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Universal mobile laser scanning complex PolyScan of Drakkar ltd. company

Abstract

The PolyScan system can be used as on-ground, navy and aerial surveying tool. Drakkar ltd. Company has developed and introduced a unique method in using the universal mobile lidar (laser scanning) complex PolyScan. In the fallowing article we wish to explore the following topics (aspects): The reasonability of developing and constructing our own mobile lidar (topographical and geodetic) equipment for small companies (like Drakkar) in comparison to buying readymade devices. As an example buying analogous or a more productive laser scanner (lidar mobile mapping system) from one of the world's leading manufacturers – Optech, Leica, Riegl, AHAB and so on. The second aspect which we wish to deal with is the technical decisions which were made at the productive (designing) stage, as well as the preliminary experience of the systems use while making topographical, geodetic and civil engineering works in Israel (this is not a question, rather a research topic). Last, we will examine the advantages of the concept of automated mapping (which is proposed by Drakkar ltd.) and its perspectives.

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1. Case Study

An effectiveness of laser scanning systems (lidars) in a great number of topography, geodesy and special applications are widely recognized [1,2]. Joint use of lidar along with digital cameras and other sources of geospatial data (such as IR scanners, multy and hyperspectral systems, etc.) is widely recognized nowadays. Such a combination greatly increases the quality and completeness of acquired data.

Today, the Lidar system is first and foremost regarded as a photogrammetrical tool. Within photogrammetry a special branch known by many authors as "lidargrammetry" has appeared. It is believed to be an applied discipline which describes a set of aspects related to acquiring and processing of precise geospatial data by means of lidars. Generally speaking, the process of splitting-off of laser locations as an independent photogrammetrical discipline (but not just as an aviation remote sensing method) began in the 1990's. 30 years prior to developing this technique, it was mainly used for military purposes. The radical transformation from remote sensing to photogrammetric discipline was a result of the appearance of innovative technologies as GNSS and inertial navigation appearing in geodetic practices.

Joint use of scanning laser range-finder and the Inertial Navigational System (INS) which combines and mutually reinforces GPS and inertial data, made it possible to offer to the market a principally new device – a lidar. Its effectiveness is based on the fact that all three of its main forms of data; range-finder optical measurements (laser scanner), geographic coordinates of current position (GPS) and angular attitude parameters (IMU) have the same level of accuracy.

These statement presented above are extremely important in spite of its common character. It allows us to understand the role of modern lidar tools and technologies in real time modern map making industry. Such considerations should serve as a basis of any approach related in any way to the practical use of the lidar, and even more so while making a decision of developing one's own laser scanner.

Today the progress in the field of laser scanner technologies is mainly related with activity of such well-known companies such as Optech, Riegl, Leica and Airborne Hydrography. These companies provide up to 90% of the world's demand of laser scanner equipment. Naturally, these companies offer complete products to their clients, which include all principal components of a modern lidar – laser block, Inertial Navigational System (INS), data storage unit, control and visualization unit and a wide set of software products. Obviously, all these technological components are extremely important and the final commercial success can be achieved only by proper attention to all of them. However, it will not be an exaggeration to say that the main part of the manufacturer's attention is paid to perfection of optical and electronic parts, scanning mechanism, hardware and firmware of signal processing and generally speaking to all aspects of the scanner block functionality. These components provide a basic range-finder measurement. At the same time the manufacturers actively declare the main goals of their Research and Development activity – increasing the pulse repetition rate: actual productivity, increasing range-finder accuracy and maximum range (height in case of airborne lidars), and increasing range-finder resolution (the ability to discriminate replies scattered from the obstacles along the laser beam). It is believed that all those parameters are important and that (mainly) the progress in their perfection determines the future development of the modern laser location. However there is another reason. The second technologically essential component of the modern lidar INS, in fact is a separate technology. As a matter of fact a lidar technique (a group of aspects related to the scanner block functionality mentioned above) and INS technology(ies) (GNSS and inertial navigation tools) are developing in parallel without any essential mutual influence.   Such a mutual influence of course takes place in a commercial aspect. When putting together these two systems we form a lidar system which is in great commercial demand for airborne, bathymetric, or on-ground applications. However, it will be fair to assume that the scanner block and the INS of any modern lidar are working INDEPENDENTLY and NON-SYNCHRONOUSLY. That's why their productive methods are independent only technologically, because speaking from a business point of view their manufacturers can be in a common holding or a long-term partners-- (maybe should be a foot note)). The task of their interconnection is resolving at a hardware level by choosing appropriate interfaces and at a office processing stage by special software.

The phenomena of "dualism" described above is not a unique one. On the contrary, it's quite a typical event in the postindustrial society for the technologically complex device to serve as a platform for producing data but not a material product. However, this phenomena and the current situation on the geoinformatic market allowed Drakkar ltd., which is a small but active company, to start designing and then producing its own mobile lidar device. The Lidar they produced is universal since it can be used as on-ground mobile, as an aerial survey or a combined tool.

The current situation where purchasing individual components provide even a small company such as Drakkar, with the capacity to start its own activity in lidar manufacturing, thus creating its own solution in this field. Later, we will demonstrate that such kind of activity can be regarded as quite reasonable, not only from a pure engineering point of view, but from a commercial one as well. To design and build its own mobile scanner can be even cheaper in many important cases as we shall see.

It's not so easy to (limnot) put forward the reasons that would bring a geodesy company to start its own production of a laser scanner instead of buying a readymade one from one of the known producers. However, they are a number of reasons one should take into consideration when approaching the matter, they are as follows:

1) **Economical factor.** In some cases such a decision is significantly cheaper than buying a universal mobile scanner. It's even truer if the company already possesses one or a few the components which are suitable for a new device. For example, in case of Drakkar ltd. it looks quite natural to use its "classical" static laser scanner RIEGL LMS Z420i which has been in use for many years and demonstrated perfect functionality.   After limited additional improvements carried out and implemented at the manufacturer's factory (relatively inexpensive) such a device can be successfully integrated with INS Novatel SPAN, which was also used for other needs before.

2) **Adaption for the companies needs.** While designing and producing a mobile lider from scratch a company always has the possibility of adapting it for specific needs of the company. Very often, “universal” systems (such as Optech) in similar conditions would be much less efficient. Here we can note such important aspects as grouping, dimensions, weight and power consumption characteristics. Peculiarities of the system control, powering and a number of other aspects can become critical to a certain extent in one or another applied sphere (power engineering, mine survey, road construction and so on). In all such cases it’s believed to be important to choose a platform properly, to combine the lidar with another remote sensing source (including developing specialized methods and software for different kinds of data fusing and mutual calibration). Realization of all these tasks can facilitate creating a lidar that turns out to be more efficient than a “universal” one.

3) **Company motivation.** Another reason which should be taken into consideration is one of company motivation. Only a company that has developed a strong technological culture and qualified staff (software programmers in particular) can construct its own mobile scanner. Thus, making its own mobile scanners can be regarded as a manifestation of the companies technological competence, which greatly raises its authority among others companies and clients.

Of course the authors of this artilce are very far from naïve attempts to persuade the reader that in “domestic” conditions of a relatively small geodesy company it’s possible to create a mobile lider which will be really competitive to the serial products of giants such as Riegl, Optech, Leica, Airbone Hydrography. However, it is obvious today that creating a mobile scanner under such “domestic” conditions is widely spread and a well defined phenomenon. Many servicing companies are engaged in such businesses to a large success . a strong example to that is Riegl’s scanners, which are used most often for combining with INS. It is the positive experience of Drakkar on this matter that should be of interest to the topography and engineering community.

