Archives of Photogrammetry, Cartography and Remote Sensing, vol. 35, pp. 85-105
ISSN 2083-2214, eISSN 2391-9477
DOI: http://doi.org/10.14681/apcrs-2023-004

REVIEW ARTICLE

TOWARDS DEVELOPMENT OF MOBILE MAPPING SYSTEMS

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KEY WORDS: MMT, MLS, review, mapping, SLAM, LiDAR, hand-held

ABSTRACT: Mobile mapping, a technology that integrates digital imaging with direct georeferencing, has developed rapidly. This article provides an overview of the development and current state of digital mobile mapping, emphasising the rapid development of this field from academic research to a commercially viable industry. The analysis of cited papers contributes to a comprehensive understanding of the market landscape. The article reviews mobile and handheld scanners. The introduction highlights the significant impact of mobile mapping systems on geospatial technologies, enabled by advancements in photogrammetry, computer vision, and robotics. Low-cost survey sensors with diverse specifications have further enhanced the systems and their applications, making mobile mapping more flexible and cost-effective. The article acknowledges the absence of a single widely adopted mobile mapping standard for a system and it aims to present a comprehensive meta-review of sensor suites and associated mobile mapping systems. The article presents studies demonstrating the accuracy achieved by scientists using mobile mapping systems, highlighting the role of sensors like LiDAR, cameras, and GNSS receivers. An analysis of the specifications of mobile mapping systems reveals diverse possibilities, including the integration of LiDAR and cameras or the limitation to one type of data acquisition. Manufacturers have focused on enhancing platform connectivity to various mobile mechanisms, expanding adaptability in challenging conditions. The article concludes with future trends, highlighting the democratisation of laser scanners, refinement of mobile and airborne scanning platforms, the ubiquity of terrestrial laser scanners, integration with complementary technologies, and advancements in development of airborne scanning systems. It predicts advancements in sensor technologies, positioning systems, data processing techniques, and integration with emerging technologies like artificial intelligence and machine learning. The future of mobile mapping technology entails continuous innovation and refinement to create more accurate, efficient, and versatile systems. What used to be a topic of academic study, has become a commercially viable industry.

1. INTRODUCTION

In recent years, mobile mapping systems have become one of the most essential geospatial technologies that have changed how environments are measured, visualised, analysed and collected. Thanks to high-tech imaging, measurement capture tools and the aid of a mobile transport platform, Mobile 3D Mapping visualises, records measurements and adapts to the environment.

According to algorithmic developments in photogrammetry, computer vision, and robotics, the last few decades have seen major advancements in mobile mapping technology

(Wang *et al*., 2019). MMS was made and implemented in 2002. This technology examines and effectively acquires current spatial data, including the right-of-way with its nearest study, and uses photos from measuring cameras and images from laser scanners (McGlone, 2004).

Firstly, the pace and volume of data collecting have also been accelerated by greater processing and storage capability (Vallet & Mallet, 2016). The applications and systems have been further strengthened by the availability of a diverse set of low-cost survey sensors with various specifications, making mobile mapping more flexible and able to acquire data in complex environments (e.g., tunnels, caves, and enclosed spaces) with lower cost and labour expenditure (Raper 2009). Commercial mobile mapping systems (MMSs) can be typically divided into handheld, backpack, trolley, and vehicle-based categories (depending on the platforms on which they are hosted). On the other hand, some systems can only operate indoors without using GNSS, while others can operate both inside and outside. Even if there are a few mobile mapping solutions available on the market, the MMS technological landscape is very diverse. There is no single-accepted MMS that is commonly adopted by the mapping industry. The majority of the currently available MMSs are modified, utilising various sensor suites at various levels of integration. Each, therefore, has its benefits and drawbacks.

It must be noted, that prior research has mostly concentrated on comparing various devices or targeted systems for particular application circumstances (such as indoors or outdoors) (Otero *et al*., *2020*; Karimi *et al*., 2000, Lovas *et al*., 2020*)*. The current capabilities of these crucial MMS components may not be fully reflected by a few integrated systems due to the rapid advancement of imaging, LiDAR, location sensors, and onboard computers, making such studies less relevant. Studies that examine the whole spectrum of sensor suites and associated MMSs are generally lacking. Meta-review of the sensors and platforms utilised to create ground-level 3D mappings were the main goals of this paper. MMS is a mobile mapping system that is placed on a vehicle and uses various positioning and data collection sensors to produce precise georeferenced maps. The following sections present a review of commercial mapping systems and accuracy obtained by scientists using mobile platforms.

