ADAPTIVE DIGITALIZATION METHODS AND DIGITAL TRANSFORMATION TRENDS FOR SECURITY

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Abstract: The aim of this paper is to present advanced digitalization technologies that are applicable to the purposes of security, as well as to highlight the issues related to the importance of the ensuring security of the digitalization processes themselves. The author proposes an adaptive method of digital transformation based on a comparative analysis.

Key words: digitalization, security, 3D scanning, photogrammetry software, triangulation.

1. INTRODUCTION

Transformations of information from analogue to digital form by specialized devices help to perform the main activities related to information such as processing, storage and transmission, but require an environment with a high level of security to carry out these processes. Professional use require however objectivity and repeatability of digitization process. Some systems, used for automatic 3D models obtaining were developed to be universal, allowing to digitize objects of various shape [1], contributing to the security.

The main advantage of using 3D digitalization is a secure storage of the information about the parameters that characterize a physical object (shape, size, location, surface area) obtained by using 3D scanners and scanning facilities. Practically, these objects can be any assets from the critical infrastructure such as artifacts from the national cultural-historical heritage.

Besides, 3D digitization is widely used in tests of product quality, allowing a comparative characteristic of machine-made products and their relevant 3D models. Another practical application in manufacturing is related to the creation of 3D models of machine elements when the technical design is no longer available. In this way, 3D modeled details can be improved in a virtual environment in terms of design, construction and functionality. After this process their prototypes can be 3D printed and tested before serial machine production.

3D laser scanning is the most advanced method that:

- *provides accurate, reliable and comprehensive digital information that is available for sharing by the stage of design to stage of production and installation.*
- *reduces the study time, potential risks and investment costs;*
- *allows remote measurements* [2].

In a narrow sense the digitalization strategy is based on automation and integration by innovative software and hardware solutions, as well as through improving computer networks and actualization of protocols, standards and policies related to them. A specific example related to security is an update that enables Transport Layer Security (TLS 1.1, TLS 1.2, TLS 1.3) as default secure protocols in WinHTTP in Windows [3]. The TLS protocol ensures confidentiality, integrity and availability according to the methodology known as CIA triad and prevents eavesdropping and unwanted modification of messages.

Security of data at rest (e.g. an application database) is very important especially when we consider applications that are said to provide a high level of messages confidentiality and privacy. The simplest way to secure data at rest is to store them in an encrypted form [4].

Today, there is an increase in attacks aimed at the manufacturing sector, in particular at industrial control systems (ICS). This area is the least protected today from external threats [5].

On the other hand digitalization can transform the security area strengthening its most important sector – cybersecurity. The cyber space is based on remote access to resources in information environments (IE) which must organize the information service, including registration module and collection of users' personal data (PD) in own database. The cloud proposes a common virtual space for many customers (multitenancy) and summarization of the possible security problems. Therefore the main security threats in the cloud environments relate to the multi-tenancy [6].

In such cases the potential risk must be reduced by using specialized technologies, new business methods, creative concepts and especially expert knowledge. Expert systems are based on knowledge AI (Artificial Intelligence) systems that:

- ***use digital information***

AI and Machine Learning (ML) together are the most effective tool for data analytics. Actually, while AI can be described more like a concept, ML is a real means of generating responses using data. Deep Learning (DL) is a more advanced variant of ML, because is based on artificial neural networks, which are characterized by complexity and multilayeredness. The individual layers correspond to a certain aspect of the analyzed image.

- ***can manage the digitalization process***

The most innovative 3D scanners with AI represent real-time intelligent detectors equipped with an image system that shows the main parameters (shape, depth, sizes) of pieces of metal and cavities. An artificial neuron network allows the use of adaptive learning algorithms to provide superior form of extraction and depth indications. The advanced device is able to recognize the following targets: treasures and relics; cash and coins; soil anomalies; cavities and tunnels [7].

Advanced digitalization methods, 3D scanners for professional usage and other specialized equipment for 3D scanning are analyzed in Section 2 in order to highlight the advantages of the experimental method proposed by the author in Section 3.

2. COMPARATIVE ANALYSIS OF METHODS AND FACILITIES FOR 3D SCANNING

The comparative analysis of selected digitalization technologies is based on an expert assessment according to the main criteria of complexity, accessibility and investment cost. The criteria weights for decision making are conditionally accepted by the author as follows: 1 – low level, 2 – middle level and 3 – high level.