Choosing Riegl LMS Z-420i as the core of the system can be explained by the following criteria: Drakkar has been working with Riegl products for over ten years. Within this time period, all of Riegl’s devices and software have demonstrated excellent performance. In comparison to its competitors Riegl’s scanners have superior range finder accuracy, resolution (make foot note: by the way, the real accuracy is usually even higher than a value from the specification and sometimes the accuracy is on the level of first mm), and high reliability in exploiting and usability. In addition, the Riegl system provides a wide set of technical options in choosing desired modes of work, which makes them next to universal. One of the greatest benefits of working with Riegl’s is the technical support interface.

Carrying out works for automobile, rail road agencies, and power engineering companies, which are all characterized by work environments where the geospatial accuracy is of great importance - is a major part of Drakkar’s activity. We believe that for all these areas, Reigl products occupy the leading positions in the world and that was one more argument for their use in the Drakkar mobile mapper (rephrase sentecen).

The following criteria detailed below present(s) the priority in Drakkar's activity while creating a mobile mapper. The criteria used are as follows:

1) It was an attempt to create a universal device which without any deep modification of its configuration could be used as static, mobile (on-ground, marine) and airborne. – play with sentence

2) Guarantying dimension, weight and power consumption on the level (?) makes it possible to mount the system on light and super light flying platforms. In addition, the total weight of the devise should not exceed 20 kg and duration of uninterrupted operation should be at least 6 hours while powered from a standard car battery.

3) To achieve a maximum usability for fulfilling specific topographical and civil engineering tasks should be taken. These tasks are included amongst the main areas of the company's activity mentioned above, such as: surveying of automobile and railroads, power engineering objects, coastal line mapping, survey of comprehensive urban scenes (including historical sites). The "maximum usability" here is understood as a possibility of choosing appropriate modes of scanning, scanner block position and attitude, combining static and mobile methods of survey, applying photogrametrical and direct (by means of GNSS/IMU) methods of geopositioning or their combination (dependently on survey object type). The usability category assumes a possible integration with other remote sensing methods such as digital photography and infra-red scanning (thermovision).

4) Finally, Drakkar regards its device as a prototype for further development of technologies of geospatial data acquisition and processing for various topographical applications. In particular, Drakkar's next possible move will be to create a portable mobile laser scanner (of about 5 kg), which will be used for mine surveying needs without any need for GNSS.

   As will be presented in the paper, the criteria outlined above was taken into consideration while designing Drakkar's mobile mapper PolyScan.

2. Functional scheme and main technical parameters

The system is made by classical functional scheme shown in Fig. 1.

As mentioned above, the core of the system is Riegl laser scanner LMS Z-420i. It is specially equipped with a module which allows to synchronize each scanner measurement (oblique range and corresponding angular parameters of horizontal and vertical scanning - ϕ and θ) with GPS time. For that reason a synchronization of the scanner's internal timer by GPS time is implemented as an initial step. The control computer receives the NMEA message generated by INS SPAN-SE which contains information about current GPS time.

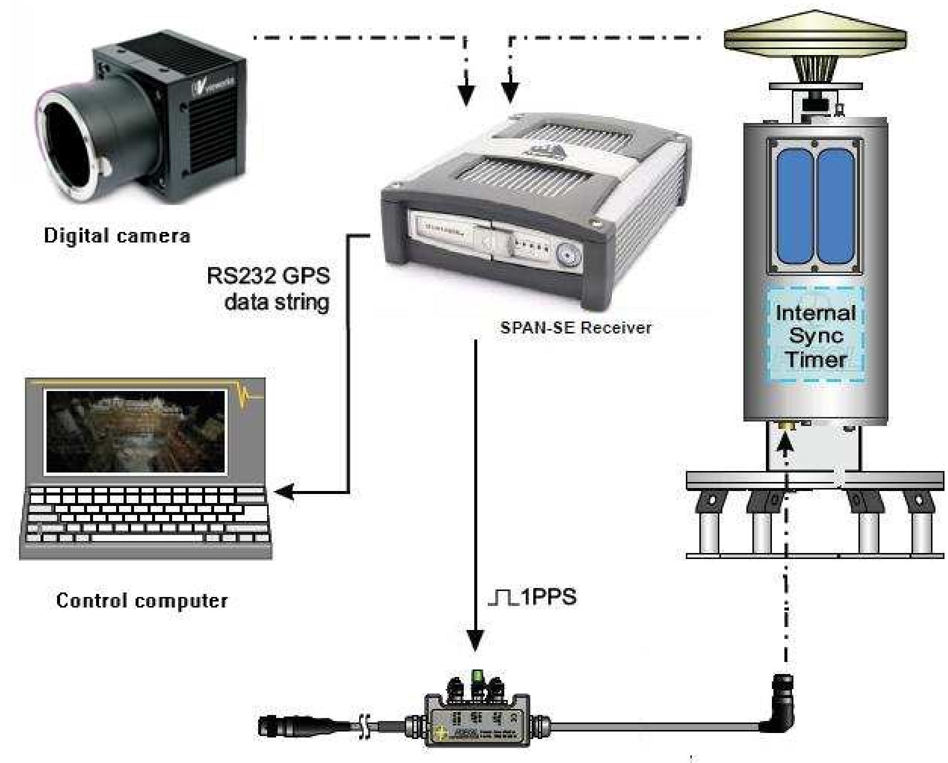


Fig. 1. Functional scheme of Drakkar's mobile lidar scanner PolyScan

In advanced operations of the scanner, the internal scanner timer is being synchronized by a falling front of the PPS one second (how to refer to PPS pulse) GPS impulse keeping up stability of synchronization. The synchronization initializing process and further support are ensured by the special software which is allocated in the control computer memory. Therefore, the LSR together with the additional equipment and software generate the first data stream, which can be named as "range-finder" ones. It can be represented as a table:

GPS time,c	*Φ, degrees*	*Θ, degrees*	*Range, m*	*Amplitude*
56789.2345	56.456	81.342	45.567	456
56789.2356	56.951	81.346	49.074	459
…				

Table 1. Form of representation of the "range-finder" data stream

The second data stream, called navigational is constituted by the data from Novatel Inertial Navigational System (INS) SPAN-SE. This device generates and stores the original navigational data (GNSS and IMU) and the complete real time navigational solution (spatial coordinates and attitude angles in geodetic space if RTK mode is applied) with a rate up to 100 Hz. This is believed to be sufficient for ensuring proper accuracy in all modes of PolyScan functioning. This information stream can be seen in Table 2

GPS time,c	Latitude, degrees	Longitude, degrees	Altitude, degrees	Roll, degrees	Pitch, degrees	Yaw, degrees
56889.2645	31.567834	35.45690	251.456	2.5673	-4.5672	123.7894
56889.2646	31.562312	35.456883	252.601	2.95673	-5.7206	122.0892
…						

Table 2. Form of representation of the "navigational" data stream

PolyScan INS SPAN-SE works as a direct geopositioning module, providing and generating an output of all 6 values of the complete navigation solution, which is needed for the ultimate geopositioning of the scanner data. Geopositioning can be achieved without ground control points and other photogrammetrical methods (as well as photo and thermo imagery). The accuracy level of output results in the Post Processing mode (accordingly the producer's specification) as shown in table 3:

	Position Accuracy (m) Horizontal RMS	Position Accuracy (m) Horizontal RMS	Attitude Accuracy (degrees) Roll, Pitch RMS	Attitude Accuracy (degrees) Heading RMS
Normal GPS	0.010	0.015	0.015	0.030
60 sec GPS outage	0.29	0.1	0.018	0.049

Table 3. INS NovaTel SPAN-SE output data accuracy

The first row in table 1, corresponds to the normal working conditions with a sufficient GPS support and when the resulting data is produced after on-ground post processing (in contrast to RTK, DGPS, OmniSTAR modes and so on). The second row demonstrates the accuracy degradation (while applying the same on-ground differential post-processing) in case of full absence of GPS signal for 60 seconds. As observed in table 1, the most significant degradation (by more than one order) takes place in planimetric and height coordinates, while the angular parameters accuracy remains on an acceptable level. Therefore, such peculiarities of INS Novatel SPAN-SE work allow us to draw two conclusions:

1) GPS signal problems (including its full absence for a short time) are less critical for aerial survey applications of PolyScan in comparison to on-ground ones. First, an aerial survey project typically demands less strictl accuracy, and second in case of larger ranges (distance between the scanner and the object of survey) the resultant error component caused by inaccurate determination of angular parameters is more valuable than the geopositioning error (errors in XYZ coordinates of the carrier). In the PolyScan's on-ground applications the situation is reverse – the short distances make geopositiong component of error more important. As it clear from Table 3 this component is subject to more rapid degradation in case of GPS signal outage.

