronic platform was obtained, an IMU module, camera triggering and encoder operation module with software for device synchronization, GPS module and measurement devices synchronization module, 360-degree laser scanner support module, post-processing module locating all events in space with an accuracy of several dozen centimeters, road sign recognition module with a 250-character library and recognition of license plates and damage, module support for 6 area cameras operating at 60km / h and triggering every 3 meters, trigger module and operating a line camera, point cloud coloring module and DPC cloud support and developing the DPC format. A point cloud publishing module was also developed in the web browser.

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KEY WORDS: dane geoprzestrzenne, synchronizacja, mobilny skaning laserowy, pomiar skrajni, fotogrametria, baza danych

Streszczenie

W artykule przedstawiono analizę mobilnych systemów skanowania do pomiarów geoprzestrzennych oraz problemy synchronizacji wielu wykorzystywanych do tego celu urządzeń. Celem badań było zdobycie innowacyjnej wiedzy i umiejętności dotyczących działania platformy do automatyzacji w pozyskiwaniu danych drogowych i wykorzystaniu ich w systemie eDIOM. Prace koncentrują się na jak największym uproszczeniu na: pozyskiwania danych z przejazd z danymi wideo, skanowania laserowego i wektoryzacji obiektów drogowych. System obsługiwany jest przez jedną osobę, bez dużej wiedzy z zakresu systemów GIS czy wiedzy informatyczno-geodezyjnej. Autorzy skupili się na systemie eIDIOM, który jest przeznaczony do takich zadań. Rozwój systemu koncentrował się na kwestiach ekonomicznych, tj. obniżeniu kosztów stosowania systemu do pomiarów geoprzestrzennych i ułatwieniu korzystania z takiego systemu. Nadrzędnym celem w projekcie było zapewnienie jego kompleksowości w pomiarach. Autorzy omówili również zagadnienia innowacyjności, ekologii oraz wpływu badanego systemu na sektory gospodarki, tj. administrację lokalną i publiczną, infrastrukturę i geodezję. W wyniku przeprowadzonych badań udało się opracować kilka modułów pozyskiwania danych geoprzestrzennych.

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