The text presents a summary of all mobile scanners in one place. In individual chapters, they were divided into stationary and manual. A quite satisfactory combination was obtained, along with the corresponding parameters. The improvement of direct analysis of georeferencing technology allowed for cell mapping systems. GNSS and Inertial Navigation Systems allowed fast and correct dedication of role and mind-set of remote sensing equipment (Vallet *et al*., 2016) mainly for direct mapping without the need for complicated post-processing of the found data.

Interestingly, mobile mapping systems (MMS), which usually use international positioning systems, have numerous advantages compared to aerial and conventional terrestrial surveying systems. From the beginning, MMS has used virtual cameras as imaging sensors, casting off the need to test photographs, decreasing the time from unprocessed statistics series to their dissemination. MMS additionally no longer requires occupation of each factor of interest. This article presents a short review of MMS development. The varieties of MMS have been mentioned and examples collectively with an outline have been collected. The power of MMS lies of their capacity to georeference their mapping sensors without delay. Georeferencing approaches and an estimated accuracy are mentioned. Finally, the mixture of advances in virtual imaging and direct georeferencing now no longer has the simplest expanded the performance of cell gadgets mapping, however, additionally led to extra flexibility and decrease cost. In this article, all kinds of solutions have been introduced with their characteristics, provided within the following chapters.

2. THE ACCURACY OF MOBILE MAPPING PLATFORMS IN VARIOUS APPLICATIONS

MMS are sensor systems that allow a wide range of applications. Depending on the field, MMS platforms take different forms. Depending on the purpose of the platform, they will differ in equipment. However, they can be grouped into certain areas:

1) Urban space - has a wide range of applications, which include built-up areas. Scanning platforms inside various buildings are also included here.
2) Environment – there is a large number of applications for monitoring the environment and the processes that take place there. It is possible to monitor such phenomena using laser scanning technology. It is also important to remember the applications of underground research and the study of the impact of objects in terms of anthropogenic activities. When it comes to the environment, one should also remember a wide range of applications of geomatic technologies in forestry, used for metric extraction of trees. The environment in the context of agriculture should not be forgotten as well. Farmers are more and more willing to improve their yields, thanks to which precision farming is becoming more and more popular, with the leading techniques being those used on mobile platforms.
3) Culture - these are applications related to the reconstruction and creation of 3D documentation of various historic objects. An increasingly popular creation of archaeological sites.

Depending on the application, the expected accuracy will be greater or lesser. Another aspect is the type of platform. The research presented in the work "Mobile 3D scan LiDAR: a literature review". Di Stefano *et al.* (2021) indicates the superiority of literature on human-based and wheel-based platforms it also shows a tendency toward interest in technology and thus an increase in publications, which so far are few.

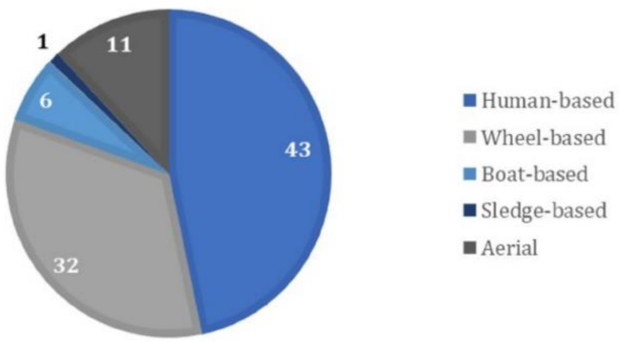


Fig. 1 Number of papers related to MLS platform typologies (Di Stefano *et al.*, 2021)

When it comes to accuracy, it was necessary to choose parameters that would allow a reliable evaluation system. Table 1 lists the studies and their authors. Information on the study subjects is also presented together, as it is considered more reliable. In addition, the RMSE and MAE errors and the sensors used are shown.