2) In the applications where GPS signal outages are expected (for example for tunnel survey) it's important to undertake additional measures to increase resulting geodetic accuracy. It can be done by means of deploying special marks (signals) whose coordinates are measured independently (by traditional geodetic instruments). Such an approach is used in Drakkar's experimental activity in the field.

As noted above, the two main data streams – "range-finder" one (provided by Riegl LMS Z-420i) and "navigational" one (provided by Novatel INS SPAN-SE) are in fact independent and mutually NON-synchronized. They can be jointly processed at the on-ground processing stage just because each data portion (message) of both streams is provided with a time stamp of similar format. Both systems use the same time source of GPS receiver which guarantee at least 10 mcs accuracy. And even without Real Time Kinematic (RTK) mode INS SPAN-SE generates the complete navigational solution (for spatial coordinates and attitude angles in geodetic space) in real time. This feature can be used for quick data quality control right after the survey mission is over.

The whole set control and user's interface as well as all main and auxiliary kinds of data storage are carried out by means of a personal computer. This computer is also used for allocation of all necessary software of Riegl, NovAtel, WayPoint and Drakkar. All these software's together ensure the following technological stages of PolyScan operation:

- Off-set parameter measurement after new mounting.
- Calibration procedure.
- Data transfer to the control computer and registration (storage).
- Joint processing of range-finder and navigational data, generating the final product – cloud of laser points.

Also the digital camera is included into the standard PolyScan set. It provides acquiring digital photos along with the full set of the external orientation parameters for each photo. See Section 4 for more details about the camera (what does this phargraph come to show).

As it was noted above, an IR-scanner can be included into the PolyScan standard set. It is used mainly in power engineering applications.

At the end of this chapter we have produced a set of PolyScan basic technical parameters (see Table 4). The parameters are given for the aerial survey configurations of PolyScan.

Pulse repetition rate	24 kHz
Productivity	11 kHz (oscillating mode) 8 kHz (rotating mode)
Range finder accuracy	Better than 5 cm (at flight altitude less than 300 m) Better than 10 cm (at flight altitude less than 1000 m) Better than 20 cm (at flight altitude less than 2000 m)
Planimetric (X,Y) accuracy	1/5000 * H, where H is a flight elevation
Reply registration mode	First, Last
Field of view	80 ° across the flight direction
Power consumption	350 Wt
Weight	19 kg

Table 4. Basic technical characteristics of PolyScan

3. Grouping and modes of operation

The general grouping of PolyScan is an on-ground configuration, as shown in Fig. 2. All necessary equipment is mounted on a special platform, which is designed to be easily put on the roof of any car, truck, rail road coach or any other moving vehicle. Another platform is used for airborne applications (it is not discussed in this article). The control computer, the INS SPAN-SE control rack and the power supply module are placed inside the cabin.

The following ideas (except for the convenience of mounting and dismounting) were taken into consideration at the platform design level. Thus providing a metrological support, which include precise measurement of off-set parameters of mutual position and orientation in the following systems:

- IMU sensor– GNSS antenna.
- IMU sensor – scanning block.
- IMU sensor – photo camera.

Obtaining resulting quality lidar data is possible only if the accuracy of the above mentioned measurements are not worse than the first mm in spatial coordinates and not worse than the first mrad in angular (attitude) parameters. Besides the possibility of precisely measuring these parameters, another task which stood before the designers of PolyScan was to ensure their stability (avoiding possible mutual shifting and rotating) during operation. The later, demanded including additional constructional elements into the platform frame.

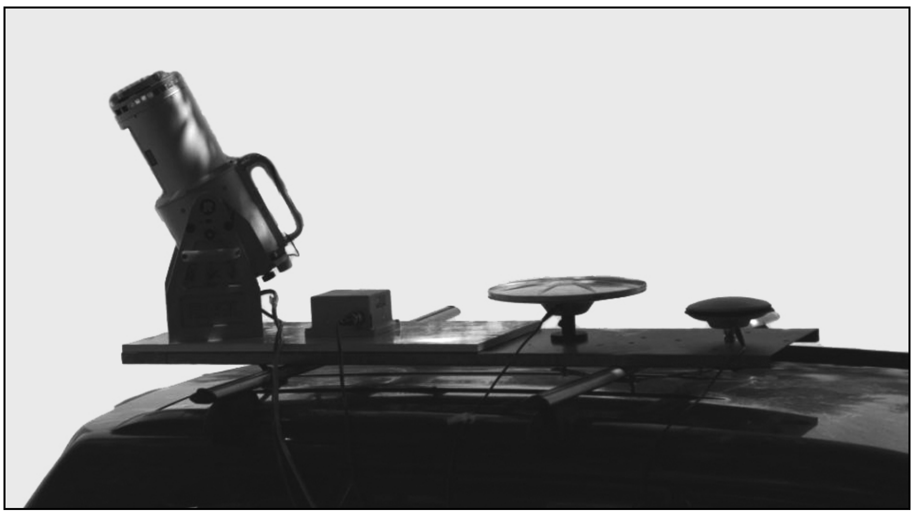


Fig. 2. Typical PolyScan grouping in on-ground configuration

In accordance with Novatel and WayPoint recommendations two parted GNSS antennas are used. Applying two antennas ensure better results at the processing stage. In particular it ensures more accurate Heading (Yaw) angle determination. And that’s an important question, because Heading accuracy is always worse than Roll & Pitch accuracy.

Besides the possibility of using two antennas, the PolyScan designers foresaw possible reception of both GPS and GLONASS signals, which significantly increase the probability of getting acceptable results while working at urban conditions with a great number of radio obstacles.

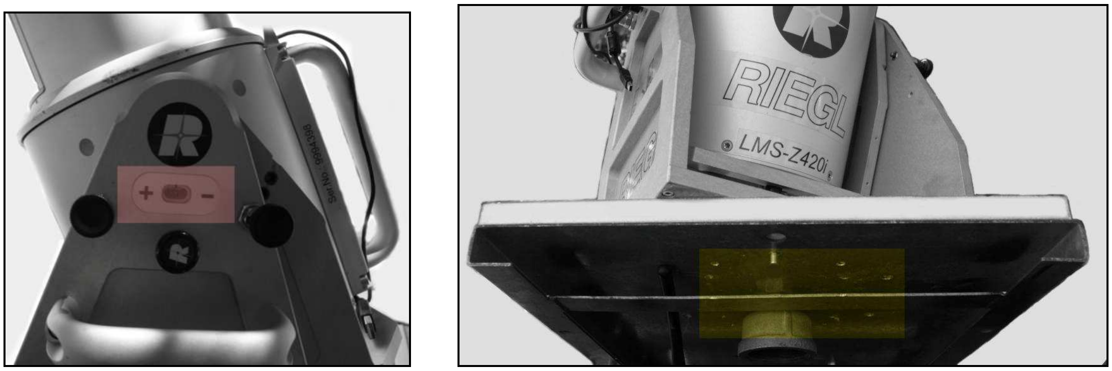


Fig. 3. Variants of scanner block mounting

Generally, while working in urban conditions where GNSS signal is usually weak, the designers undertook a number of additional measurements to guarantee normal operation. They are as follows:

1) Free location of the GPS/GLONASS antennas on the platform (sometimes with special brackets) is needed in avoiding any extra shielding while receiving satellite signal. Extra shielding can be caused by the scanner and car bodies. The special software created by Drakkar's makes it possible to measure "sensor IMU – GNSS antennas" off-set parameters very quickly (within a few minutes) and accurately (up to 2 mm) for arbitrary configuration of the antennas and the IMU sensor on the platform. These technicalities are discussed in more details in Section 5.
2) Usage of proven and very sensitive Trimble antennas with maximum aperture.