The results of this research are presented in *Table 1* that consists only of conventional 3D scanning methods, as follows:

- ***LiDAR (Light Detection and Ranging)*** **-** also known as ALS (Airborne Laser Scanning) or time of flight (ToF) is a high remote sensing technology that detects objects and maps their distances. Therefore this method is applicable for the purposes of mapping, monitoring and assessment, including accurate registration of spatially distributed data. The complex functionality of a LiDAR system is due to the set of important devices and additional facilities:

- *laser device* - emits pulses (or beams) of light to determine the range to a distant target. The technology works by illuminating a target with an optical pulse and measuring the characteristics of the reflected return signal. The width of the optical pulse can range from a few nanoseconds to several microseconds.

- *entire functional subsystem* – includes the signal chain, power, interface, clocking and monitor/diagnostics subsystem. The main subsystems of the LIDAR signal chain comprise a transmitting system (T_x), a receiving system (R_x) and a custom digital-processing system to extract point-cloud information. The computer interface manages communication among devices and data storage [8].

- *INS (Inertial Navigation System)* – its main component represents *IMU (Inertial Navigational Measurement Unit)* which mechanism is composed of three orthogonal gyros and three orthogonal accelerometers. A full range IMU will measure movement about six degrees of freedom including the three rotational moments M (pitch (M_y), roll (M_x), and yaw (M_z)) and the three translational moments F (heave (F_z), surge (F_x), and sway (F_y)) [9].

- *aiding device* - GPS (Global Positioning System) is used to record the three-dimensional position of the aircraft.

- ***UAS (Unmanned Aircraft System) –*** a geospatial technology for taking images which are commonly georeferenced. It uses ground control points (GCPs), overlaying Landsat satellite data, or a combination of the two. These images can be stitched together using various photogrammetric software packages. The main components of such a system are:

- *GNSS (Global Navigation Satellite System) receiver* – communicates with the satellites. A few common GNSS systems include: GPS from the United States, GLONASS (Global Navigation Satellite System) from Russia, Galileo from the European Union, and BeiDou from China.

- *on-board computer or a GCS (Ground Control Station)* - for processing the data from the sensors [10].

- ***Markscheider scanning -*** the term originates from German „markscheider" (*marke* - "border" and *scheiden* - "divide, cut off") and it can be literally translated as "defining borders". This technology is applicable for capturing inaccessible surfaces in order to ensure safety. Therefore, the measurements are performed using non-contact and non-reflective measurement technologies and are realized on the base of a point with known coordinates to a point for which the computational data are known, but its directly measuring is not possible [11].

- ***Mobile 3D Laser scanning -*** the experiment described in ***Section 3*** is based on Moedls (Mobile 3D Laser Scanner) [12] and realized by accessible conventional components.

Actually, the number of points in the 3D point cloud (a group of points outlining the surface of an object) and respectively the resolution of the resultant 3D model (R_M) depend on the resolution of photos (R_F) taken from all sides, as well as their number N.

The higher complexity of the proposed method compared to Moedls is determined by the need for a proper selection of the individual components of the hardware complex to achieve compatibility between them in view of satisfactory results. It is possible to use open source software products, which leads to an important advantage in terms of investment costs.

Besides, there are other categories of professional scanning methods like NCI (Nanophotonic Coherent Imager), CLSM (Confocal Laser Scanning Microscopy), NMR (Nuclear Magnetic Resonance) and CT scan (Computed Tomography Scan), which require additional tests that can only be performed in specialized scientific laboratories. Therefore, the described advanced scanning methods are selected by the author to be considered in detail due to their wide applicability and non-medical focus.

Table 1 includes an assessment of the main 3D scanning methods based on the three optimal criteria:

- *complexity* – it can be assessed by the following function:

$$I_p = \sum(af)/AF \qquad (1)$$

where $\mathbf{I_p}$ is the importance index, **a** - the weighting, f - frequency of possible weighting, **F** - total number of respondents. Some of the main factors of complexity are inherent complexity, uncertainty, number of technologies, rigidly of sequence, etc. They can be identified during interviews and each of them is scored on a Likert scale from 1 to 10 according to its effect [13].

- *accessibility* – this criterion can be defined on the base of the following principles: ease of providing, ease of operation, usability, comprehensibility and sustainability.

- *investment cost*.

Table 1. An assessment of 3D scanning methods.