Table 1 Selected accuracy obtained by researchers

Authors	**Context**	**MLS system**	**Accuracy**
Chiappini *et al*., 2020	Industrial area	KAARTA Stencil 2	RMSE = 34 cm
Kaijaluoto *et al*., 2015	Building indoor	FARO Focus 3D X330	RMSE = 1.7 cm
Kukko *et al*., 2012	Urban and environmental	FARO Photon 120	RMSE = 2 cm
Bock *et al*., 2015	Cities	RIEGL VMX-250	15 cm
Lauterbach *et al*., 2015	The University of Wurzburg indoor and outdoor	RIEGL VZ400	Up to 2.9 cm
Thomson *et al*., 2013	UCL college indoor	GeoSLAM ZEB1, Viametris i-MMS	Mean = 3.2 cm Mean = 2.6 cm
Yan & Hajjar, 2021	Infrastructures	Velodyne VLP-16	8 cm
Tucci *et al*., 2018	Indoor and outdoor in a fortress	Leica Pegasus Backpack, GeoSLAM ZEB REVO	RMSE = 6 cm RMSE = 4 cm
James & Quinton, 2014	Coastal cliff	GeoSLAM ZEB 1	MAE = 2 cm
Patrucco *et al*., 2019	Outdoor of historical building	GeoSLAM ZEB REVO	MAE = 3.7 cm
Di Stefano, *et al*., 2020	Landslide	KAARTA Stencil 2	MAE = 5.6 cm
Gollob *et al*., 2020	Forest	GeoSLAM ZEB HORIZON	RMSE = 2.87 cm
Barba *et al*., 2019	Chapel	GeoSLAM ZEB REVO	MAE = 2 cm
Pierzchała *et al*., 2018	Forest	Velodyne VLP-16	RMSE = 2.38 cm
Williams *et al*., 2020	Fluvial sediment	Leica Pegasus	MAE = 7.1 cm
Di Stefano, *et al*., 2020	Ancient city walls	KAARTA Stencil 2	Mean RMSE = 10 cm
Wonwoo *et al*., 2017	Roads	Leica Pegasus	Mean RMSE = 8.8 cm
Lin *et al*., 2019	Coast	Velodyne VLP-32C	MAE = 2 cm
Corte *et al*., 2020	Forest	Velodyne Ultra Puck	RMSE = 3.46 cm

RMSE = Root Mean Square Error, MAE = Mean Absolute Error

Selected studies indicate that these systems allow us to obtain accuracy at several centimetres, as is the case of the coast study (Lin *et al*., 2019) and the indoor study (Tucci *et al*., 2018). The best results were obtained with the FARO Focus 3D X330, according to the publication in 2015 (Kaijaluoto, 2015). On the other hand, the worst accuracy at several dozen and several centimetres was obtained with the KAARTA Stencil 2, both tests carried out in 2020 (Chiappini *et al*., 2020; Di Stefano *et al*., 2020). Survey-grade mobile mapping systems typically have a laser scanner, cameras, a suitable positioning system, and various additional systems. However, one should be aware that, as it was said by Sairam *et al.* (2016), it is expected from mobile mapping systems, especially commercial ones, to provide an average absolute accuracy of 0.5 m.

Typical MMS platforms incorporate sensor suites for positioning and georeferencing, such as light detection and ranging (LiDAR) and/or high-resolution cameras, as their principal sensors to collect data for objects and areas of interest. Inertial measurement unit (IMU) with global navigation satellite system (GNSS). An important aspect to consider when transitioning from traditional surveying methods to mobile mapping technology is the high initial cost of the system. Several approaches describe the development of low-cost mobile mapping systems with laser scanners and cameras. GNSS is especially important for portable MMS. The choice of a dual-frequency receiver would seem to run counter to the design goals of a less expensive system. However, due to the relatively low accuracy of the orientation sensors in backpack MMS, the GNSS position is critical to controlling the orientation of the photogrammetric network as measured from the images taken by the system. The precise GNSS position is crucial in controlling the accuracy and precision of the data collected by a backpack MMS. This system usually includes sensors like cameras, LiDAR, and GNSS receivers that work together to capture high-quality images and point clouds for creating accurate 3D models and maps. By determining the position and orientation of the backpack MMS as it moves through the environment, the GNSS receiver enables the data collected to be accurately geo-referenced and aligned. If the GNSS position data is missing, the accuracy and precision of the collected data can be compromised, leading to misalignment and errors in the resulting 3D maps and models. Therefore, the GNSS position plays a crucial role in controlling the accuracy of the backpack MMS. Thus, the increased cost of the dual-frequency receiver is justified by its greatly improved accuracy and reliability. You can also consider that the accuracy of the positioning components required for mobile mapping systems is much lower than the accuracy of airborne LiDAR. It is important to note that the accuracy of theoretical models, determined through empirical means, may not always translate to the final accuracy of data. Factors such as weather conditions, characteristics of the scanned area, and methodology for data processing can all impact the final accuracy of the data. Pilarska *et al.* (2016) found that IMU units were the most important component of errors for scanning systems used with UAVs. However, these units do not need to be as accurate as INS systems for airborne laser scanning, as the lower flight altitude of UAVs means that the impact of angular measurement errors is lower. The horizontal accuracy of the data is most affected by the yaw angle, while the pitch angle has a negligible influence in comparison to other factors. The IMU solutions used in UAVs should be light, and their measurement accuracy can be 5-10 times lower for roll and pitch angles and up to 15 times as low for yaw than the IMU accuracy used in ALS (Pilarska *et al.*, 2016). Therefore, choosing a less accurate GNSS-IMU system can reduce overall costs.