As noted above, providing multi functionality of the PolyScan complex was a main priority of its designers. We would like to reiterate, that the system was built on the basis of Riegl LMS Z-420i scanner which was originally intended for static applications only. The scanner has a 360° field of view for planer (horizontal) scanning and ±40° field of view for vertical scanning. Quick scanning (by prism oscillation or rotation) is available only for vertical angle. At the same time the horizontal scanning is implemented relatively slow and is only due to the scanner's head own rotation. Therefore, the use horizontal scanning in PolyScan is limited and applied only for certain special cases.

Taking this peculiarity into consideration, from a practical stand point it is very important to have the possibility to set the scanner's head to arbitrary position, depending on the desired survey mode (type of object of survey) . The approach adopted by Drakkar comprises the following:

1. Possibility of a front-face tilt of the scanner head within±90° range with a 5° step. Such a possibility is provided by the scanner's manufacturer. While doing so the systems internal orientation parameters (vector of the mutual position, orientation of the scanners coordinate system and the coordinate systems of another surveying device, i.e. photo camera and thermovisor) can be calculated by the special Drakkar's software without repeating the procedure of off-set measurement and calibration. The angle of tilt is fixed by the special indicator (Fig. 3 left). The accuracy of angle fixing is guaranteed by the manufacturer at the level of 0.05°, which fully corresponds to the expected accuracy of angular parameters

determination. Furthermore, the RiSCAN PRO software gives an additional possibility of precise measurement of the systems internal orientation parameters for each front-side angle of tilt by means of implementing a special calibration procedure. This procedure is based on making photodrammetrical orientation for each angle of tilt with further calculation of the shift (tilt) matrix for each angle of tilt relatively to the scanner basis (vertical) position.

2. Such an approach was developed by the PolyScan designers to ensure the similar possibility for the plan rotation of the scanner head. The special precisely positioned holes (corresponding to plan tilt angles with 30° and 45° steps) were made on the scanner support by Riegl. Attachment is implemented by the special shift (Fig. 3, right). The analogous holes were drilled in the PolyScan main platform. This makes it possible to implement the plan rotation without any problems and the accuracy of fixing is ensured at the same level of 0.05°. For providing accurate values of the internal orientation parameters, while at the same time its plan rotated position, Drakkar ltd. has developed special software for realization of a calibration procedure. The principles of this procedure are quite similar to those which are applied in the front-side calibration procedure of Riegl RiSCAN PRO.

The ability to realize a front-side tilt and plan rotation is very important in a practical sense. As we mentioned earlier, the scanner construction provides automatic scanning by ϕ, θ angles in 0°—360° and ±40° respectively (Fig. 4). Additional rotating possibilities are provided by PolyScan designers by Drakkar. As a result, PolyScan can cover the whole upper hemisphere and major part of the lower hemisphere. This can be done in field conditions and without any significant time delays, which is of great importance since it increases the system's effectiveness. Such a possibility (wide full angle of coverage) is in demand while making a repeated survey of the same object. Another reason is worth considering because PolyScan's capacity field of view (in the field only ±40°) is limited in comparing with modern "classical" lidar mobile scanning systems.

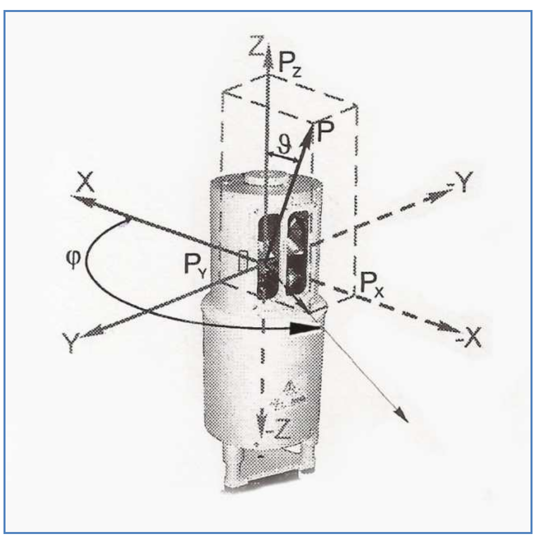


Fig. 4. Horizontal and vertical scanning implemented by the Riegl Z-420i scanning block

Now let's proceed with considering PolyScan modes of operation while working with on-ground configuration, for instance while it is mounted on a vehicle. Generally speaking the category of "mode of operation" is a complex one and includes all the questions of choosing a correct scanner head position, the trajectory of survey, the parameters of scanning (laser beam divergence, pulse reparation rate, etc.), and the overlap value. All these parameters are important and their setting up should be done differentially, and taking into consideration the main object of survey. (For example, common topography mapping, road survey, power lines inspection, etc.).

The questions pertaining to GNSS (GPS/GLONASS) receiver mode have a special significance, since the proper choosing of the mode directly influences the final output accuracy. Here, in the first approach we should discriminate between Real Time Kinematic (RTK) and stand-alone mode. In the latter case, getting quality results is possible only by means of applying special software of differential correction in office conditions. On the contrary, while working under RTK conditions we are provided with an accurate and final navigational solution in real time. Therefore the RTK mode is a preferable one because its use shortens the total duration of a technological chain. However, working in RTK mode is not always possible, mainly because of obstacles and interference for GNSS correction signal receiver. Such unfavorable conditions usually take place in cities with a dense architecture or in distant areas where there is no RTK signal broadcasting. If such circumstances take place it demands a special approach to choosing PolyScan modes of operation.

The consideration of choosing a proper PolyScan mode as presented below is done in a narrow set of circumstances. It's limited by the factors of choosing the scanner head position with regards to the goals of the project to be accomplished. While such an approach is accepted we can say that from the pure mathematical point of view the PolyScan working mode is fully defined by such parameters as scanning prism frequency and its behavior (rotating or oscillating) relatively to the vector of carrier motion.

The mode of static survey shown below (Fig. 5) includes a car carrier in a static position. The carrier remains in place while acquiring lidar and photography data. Such a kind of survey can be done only in start-stop mode and therefore is not very productive. However, this mode can be of assistance in cases when maximum accuracy is demanded. The External Orientation Parameters (EOP) can be defined either automatically (by Novatel SPAN output) or photogrammetrically by the 4 special marks located on the 4 corners of the roof of the car (further details in [1]). Besides, it's always possible to determine them by the "classical" Riegl's procedure (by 4 or more distant marks).