	Complexity	*Accessibility*	*Investment cost*
LiDAR	*3*	*1*	*3*
UAS	*3*	*2*	*2*
Markscheider Scanning	*3*	*1*	*2*
Mobile 3D Laser scanning	*3*	*3*	*1*

In this study, the complexity factor chosen by the author is only a number of technologies used in each 3D scanning method. Therefore, calculations are not necessary, because the aim of the current study is the use of an alternative variant to avoid group surveys. This is required because of the potential application of these 3D scanning methods in educational organizations which consist of categories of representatives with different levels of competence.

Actually, it is made an expert assumption that if the number of technologies for realization of each 3D scanning method presented is three or more, the complexity is high (3), as well as if the number of technologies is 1 or 2 the complexity is respectively low (1) and middle (2).

The analysis of the accessibility cannot be unambiguous, because of the relativity of its characteristics and how they change under the impact of different external factors. For example, the ease of operation and comprehensibility depend on the individual abilities of consumers. Sustainability can be ensured by high quality physical protection and can be proven by vulnerability detection tests. Therefore, the author evaluates the accessibility on the base of ease of providing and usability. In terms of applications for educational purposes the mobile 3D Laser Scanning has maximum accessibility (3) unlike LiDAR from aboard an airplane and Markscheider Scanning that needs additional equipment. The level of accessibility of UAS is middle (2), because of the great variety of data processing software.

Table 2 represents a sample classification of 3D scanners for different applications as the criteria weights for decision making are the same like those applied in *Table 1*. In this case the analysis is made on the base of three optimal criteria as following:

- *resolution* - while the minimum scanning resolution is 640x480 dpi, 1920 x 1080 dpi is considered high. The high scanning resolution ensures the detail and accuracy of the 3D model and this explains why this criterion is very important for the analysis of 3D scanners and devices.
- *compactness* - the safe transportation of massive and heavy structures requires provision and maintenance of appropriate transportation vehicles.
- *investment cost.*

The conclusion is that the mobile 3D Laser scanning is one of the most optimal methods in terms of the selected main criteria with a view to improving the quality of education.

Table 2. A classification of 3D scanners.

	Resolution	***Compactness***	***Investment cost***
Professional 3D Scanner	*3*	*2*	*3*
Manual 3D Scanner	*1*	*3*	*1*
Mobile 3D scanning devices	*3*	*3*	*1*

3. DIGITAL TRANSFORMATIONS OF PHOTOS INTO 3D MODELS USING PHOTOGRAMMETRY SOFTWARE

The proposed method of digital transformation is determined as adaptive because of its two main characteristics:

- ***applicability for various purposes, including education and training –*** this technology reduces the complexity of providing any devices and facilities for aerial photography of large objects using a set of photos taken from all sides.
- ***usage of relatively accessible resources, of which the total cost does not exceed that of a 3D scanner*** - mobile 3D scanning devices like a smart phone or professional photographic camera for taking a set of photos with a high resolution; additional facilities like specialized tripods, an automated rotary table, a green laser; open source photogrammetry software products, etc.

This experiment is realized by using the photogrammetry software VisualSFM [14], which is able to convert multiple photos of a physical object in its 3D model by a calculation of missing matches using embedded triangulation algorithms. The principle of operation of the product is based on simulating different camera poses called Structure from Motion (SFM). The 3D reconstruction is done when all missing matches are calculated and generated in a Task Viewer.

Actually, triangulation represents a measuring of distances by using triangles. There are different classes of triangulation depending on the figures formed by the triangles. The strength of a figure depends on the amount of variations of the sines of the distance angles per unit of change in the angles themselves, multiplied by a factor, peculiar to the figure, which is a function of the number of observed directions and of conditions to be satisfied with the figure. Some examples of permissible figures can be given, as follows:

- ***simple quadrilateral*** – this is the best figure, because combines maximum strength and progress with a minimum of essential geometrical conditions.
- ***four-sided central-point figure with one diagonal*** – when one diagonal of a quadrilateral is obstructed, a central point, which is visible from the four corners can be inserted.
- ***four-sided central-point figure without a diagonal*** **-** the central point in this case should be located near one side line and about midway along it.
- ***three-sided central point figure*** – a simple and very strong figure that is often used to compensate for a great variation of the side lines of adjacent quadrilaterals, and to quickly changes the direction of the scheme.
- ***five-sided figure with four diagonals*** **–** it can be considered as a four-sided central-point figure with one diagonal, in which the central point is outside the figure. It is used to afford a check when either a diagonal or a side line is obstructed.