Considering the burden of labour costs associated with traditional field surveys, using a mobile mapping system with map-level accuracy while keeping initial costs low is the best way to go. The main challenge of using mobile mapping systems is the time and effort required to process the vast amount of data and digitize individual features. However, improvements in data management and automated feature extraction technologies can solve these problems. Mobile mapping systems are a quantum leap forward from traditional surveying methods and are attracting attention as a new mapping technology because of their high accuracy. What is more, Mobile Mapping Systems are commonly used in BIM technology which is one of the most established technologies in architecture, engineering and construction. BIM provides a comprehensive digital database of assets (e.g. 3D models of buildings and everything connected with cities) throughout the project lifecycle. However, the large amount of data to be collected and the lack of automated processes made this task difficult and led to an increase in time and cost. Today, MMS is widely used in BIM projects due to its high accuracy, time efficiency and low cost. The collected point clouds and images are used to create a 3D reconstruction model, which is then processed under segmentation or semantic classification to extract detailed information about all the elements of the asset. The final output is then transferred to BIM software to extract and simulate key information relevant to the project life cycle. In general, MMS can provide reasonably accurate results for BIM-derived products. These derived products can be 2D drawings, 3D meshes or many more representing the life cycle and construction process of building structures. A common example of MMS in BIM is 3D urban modelling, where MMS can extract information about buildings along a street (Janakkola *et al.*, 2010; Barba *et al.*, 2021*)* and extract structural building information (Malinverni *et al.*, 2018]. In addition, MMS can be used to design and maintain records of 3D assets indoors and for building layouts that can be created using handheld backpacks (Di Stefano *et al*., 2021).

3. REVIEW OF COMMERCIAL MAPPING SYSTEMS

The trend in the development of MMS is driven by the need for fast and economical data acquisition. Commercial MMS are categorized by platforms: handheld, wearable (James et al., 2014), carted, and vehicular. The platforms have been developed to meet the growing demand for up-to-date and accurate urban GIS. Due to the high costs (IMU, sensors, etc.) and the complexity of the systems based on vans, other solutions have been developed, such as the MMS backpacks. These types of solutions compete both in terms of accuracy and cost (Patrucco *et al*., 2019). Platforms can also be divided into those that work indoors and do not require GNSS, and those that can work both indoors and outdoors.

The table cumulates commercial MMS systems available on the market, limited to handheld and wearable platforms. The table shows their capabilities and introduction dates showing the developing trends. The table showcases various aspects of system specifications, which, according to the market analysis, have been noticed to change, improve, etc. Additionally, attention has been given to the elements that manufacturers prioritize while promoting new products. These are factors such as product weight, camera and scanner capabilities and their presence, the presence of GPS, IMU and real-time options, the temperature range in which the system can operate, as well as operating time.

The MMS has been arranged in terms of production date, thanks to which you can see how technologies have developed. Since 2018, the temperature range in which the system can operate has been increased. The popularity of the Velodyne scanner is also visible, which has been used in almost all scanners since 2018. In the case of scanners, there is a trend of higher scanner speeds, reaching up to 640,000 points per second. In the beginning, the camera was only an option; in later years, you could get up to 5 cameras in the system.

Table 2 Selected available hand-held MMS systems.

MMS system	Year of intorduction	Weight [kg]	Lidar (Range, Speed)	Camera	GPS/IMU	Real-time	Operating temperature [celcius degrees]	Operating time
Lidaretto Lidaretto UAS Lidar System	2015	1.2	hesai xt32 / xt32m2x Up to 300m, 360º x 360º 640000 points/s	Is an option	yes	no	0 – 50	ND
ZeissT-SCAN	2016	1.1	T-Scan 1.5m –7.5m 210 000 points/s	no	ND	no	ND	ND
GeoSLAM Zeb Revo RT	2017	2.45	0,5m – 30m 360º x 270º 43 000 points/s	Is an option	no/yes	yes	0 – 50	1,5h
GeoSLAM Zeb Horizon	2018	1.3	Velodyne Puck 0.5m – 100m, 360º x 270º 300 000 points/s	Is an option	no/yes	no	0 – 50	1,5h
ScanViz SV-32.200	2018	1.4	Velodin (or Oster) Up to 200m, 360º x 360º 1200000 points/s	Is an option	yes	no	-10 - 40	10h
Leica BLK2GO	2019	0.78	0.5m – 25m, 360º x 270º 420000 points/s	4 cameras 300◦ × 150◦ FoV	no	no	0 – 40	45-50min (1 battery)
Gexel HERON LITE Color	2019	1.9	Velodyne Puck LITE 0.4m – 100m, 360º x 360º 300000 points/s	4 lenses 360◦ × 360◦ FoV	no	yes	-15 – 60	6/8h