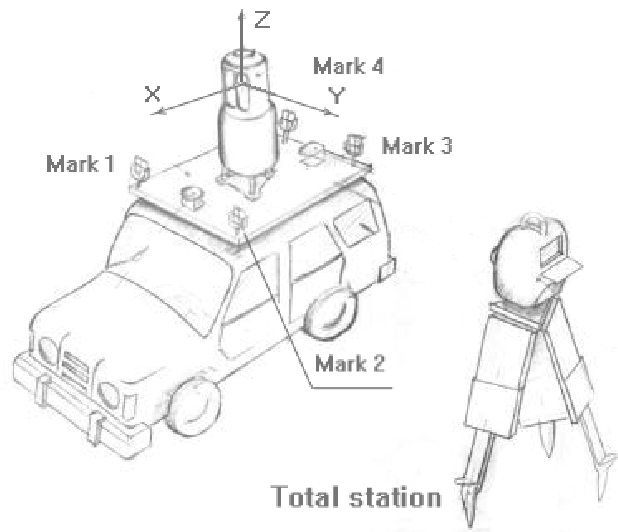


Fig. 5. Static survey mode

While making a real mobile survey (the scanning is being implemented when the platform moves) the scanner head is positioned towards one of the positions (relatively to the vector of drive) shown below.

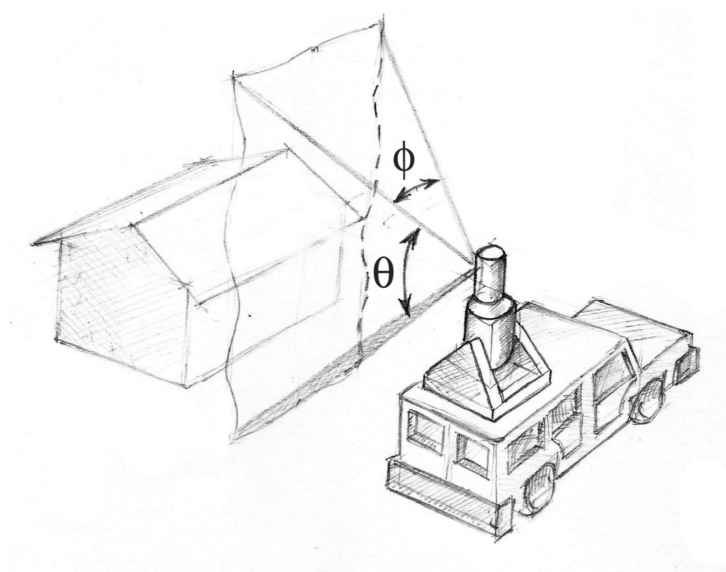


Fig. 6 Classical (vertical) scanner head mounting

When the classical scheme is in use (Fig. 6) the scanner head is placed vertically and scanning is implemented on the vertical surface. The scanner head is moving clockwise, anticlockwise or it can be at any fixed angle ϕ position (profiler mode) or it can periodically move within a certain range of ϕ_{MIN} – ϕ_{MAX} . Each of this mode can be set by an operator. All modes are supported by the scanner's basic version. The variation ϕ mode is very useful in an urban environment, because it allows minimizing the “dead zones” and consequently reduces the amount of passes along the same route. For example this is useful when needed to survey both left and right sides of a street. The problem of “passes matching” does not appear as a principal matter, because the direct geopositioning accuracy (guaranteed by Novatel SPAN) is always enough.

Horizontal scanner head mounting (Fig. 7) is used mainly for surveying of automobile and railroads. Scanning is done “from above” with a small vertical angle (angle between the plane of scanning and vertical line). Due to a very short range (usually no more than 10 m) maximum accuracy (first mm) and resolution can be achieved. An example is shown in Fig. 8, where PolyScan has been used for the Israeli Rail Road service. The project included a precise survey of rails and all other essential components.

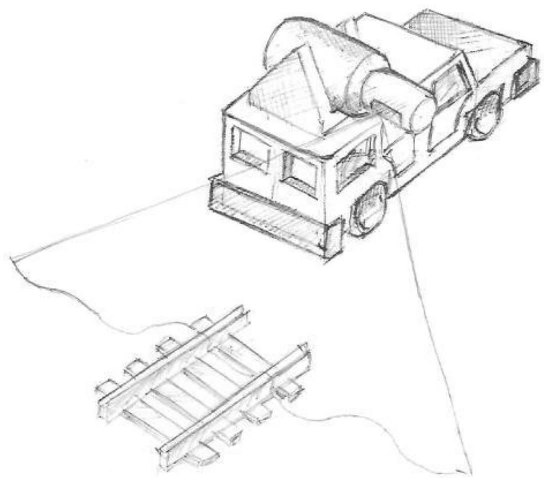


Fig. 7. Horizontal scanner head mounting

Fig. 8. Example of horizontal scanner head mounting in the project for the Israeli Rail Road service

Also, the combined mounting scheme is possible (Fig. 9), which in a sense inherits advantages of the both previous schemes. Such a scheme combines both the possibility of dense (detailed) survey “from above” and receiving the full coverage in the left (right) hemisphere. Under such a mode the detailed survey is carried out with short and ultra short laser ranges for achieving maximum accuracy and density.

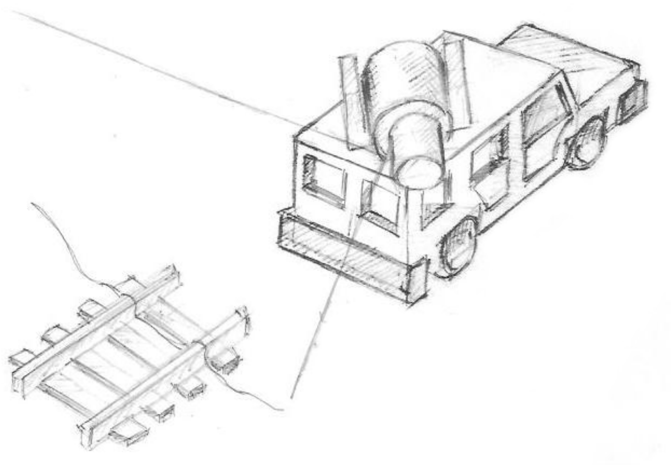


Fig. 9. Combined scanner head mounting

For all considered schemes of mounting the lidar point distribution, diagrams are shown through Fig. 6 – Fig. 9. Additionally, these diagrams help us to understand their applicability in some cases.

4. Applying photo camera

Applying a metrical photo camera is regarded as mandatory in both on-ground and airborne applications. Presence of photo data acquired parallel to lidar data significantly increases the informatics value of the entire data thanks to two main directions of the camera data use:

A) “Coloring” (rendering) clouds of lidar points giving them a natural color, increase the effectiveness of office camera decoding.
B) Gaining parallel and independent (relatively to lidar data) geospatial data – stereo pairs, can be used for both stereophotogrammetric measurements and for visual decoding (including stereo mode also).

Among those “typical” tasks, which any mobile lidar designer faces, there are specific ones which were raised by Drakkar engineers. Such a specific task relates to acquiring fully draped scenes with sub-pixel resolution [2]. The critical parameter there is a frame rate which allowed Drakkar to conduct a survey with a high along-track overlap. As a result, Camera VA-29M from Vieworks Co., Ltd with a 6576 × 4384 pixel matrix was selected for combination with a lidar (Fig. 10).

Fig. 10 VA-29M sensor block and its mounting on PolyScan base platform

The camera's main technical characteristics are presented in Table 5.

Resolution (H × V)	6576 × 4384
Sensor	Kodak KAI-29050
Sensor Size (Optical Format)	Progressive Scan Interline 35 mm
Sensor Type	Transfer CCD
Pixel Size	5.5 µm × 5.5 µm
Max. Frame Rate	5 fps
Electronic Shutter	Global Shutter
Pixel Data Format	8 / 10 / 12 bit
Interface	Base Camera Link
Camera Link Clock Speed	40 / 80 MHz
Trigger Mode	Free-Run, Standard, Fast, Double, Overlap Programmable Exposure Time and Trigger Polarity
Dynamic Range	64dB
Dimension / Weight	68 mm× 68mm × 54mm / 420 g (with C-mount) 68mm × 68mm × 83m / 460 g (with F-mount)
Temperature	Operating: -5°C - 40°C, Storage: -30°C - 65°C
Lens Mount	C-mount or F-mount, Custom mount available
Power	10 - 14 V DC, Max. 6W 10-14 V DC, Max. 8W

Table 5. VA-29M camera main technical characteristics

After Camera to Novatel SPAN integration is done, each photo frame is provided with an accurate (on the level of 0.01 ms) triggering pulse. At the processing stage this information (actual time of triggering) is used for precise determination of each frame's exterior orientation parameters and implementation at an utmost geopositioning frame without making photogrammetry procedures (don't understand this sentence).