Area triangulation consists of a scheme expanded by adding triangles in all directions to form a spider web effect [15]. There are different triangulation algorithms which are widely used for solving problems related to the generation of meshes:

- ***Delaunay triangulation (DT)*** - the mesh is a network of discrete cells and can be divided into:

\- *structured* - points are distributed regularly, basic elements of discretization are quadrilaterals in 2D and hexahedra in 3D.

\- *unstructured* – irregularly placed points, such meshed consist in triangles in 2D and tetrahedra or hexahedra without directional structure in 3D. This type of meshes are more flexible for the discretization of complex geometrics [16]. Related to DT, the Voronoi Diagram (VD) of a set of points is defined as follows: Let P be a set of points in an n-dimensional Euclidean space $\boldsymbol{R^n}$. The Voronoi cell of a point $p \in P$, called $V_p(P)$, is the set of points $x \in R^n$ that are closer to p than to any other point in P [17]:

$$V_p(P) = \{x \in R \mid \|x-p\| \leq \|x-q\|,\ q \in P,\ q \neq p\} \quad (2)$$

The union of the Voronoi cells of all points $p \in P$ form the Voronoi diagram of P, noted as VD(P):

$$VD(P) = \cup V_p(P), p \in P \quad (3)$$

- ***Ball-Pivoting allgorithm (BPA) –*** this is an approach for surface reconstruction by finding a triangle mesh that interpolates an unorganized set of points. In sculpting-based methods, a volume tetrahedralization is computed from the data points, typically the 3D DT. Tetrahedra are removed from the convex hull to extract the original shape. Region-growing methods start with a seed triangle, consider a new point and join it to the existing region boundary, and continue until all point have been considered. But while 3DT can be expensive in terms of time and memory required and can lead to numerical instability when dealing with datasets of millions of points, BPS exhibits linear time compexity and robustness on real scanned data.

A pivoting operation starts with a triangle and a ball of radius r, that touches its three vertices. The pivoting is a continuous motion of the ball, during which the ball stays in contact with the two endpoints of the pivoting edge, which lies on the z axis (perpendicular to the page and pointing towards the viewer). The center of the ball describes a circle which lies on the plane perpendicular to the pivoting edge [18].

In the first part of the current experimental research the 3D scanned object is chosen to be in the form of a standard primitive “cylinder” and therefore it can be classified as an ordinary one. The second scanned object represents a kind of a key that can be determined as an object with a higher level of complexity compared to the first one.

Minimum 30 images are required for obtaining a detail and accurate 3D model. Therefore in the current research $N_1 = 30$ for the cylindrical object and $N_2 = 50$ for the second one. The point clouds of the two objects are shown respectively in *Figure 1* and *Figure 2*.

It is visible that while 30 photos are sufficient for the first object to achieve a high density of the point cloud, a similar result for the second one can be obtained only if an average of 50 photos are used for the digital transformation.

The logical conclusion of the result analysis is that the time T for calculating missing matches is an indication for their amount, because when the number of photos N increases from 30 to 50, then T decreases from 40 to 15 s, which means that there are less missing matches. If T_1 and T_2 are the times for calculating missing matches respectively in the first and the second case and $N_2 \geq 30$, then $T_2 < T_1$.

In the figures below are shown the resultant point clouds characterized by a satisfactory density and absolutely the same shapes as the original objects, that is achieved by performing the steps of the proposed algorithm:

- combining separate devices to perform the functions of a 3D scanner;
- taking photos with high resolution of the physical object from all sides at regular intervals;
- selecting a suitable photogrammetric software for digital transformation of photos into a 3D model;
- analysing the similarity of the obtained point cloud and the original object.