GeoSLAM Zeb GO	2020	2.65	0.5m – 30m 360º x 270º 43 000 points/s	Is an option	no/yes	no	0 – 50	1,5h
Kaarta Stencil Pro	2020	3.4	Velodyne ultra puck VLP-32c 1m – 200m 600000 points/s	5 cameras	yes	no	-10 - 45	ND
ZZCOMM technology Cybermap	2021	1.6	Up to 80m, 360º x 270º 600000 points/s	no	no	yes	ND	ND
Exyn Technologies ExynPak	2022	3.15	Up to 100m 360º x 360º 600000 points/s	2 cameras FLIR Chameleon3	no	yes	-20 - 45	3h
Emesent Hovermap ST-X	2022	1.57	0.5m – 300m, 360º x 290º 640000 points/s	no	no	yes	-10 - 45	4h
FJDynamics Trion S1	2022	1.8	Trion S1 3D LiDAR scanner Up to 120m, 360º x 270º 320000 points/s	2 cameras	yes	yes	ND	4h
Tersus GNSS Tersus Metaverse Painter	2023	1.17	Hesai (VELODYNE VLP / QUANERGY / RIEGL / OUSTER / Livox) 0.05m – 120m, 31º x 360º 1280000 (dual returns)	Is an option	yes	no	-20 – 65	ND

Tab. 3 Selected conventional MMS systems

Company	NAME	Year of Introduction	Weight [kg]	Integrated Camera	GNSS	IMU	Real-time	Range [m]	Max, Measurement Rate [pts/sec]	Field of View
Leica	RTC360	2018	6	Yes	Yes	Yes	Yes	0.5-130	2000000	360° x 300°
	MS60	2020	7.7	Yes	Optional	Optional	Yes	1.7-1000	30000	360° x 270°
	RTC360 LT	2019	5.9	Yes	Yes	Yes	Yes	0.5-130	1000000	360° x 300°
	ScanStation P30	2015	12.65	Optional	Optional	Optional	Yes	0.4-120	1000000	360° x 290°
	BLK360	2017	1	Yes	Yes	Yes	Yes	0.4-60	360000	360° x 300°
	ScanStation P40	2015	12.7	Yes	Yes	Yes	Yes	0.4-270	1000000	360° x 290°
	ScanStation P50	2017	12.7	Yes	Yes	Yes	Yes	0.4-1000	1000000	360° x 290°
Riegl	VZ-200	2018	9.4	Optional	Optional	Optional	Yes	1.5-750	550000	360° x 110°

	Riegl VZ-2000i	2017	9.8	Yes	Yes	Yes	Yes	1.00-2500	500000	360° x 100°
	Riegl VZ-400i	2015	9.7	Yes	Yes	Yes	Yes	0.5-800	500000	360° x 100°
Faro	Focus S150	2018	4.2	Yes	Yes	Yes	Yes	150	976000	360° x 270°
	Focus M70	2016	4.2	Optional	Yes	Yes	Yes	0.6-70	500000	360° x 300°
	Freestyle 2	2015	1.5	Yes	No	No	Yes	0.6 - 0.8	88000	320° x 80°
	Focus S350	2018	5.2	Yes	Yes	Yes	Yes	350	976000	360° x 270°
Topcon	GTL-1000	2019	7.2	Yes	Yes	Yes	Yes	0.6-70	100000	360° x 320°
Trimble	TX6	2016	11.2	Yes	Yes	Yes	Yes	0.6-80	500000	360° x 317°
	X7	2020	5.8	Yes	Yes	Yes	Yes	0.6-80	500000	360° x 282°
	SX12	2021	8	Yes	Yes	Yes	Yes	1.0-600	26600	360° x 300°
	TX8	2016	11	Optional	Yes	Yes	Yes	1.0-340	1000000	360° x 317°
	Trimble SX10	2016	12.7	Yes	Yes	Yes	Yes	600	26600	360° x 270°
Z + F	IMAGER 5010	2010	9.8	Yes	Yes	Yes	Yes	0.3-187.3	1016027	360° x 320°
	IMAGER 5016	2016	7.5	Yes	Yes	Yes	Yes	0.3-365	1097000	360° x 320°
	IMAGER 5006EX	2014	30.6	Optional	Yes	Yes	Yes	0.4-79	508000	360° x 310°