The chosen camera is fully metrical and without any qualifications can be used in photogrammetrical and lidargrammetrical applications. The camera has a central electronic shutter and the already mentioned system for triggering signal registration. It is also provided with high-aperture lenses and has a wide dynamic range and high sensibility. As a result the camera gives quality shots with exposition duration of 1/500 – 1/1000 if the light conditions are normal and so no blur occurs even in an aerial survey mode (while the fast platform is moving). The lens has a screwed connector to the camera which provides its reliable fixing and stability of the internal orientation parameters.

The camera synchronization process is as follows. The sensor block produces the digital video stream that is being recorded lossless according to the user's setup. The selected mode of synchronization allows recording from the camera while using the camera's internal timer. By initiating acquisition from the host computer, images arrive from the camera at a fixed rate as predefined in the camera setup software (see Fig. 11). Camera exposure time is changeable in real time. The strobe always corresponds to the moment when exposure begins, so it is used as an event marker for Novatel SPAN INS.

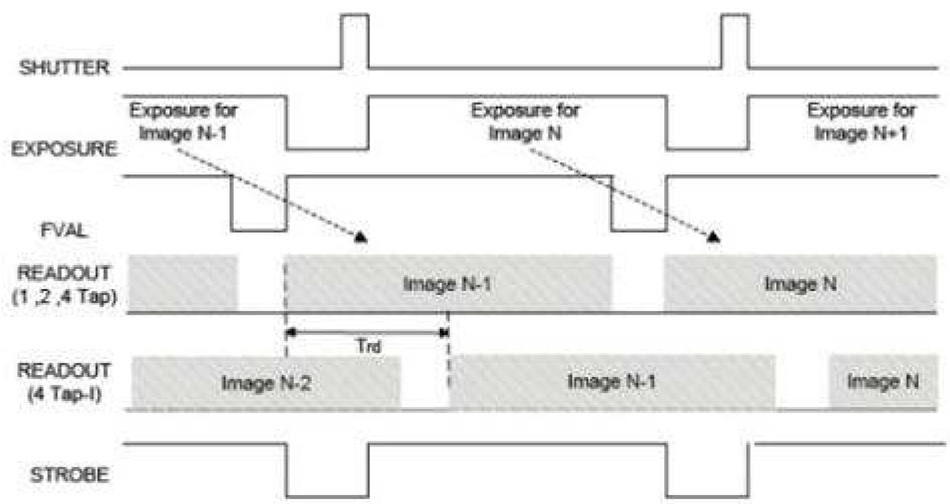


Fig. 11. Camera synchronization diagram

5. Software and methodological support

The mobile lidar scanner PolyScan should not be regarded as a mechanical sum of its main components. The designers have done their best to get a full-scale survey device, which is fully equipped with all the necessary tools for mission planning and result analysis, convenient user interface, metrological support and various tools of resulting data control.

For ensuring that the system will be the ultimate device for topography and geodesy data collection, the following measures were taken:

1) The entire complex control was conducted through a single personal computer. Its calculation capacity is sufficient for controlling all three basic components: - laser scanner Riegl LMS Z-420I, INS SPAN and digital camera VA-29M.
2) Additionally, a small format video monitor was installed for picture photographic quality control in real time and for setting up operational exposure parameters (if light conditions were to change).
3) Laser scanner control is managed by means of RiEGL's standard program RiSCAN PRO. The Novatel CDU program is used for INS SPAN control. Special software for the digital camera control is also used. It will be discussed below.
4) The special software ensures that the synchronization process between the INS and the laser scanner will take place. For that reason at the initializing stage the scanner receives the NMEA message generated by SPAN. That's the way to synchronize internal timers of both devices. Then synchronization is kept by the precise PPS pulse generated by INS every second.

The system control display includes a user interface for system management and a preview screen for previewing live video connected to the system or playback of recorded video streams. The recording computer can also be used as an offline debriefing system. Debriefing capabilities includes playback of the recorded video forward/backward, frame by frame display, export the video to image files, etc.

The video recording computer has a capability for comprehensive debriefing of recorded data. The debriefing system is based on software that provides capabilities of data selection, playbacks and export. The main abilities are:

- Viewing recorded data in playback mode.
- Viewing data and time of each frame (time stamp based on computer time).
- Zoom in and out visual data.
- Playback speed selection.
- Frame by frame playback.
- Go to time (forward and backward).
- Pause (video output is displayed but frozen).

The video recording computer has a capability for displaying the real-time recorded signal during the recording session or off-line when debriefing. The software can apply some image processing operations for enhancing the video display: e.g. color remapping, image rotation, etc.

At the laboratory processing stage joint processing of GNSS and IMU data is implemented. Waypoint Inertial Explorer program is mainly used for that reason. For laser point cloud generating Riegl's RiWORLD program is used. This program carries out joint and synchronized processing of trajectory data and laser scanning data. The final data is presented in arbitrary geodetic coordinate system.

In addition Drakkar ltd. has created a number of its own software. This software is used at the labotatory processing stage and bears the following functions:

1) Exact determination of the off-set parameters (parameters of mutual position and orientation) inside the Scanner– IMU– GNSS antennas. Linear parameters (GPS, GLONASS antenna's phase center spatial coordinates) must be measured with an accuracy not worse than 1 cm. It can be a problem, especially if the antennas are deployed at a distance of more than 3 meters from the IMU sensor and from each other. This problem is usually prevalent when being mounted on

planes or helicopters. As to the demanded accuracy of mutual 3D position of the IMU principal point and the scanner central projection point , an accuracy of no worse than 1 cm should be guaranteed here as well. Much more critical is an accuracy of mutual angular attitude of IMU and the scanner head, because any error here will be directly translated into the final output coordinates (and multiplied by a value of scanner to object distance). It's is estimated that scanner to IMU attitude accuracy must be measured at the level of 0.5 arcmin. To provide such an accuracy the special procedure and software are made in Drakkar ltd. More details on this matter in [3].

2) Besides the special software for measurements of camera off-set parameters was made. It gives the full set of mutual parameters of position and orientation in the IMU-Camera system and also that of the camera calibration parameters (principal point, focal length, and distortion). More on this matter in footnote [4]. The matter bears important meaning, because knowing of these parameters makes it possible to carry out a high quality rendering (matching of lidar and photo data), automated searching tie (corresponding) points on photo stereo pairs and attain a sub-pixel accuracy level of matching and resolution.
3) In addition Drakkar ltd. has developed a number of utilitarian software products, which facilitates making survey and post processing. The following products must be noted: photo frame package processing routine, matching pictures and their EOP's (acquired by SPAN CPT) making photo transformation (projecting into DTM surface) and data segmentation (classification) programs. Preparing for further stages of processing is done with packages such as AutoCAD, Micro Station, TerraScan, Socket SET and others.

6. Results

At the initial stage of its life cycle (first half of 2012), PolyScan equipment was used mainly for topography and geodesy projects for a number of Israeli companies and governmental agencies.