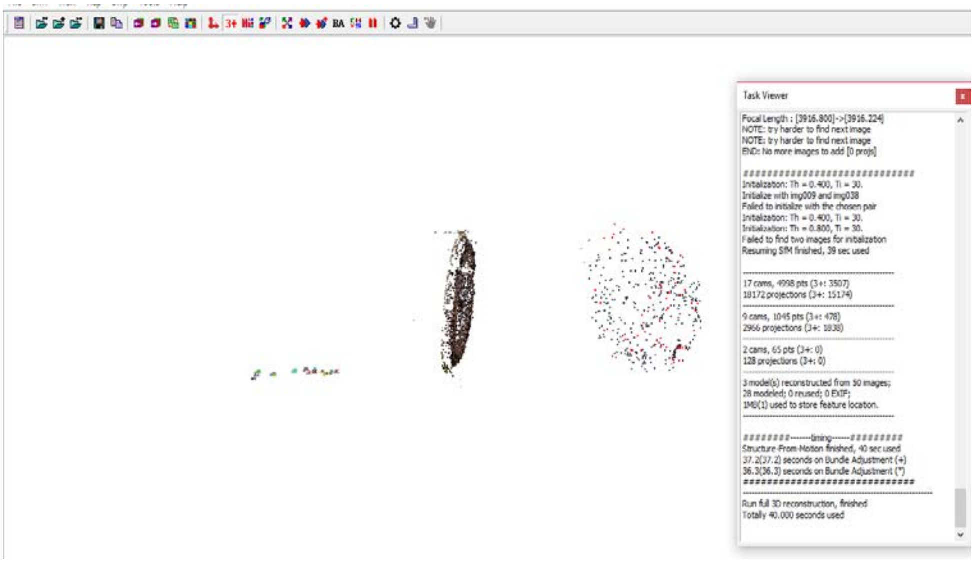

Fig. 1. A point cloud of a cylindrical object obtained in VisualSFM.

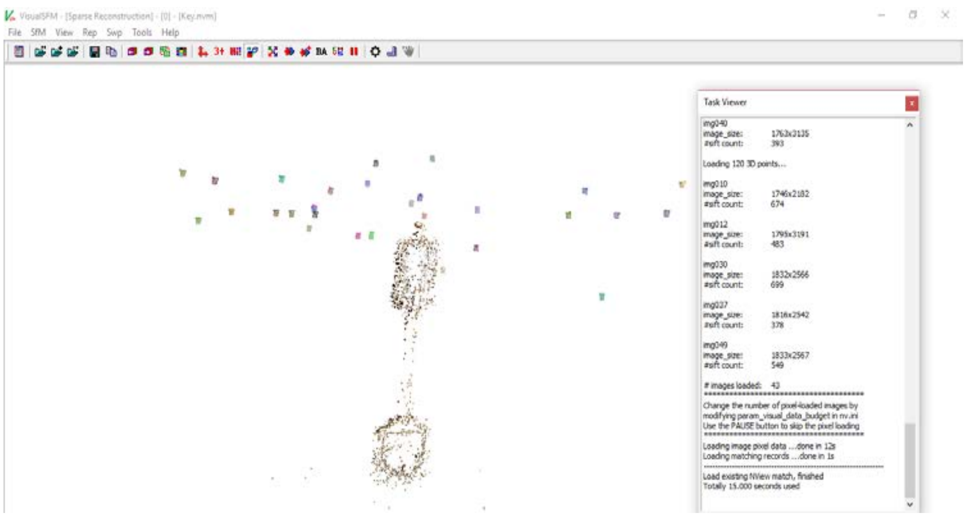

Fig. 2. A point cloud of a key obtained in VisualSFM.

4. CONCLUSION

The main issue related to digitalization is how to provide security of digital transformation, so all potential risks to internal digital processes or products to be predicted and cyber threats via Internet to be prevented. There are advanced integrated solutions that combine deep machine learning, algorithms, analytics to detect threats and respond to them effectively.

Seen from another angle, digital transformations, especially 3D laser scanning are a cost-effective way to improve production processes by performing a reliable quality control in a virtual environment in order to reducing losses due to errors and malfunctioning in the end products. Digitalization technologies, automation of production processes and especially the implementation of AI-systems in management further increase the level of productivity, as well as the quality of products.

Therefore, on the one hand the digital database needs to be secured, but on the other hand digitalization technologies contribute to strengthening the security in various critical infrastructure sectors.

The proposed experimental method represents an alternative to 3D laser scanning realized by combining conventional devices instead of using complex and costly technologies. This circumstance classifies the method as adaptive to learning processes in which the accessibility of technologies is crucial in their choice. Actually this method does not aim to replace the professional 3D scanners, but helps the students to realize experiments in the conditions of e-learning.

For example, the described approach can be used for a technical analysis by a visualization of 3D scanned machine elements in a virtual environment where they could be modified. The current research realized by VisualSFM can be continued in another software for post-processing and editing 3D triangular meshes like MeshLab [19].

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