	IMAGER 5010C	2013	9.8	Yes	Yes	Yes	Yes	0.3-187.4	1016027	360° x 320°
Carlson Software	FiX1	2020	12.5	Optional	Yes	Yes	Yes	0.5-250	15000	360° x 200°
	Scan750	2020	11.2	Optional	Yes	Yes	Yes	1.5-750	500000	120° x 300°
	Scan2K	2020	11.2	Optional	Yes	Yes	Yes	1.5-2000	500000	120° x 300°
GeoMax	SPS Zoom 300	2017	3.9	Optional	Yes	Yes	Yes	2.5-300	40000	360° x 320°
Basis Software	Surphaser Model 75 (USR)	2018	4.9	Optional	Optional	Optional	Yes	0.25-2.5	ND	360° x 270°
	Surphaser Model IR_100 HQ	2015	7.4	Optional	Optional	Optional	Yes	1.0-35.0	1200000	360° x 270°
	Surphaser Model IR_100 HS	2015	7.4	Optional	Optional	Optional	Yes	1.0-50.0	1200000	360° x 270°
	Surphaser Model IR_400 HP	2017	7.7	Optional	Optional	Optional	Yes	1.0-110.0	832000	360° x 270°
	Surphaser Model IR_400 HQ	2017	7.8	Optional	Optional	Optional	Yes	1.0-140.0	832000	360° x 270°
	Surphaser Model SR_100	2015	11	Optional	Optional	Optional	Yes	1.0-7.0	1200000	360° x 270°
	Surphaser Model 10	2016	5	Optional	Optional	Optional	Yes	1-50/110	208000	360° x 270°

Table 4 A collection of photos of selected stationary MMS systems.

LEICA						
RTC360	MS360	RTC360 LT	ScanStation P30	BLK360	ScanStation P40	ScanStation P50
						

RIEGL		
VZ-200	VZ-2000i	VZ-400i
		

FARO			
Focus S150	Focus M70	Freestyle 2	Focus S350
			

TOPCON
GTL-1000

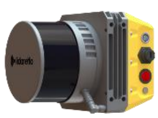

TRIMBLE				
Trimble TX6	Trimble X7	Trimble SX12	Trimble TX8	Trimble SX10
				

Z+F			
IMAGER 5010	IMAGER 5016	IMAGER 5006EX	IMAGER 5010C
			

CARLSON		
Software FiX1	Software FiX1	Software Scan2K
		

GEOMAX
Scan2K


Table 5. A collection of photos of selected handheld MMS systems.

Lidaretto Lidaretto UAS Lidar System	ScanViz SV-32.200	Leica BLK2GO	Gexel HERON LITE Color	Kaarta Stencil Pro
				

ZZCOMM technology Cybermap	Exyn Technologie s ExynPak	Emesent Hovermap ST-X	FJDynamics Trion S1	Tersus GNSS Tersus Metaverse Painter
				

Zeiss T-SCAN	GeoSLAM Zeb GO	GeoSLAM Zeb Horizon	GeoSLAM Zeb Revo RT
			

Over the years, there has been a noticeable reduction in operation time and an expansion of the operating temperature range. Companies are also very flexible in terms of their choice of scanner, camera and various tools. In order not to limit the capabilities of the platforms, both IMU, GNSS, SLAM are added so that they can work both outdoors and indoors (El-Sheimy, 2005). The real-time solution is becoming increasingly important in many applications. Real-time georeferencing is possible, but the application may lose track of GNSS satellites and georeferencing accuracy will be worse, so it is not recommended. The real-time component is also often used for quality control. You can then decide whether the accuracy of the data is satisfactory. In many applications, such as forest firefighting, require real-time mapping, accuracy is not the most important thing (El-Sheimy, 2005).