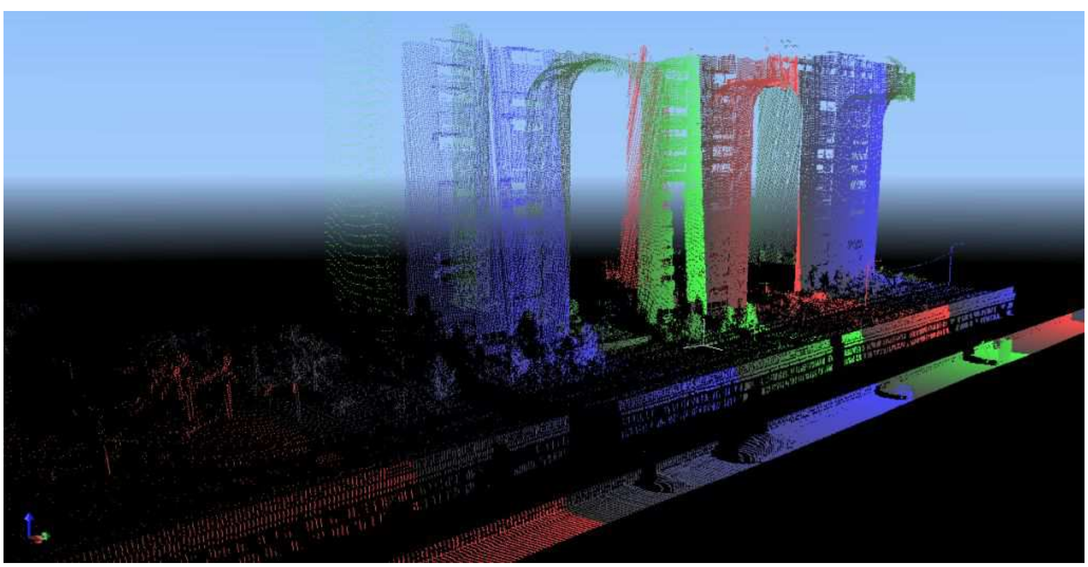
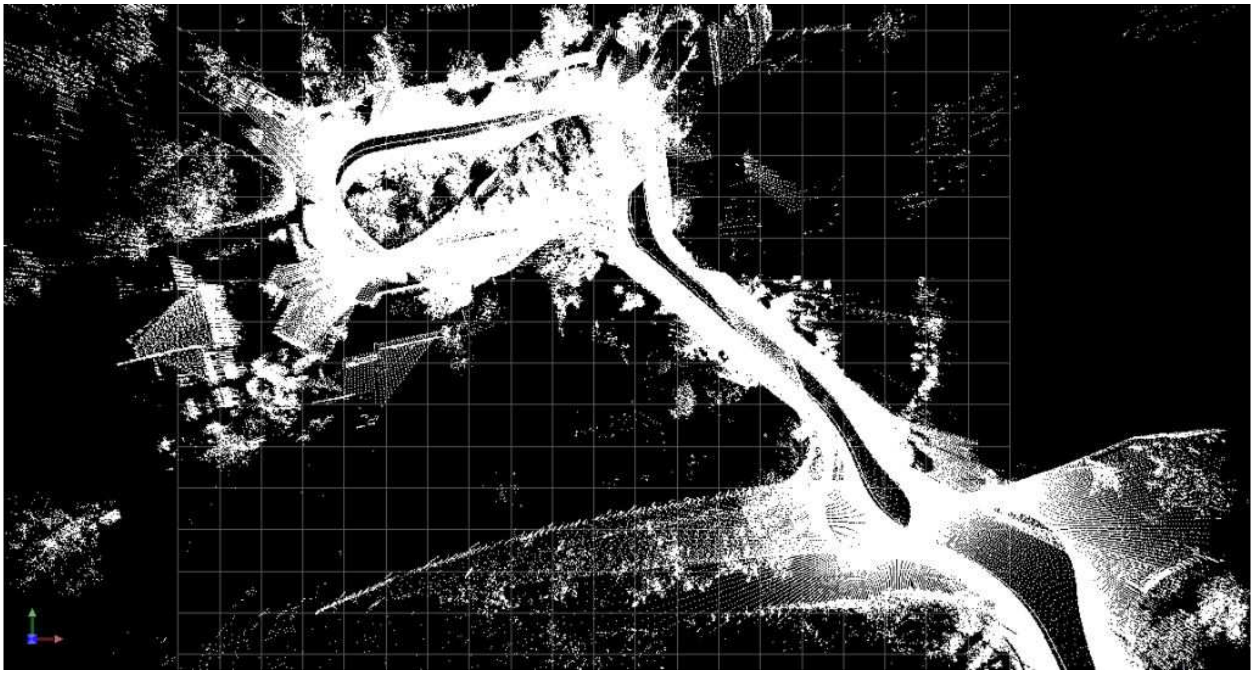
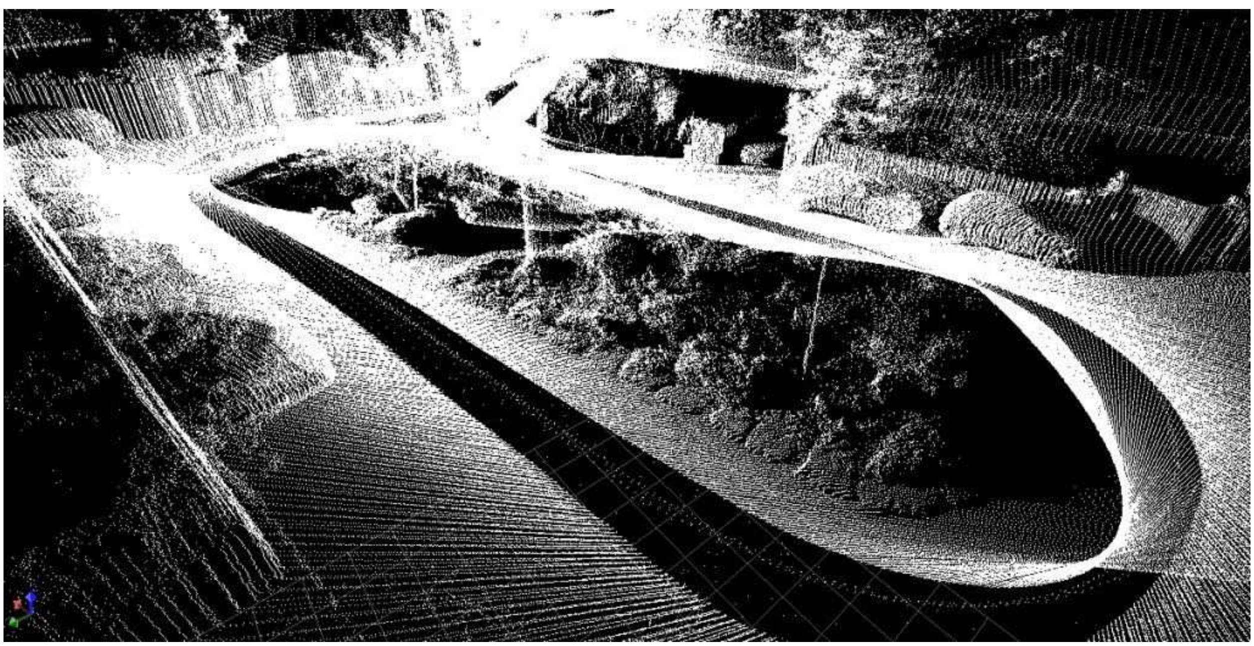


Fig. 12 City inferior survey in



A)



B)

Fig. 13 Inside yard survey in Ramat Gan

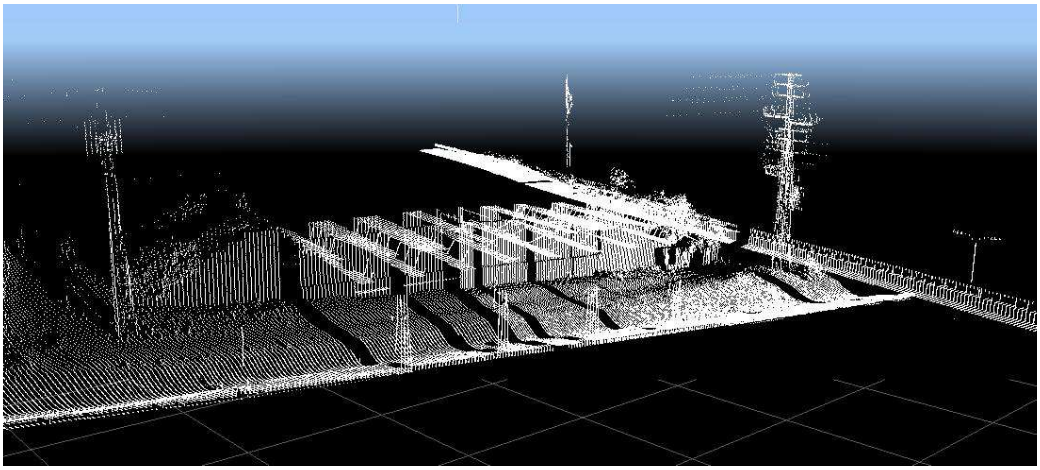
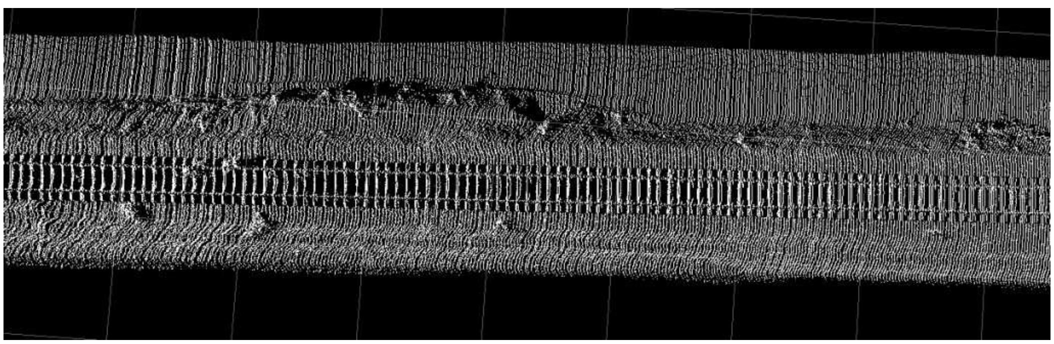
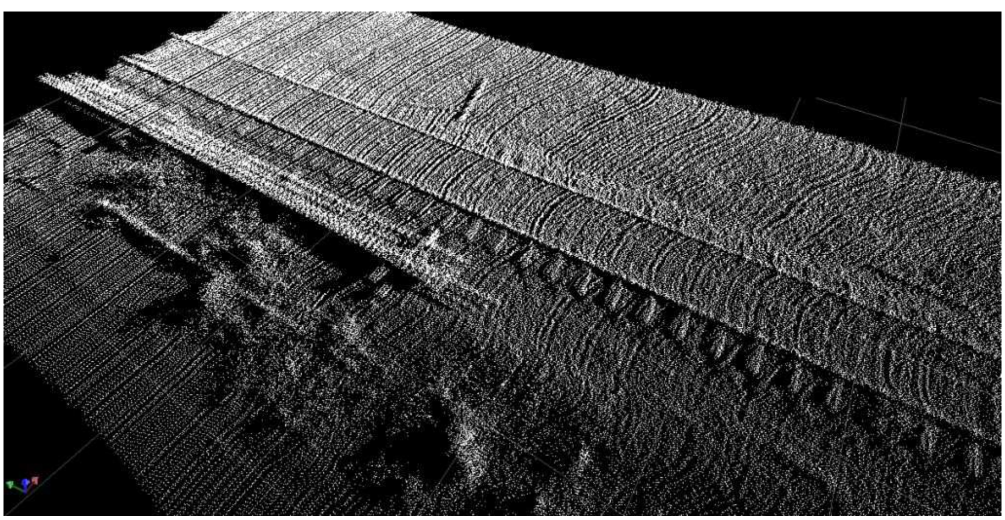


Fig. 14. Autobahn #2 near Netanya and a bridge and adjacent power line



A)



B)

Fig. 15. Rail road survey near Ashkelon

The preliminary conclusions derived from these projects and the experimental exploitation of Polyscan are as follows:

1) Its high effectiveness is confirmed in the use of multistoried urban area surveying (Fig. 12).
2) Really good results were achieved for inside yard territories where a large number of obstacles GNSS signaling exists (for example, a great number of densely located buildings, a lot of vegetation, etc.). In Fig. 13-A, we can see a survey configuration (trajectory) of a yard. In this case backward moving was also used. In Fig. 13-B, the same object is depicted on a larger scale. In spite of a great number of overlapping passes, the final matching of all passes is done with an accuracy of not worse than 3 cm for all three coordinates without ground control points.
3) Survey of autobahns and transmission power lines of 220 kV voltage and higher, can be carried out at a speed of up to 50 km per hour (Fig.14). At such a speed acquiring all necessary data parameters are still guaranteed. These parameters include: asphalt coverage defects and deformations and calculating slope angles. For power lines, parameters such as values of sags, clearances, isolator suspension point and tilt angles are also taken into consideration.
4) While conducting rail road surveying (Fig. 15-A), the geopositional accuracy of 3 cm was achieved for both rails and sleepers. Another principal result was obtaining very detailed data which provides automated recognition and geopositioning of each rail and sleeper as well as all other substantial elements of the road's infrastructure.

7. Perspectives

Drakkar ltd. is going to proceed developing its mobile scanning technologies in the following directions:

1) Widening commercial range of mobile lidar scanning technology applications. Besides traditional directions such as common topography, civil engineering, road industry, urban management, and power engineering, Drakkar is going to use the system in such areas as coastal line surveying (along with lidar bathymetric survey), forest inventory, archeology, cultural heritage and so on.
2) More active use in aerial survey applications, in particular installing the system on light and ultra light flying apparatuses (due to relatively small weight of the PolyScan).

When discussing development of mobile scanning technologies the following guidelines should be taken into consideration:

1) Further improving Drakkar's software and methodology for surveying data processing and new informatics characteristic extraction. For example: the detection of super light terrain and engineering communication deformations (in particular autobahns and rail roads), and object recognition under dense tree foliage.
2) Special attention is paid to perspective works related to joint processing of lidar data and photo imagery. Beside traditional applications (gaining photo realistic or draped 3D urban models), Drakkar Ltd. carries out investigations on making sub-pixel resolution imagery by means of

photo sets with ultra high overlap and an automated tie point detection and making photo triangulation.

3) There are plans to make a portable laser scanning device which will be based on the experience and results gained during PolyScan designing and building. Such a portable device can be applied in a number of applications; including traffic accident spot inspection, and mine surveying without GPS.
4) In power engineering (works of overhead power line inspection) Drakkar ltd. is planning to present a new research proposal thin the next few months. The research proposal, will be based on PolyScan and include an IR-scanner (thermovision system). Such a complex will make it possible to measure and survey all the important power line parameters at once – sags, clearances, and wire thermodynamic temperature.

8. Conclusion

Creating a mobile lidar scanning system PolyScan resulted from activity of Drakkar's engineers, who proved their high professionalism and devotion to innovations. Today, the system is in operational use. Construction of the PolyScan initiated a number of Drakkar's own developments, including software and the procedures of metrological support. Drakkar's experience demonstrates a number of essential advantages in building its own mobile scanners in comparison to buying a ready-made one. The main advantages are significant financial savings and the possibility to adjust the device for solving particular tasks which a small company may face, in addition to providing an intellectual stimulus for the staff.

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