An important step in choosing the right MMS system is also the analysis of Lidar scanners that companies have at their disposal. Manufacturers are flexible and give you an opportunity to choose a scanner according to your preferences, as in the case of Tersus Metaverse Painter. When choosing a scanner, it is worth considering what range is interesting for you, because, for example, in rooms, long range may be unnecessary. Then you can also save money, because it is also correlated with the working range (Elhashash *et al*, 2022). In some cases, companies also offer a possibility of optionally adding a camera to the system

(Tersus Metaverse Painter, ScanViz SV-32.200, Lidaretto UAS Lidar System). This is important because the hybrid operation of the scanner and camera is more effective. Scanners are used for obstacle detection and tracking and cameras for semantic interpretation scenes. However, their disadvantages are: in the case of LiDAR sensitivity to rain and in the case of cameras the inability to operate in poor lighting conditions. Using both visual and LiDAR sensors can reduce local uncertainty and then allow limiting global drift (Debeunne & Vivet, 2020).

4. CONCLUSIONS AND FUTURE TRENDS

This text provides an overview of the development and current state of digital mobile mapping, which combines digital imaging with geo-referencing. It highlights the rapid growth of this field from academic research to a commercially viable industry. A total of 46 papers and articles by other researchers were analysed, aiding in gaining a comprehensive understanding of the market landscape. The article reviews handheld and desktop scanners, categorizing them based on their platforms, and discusses their parameters.

The introduction emphasizes the significant impact of mobile mapping systems on geospatial technologies, enabling the measurement, visualization, analysis, and collection of data in various environments. The advancements in photogrammetry, computer vision, and robotics have contributed to the progress of mobile mapping technology. The availability of low-cost survey sensors with diverse specifications has further enhanced the applications and systems, making mobile mapping more flexible and cost-effective.

The article acknowledges the lack of a single widely adopted mobile mapping system, as the industry employs various sensor suites at different integration levels. Previous research has primarily focused on comparing devices or targeted systems for specific application scenarios. However, this study aims to present a comprehensive meta-review of the sensor suites and associated mobile mapping systems.

The text also highlights the advantages of mobile mapping systems over traditional geodetic systems and aerial mapping. It discusses the types of applications, including urban spaces, environmental monitoring, and cultural heritage documentation, where mobile mapping systems are used. The expected accuracy of these systems varies depending on the application and platform.

The article presents a selection of studies that demonstrate the accuracy achieved by scientists using mobile mapping systems. The systems incorporate sensors such as LiDAR, cameras, and GNSS receivers for positioning and georeferencing. The choice of sensors and technologies affects the accuracy and precision of the data collected. It notes the importance of GNSS position data in controlling the accuracy and alignment of the collected data. When analysing the specifications of mobile mapping systems, various possibilities were encountered. Both the integration of lidar and cameras enhances data acquisition capabilities, and limiting one type of data acquisition - either lidar or cameras - optimizes the data collection process. Both types of ingested data have satisfactory results depending on your needs. The companies outdid each other in the possibilities of connecting the systems to various mobile mechanisms. It turns out that you don't have to limit yourself to a car, but you can create a platform that can be installed on a car, walker, backpack or drone. There are also wide possibilities of adaptation of platforms in difficult conditions - temperature, water, dust, sand, tunnels and forests are not obstacles for modern MMS. What is most important for manufacturers is also the lightness of their platforms, if only for the purpose of easily wearing them.

Recent years have witnessed a remarkable surge in the advancement of laser scanning technologies, and the accompanying trends and innovations have exerted profound influences across diverse domains.

Foremost, a pronounced democratization of laser scanners has taken place, wherein these devices have garnered popularity among both large-scale enterprises and small-scale surveying firms. Mobile and airborne laser scanners have gained increasing traction, thereby fostering broader accessibility among a wider spectrum of users.

A salient trend pertains to the refinement of mobile and airborne scanning platforms. Manufacturers are diligently focused on introducing novel models characterized by an assortment of features and parameters. Laser scanners are progressively evolving into more sophisticated instruments, incorporating accelerated measurement speeds, superior resolutions, extended ranges, and heightened levels of precision. Notably, mobile scanners based on Simultaneous Localization and Mapping (SLAM) algorithms are surging in popularity due to their ability to facilitate swift measurements of indoor building environments. Although these scanners may entail a slight trade-off in measurement accuracy, their unparalleled time efficiency endows them with distinct advantages. It is also noteworthy to highlight that terrestrial laser scanners have attained a certain degree of maturity. While they continue to be utilized in scenarios that require exceptional accuracy and meticulous measurements, the developmental trajectory of lidar and cameras has experienced a moderation in recent years. Manufacturers primarily focus on incremental enhancements and fine-tuning to maintain the elevated quality and reliability of these devices.

An intriguing trajectory involves the integration of laser scanners with complementary technologies. Scanners are increasingly employed in conjunction with autonomous robots and different vehicles amplifying their versatility and expanding their scope of applications. This symbiotic relationship empowers scanners to operate in diverse conditions and undertake tasks that were previously arduous to accomplish.

Significant progress has been witnessed in the domain of airborne scanners. The surge in demand for airborne laser scanners has been propelled by the proliferation of drones. The advent of more cost-effective models has enhanced accessibility for a broader user base, concurrently stimulating the development of more advanced scanners boasting superior parameters. Airborne scanners play a pivotal role in diverse realms, including photogrammetry, terrain mapping, and environmental monitoring.

In conclusion, the developmental trends in laser scanning encompass the democratization of technology, advancements in mobile and airborne platforms, the consolidation of terrestrial scanners, integration with complementary technologies, and the evolution of airborne scanning systems. The evolution of these trends is expected to endure, engendering further possibilities and innovations within the realm of laser scanning.

Future trends in technology related to mobile mapping systems may include advancements in sensor technologies, such as improved LiDAR scanners and high-resolution cameras. There may be developments in positioning systems to enhance accuracy and reliability, including the use of advanced GPS receivers and inertial measurement units (IMUs). Additionally, there may be advancements in data processing techniques to improve the efficiency and accuracy of mapping workflows. Integration with other emerging technologies like artificial intelligence and machine learning could further enhance the capabilities and applications of mobile mapping systems.

Overall, the future of mobile mapping technology is likely to involve continuous innovation and refinement of hardware, software, and data processing techniques, leading to more accurate, efficient, and versatile mobile mapping systems.

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W KIERUNKU ROZWOJU MOBILNYCH SYSTEMÓW KARTOWANIA

SŁOWA KLUCZOWE: MMT, MLS, przegląd, kartowanie, SLAM, LiDAR, skaner ręczny

STRESZCZENIE: Kartowanie mobilne jako technologia łącząca obrazowanie cyfrowe z bezpośrednią georeferencją, szybko się rozwinęła. Niniejszy artykuł zawiera przegląd rozwoju i opis stanu obecnego mobilnego kartowania cyfrowego, ukazując szybki rozwój tej dziedziny od badań akademickich po komercyjne zastosowania w branży. Analiza cytowanych prac przyczynia się do kompleksowego zrozumienia rynku. W artykule omówiono skanery mobilne i ręczne. We wstępie podkreślono znaczący wpływ mobilnych systemów kartowania na technologie geoprzestrzenne, możliwy dzięki postępom w fotogrametrii, widzeniu maszynowym i robotyce. Niskobudżetowe sensory pomiarowe o różnorodnych specyfikacjach jeszcze bardziej ulepszyły systemy i ich zastosowania, sprawiając, że mobilne mapowanie jest bardziej wszechstronne i opłacalne. W artykule wskazano, że nie ma jednego powszechnie przyjętego standardu dla systemu kartowania mobilnego. Tekst ma na celu przedstawienie kompleksowego przeglądu zestawów czujników i powiązanych systemów kartowania mobilnego. W artykule przedstawiono badania pokazujące dokładność osiąganą przez naukowców korzystających z mobilnych systemów kartowania, podkreślając rolę sensorów takich jak LiDAR, kamery i odbiorniki GNSS. Analiza specyfikacji mobilnych systemów kartowania ujawnia różnorodne możliwości, w tym integrację LiDAR i kamer lub ograniczenie do jednego rodzaju akwizycji danych. Producenci skupili się na poprawie łączności platformy z różnymi mechanizmami mobilnymi, zwiększając możliwości adaptacji w trudnych warunkach. Artykuł kończy się prezentacją przyszłych trendów, podkreślając demokratyzację skanerów laserowych, udoskonalenie mobilnych i powietrznych platform skanujących, obecność naziemnych skanerów laserowych, integrację z technologiami uzupełniającymi oraz postęp w rozwoju systemów skanowania lotniczego. Przewiduje postęp w technologiach sensorów, systemach pozycjonowania, technikach przetwarzania danych i integracji z nowymi technologiami, takimi jak sztuczna inteligencja i uczenie maszynowe. Przyszłość technologii kartowania mobilnego wiąże się z ciągłymi innowacjami i udoskonaleniami w celu tworzenia dokładniejszych, wydajniejszych i bardziej wszechstronnych systemów. To, co kiedyś było tematem badań akademickich, stało się komercyjnie opłacalną branżą.

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Submitted 01.12.2023
Accepted 31.12.2023