7th Intercontinental Geoinformation Days

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Investigation of the usability of handheld laser scanners in reverse engineering applications

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Keywords
Reverse Engineering
Handheld Lidar
Prototype

Abstract

Reverse engineering allows for the creation of Computer Aided Design (CAD) models for both new and existing products through surface data capture. CAD is a creative process that utilises computer systems and can be software or hardware based. Typically, CAD data is a software-based tool that is used for design purposes. This process requires computer technology to assist in the creation of technical drawings by incorporating professional concepts. In reverse engineering, prototyping is necessary to quickly fabricate physical parts, assemblies, or models using CAD. Rapid prototyping, a manufacturing technology, enables the creation of physical models directly from 3D CAD drawings. Prototyping enables the design of pre-presentation products before the final product. The aforementioned process involves editing the designed products to create the final product. Therefore, prototyping is a crucial step for ensuring the required quality, accuracy, and precision of the final products in reverse engineering. As such, handheld laser scanners - capable of collecting data at lower densities than their ground-based counterparts - are being evaluated in this field. Although handheld lidar devices are typically preferred for modelling small objects in confined spaces. The study used a handheld lidar device due to its instant and efficient data acquisition, lower cost compared to ground-based lidar, and easy accessibility. Three types of objects were modelled in 3D using handheld laser scanners, which are viewed as an alternative to ground-based laser scanners within the field of reverse engineering. These objects were categorized based on their size, either small, medium, or large scale. For this study, identical models underwent scanning using both a ground-based laser scanner and a handheld laser scanner, followed by a comparative analysis.

1. Introduction

Reverse engineering is the process of obtaining geometric design data of a product in order to replicate or enhance it, in situations where there is no available design information of the original object (Kanun et al., 2021). The need for reverse engineering often arises from prolonged unavailability of an item's component, or from inadequate primary documentation. Furthermore, in situations where the original producer of a product is no longer accessible, but the demand for the product exists, enhancing the favorable features of the product based on its extensive use intensifies the requirement for reverse engineering (Ulvi et al., 2019). The inability or unwillingness of the original manufacturer to provide additional/replacement parts, updating outdated parts or old production processes with current and cheaper technologies are among the most common reasons for the emergence of reverse engineering. In reverse engineering applications, models are commonly measured through traditional methods, drawn digitally and then converted to 3D models However, the accuracy and precision of these models are heavily reliant on the operator and can be time-consuming. To circumvent this issue, rapid prototyping technology has been developed to produce highly realistic products in a shorter timeframe. Rapid prototyping technologies offer solutions to issues encountered in product design and development procedures (Ulvi & Yakar, 2010). By not using rapid prototyping, various steps, including the supply of machines needed to create a prototype of a design, mould manufacturing, and secondary processes, can be expensive and time-consuming. Rapid prototyping technology aims to minimize this problem. Prototyping involves the creation of pre-presentation products to be developed into final products. These

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Cite this study

Doğdu, Y. & Yakar, M. (2023). Investigation of the Usability of Handheld Laser Scanners in Reverse Engineering Applications. Intercontinental Geoinformation Days (IGD), 7, 222-225, Peshawar, Pakistan

products are then refined, culminating in the final product. As such, the prototyping stage is essential to ensure that the final product meets the required standards for reverse engineering in terms of precision, accuracy, and quality. This process can take several days or even weeks when using traditional methods (Kula & Ergen, 2017). During the prototyping phase, generating the desired product via 3D models instead of traditional methods has beneficial outcomes for the project, particularly concerning time efficiency. 3D models produced through the 3D modelling process are frequently used in conjunction with tools that offer a realistic depiction of the product, referred to as 3D rendering. At this point, the Lidar method, which stands out especially in fast and precise data collection, provides a great advantage (Yakar et al., 2015a; 2015b).

LiDAR, an acronym for "Light Detection and Ranging", is a remote sensing technology that employs laser beams to gauge the distance of objects (Çoşkun, 2020). The benefits of LiDAR technology, notably with local laser scanning, lie in its ability to minimize physical touch, promptly digitalize components, provide suitable resolution and accuracy, detect colours, and capture intricate details of the object (Bauwens, 2016). Furthermore, the spatial information in narrow and enclosed areas, which are otherwise inaccessible and challenging to gauge, is made available through the coordinates gathered in the point cloud data structure. Although terrestrial laser scanning has been used for this process for years, it remains a pressing issue today. In this study, a unique handheld laser scanner is used, which is not widely used in this field. Although the handheld laser scanner is not widely used in reverse engineering, if adopted, it could be advantageous in terms of price, cost and time.

2. Method

LiDAR technology, dense point clouds and 3D model production studies are commonly used sources of data (Nex and Remondino, 2012). The edges of the LiDAR model are more advantageous than those produced by photogrammetry when used in reverse engineering, due to the sharp and distinct lines. LiDAR is a popular method of remote sensing for precisely measuring the distance of objects on the earth's surface (Yakar et al. 2010). LiDAR utilizes a pulsed laser for accurately ascertaining the variable distances of an object from the earth's surface, which in turn produces precise 3D information concerning both the earth's surface and the target object (Yakar et al., 2013). The photodetector and optics are other highly important elements central to data collection and analysis (Zeybek, 2019). LiDAR is an extremely beneficial measurement system, providing an exceptionally swift surveying method that can collect substantial point data per second tremendously quickly (Yılmaz and Yakar, 2006). Building interior scans typically require around three minutes, while large-scale measurements can be completed in under an hour- making LiDAR one of the swiftest surveying techniques. In relation to precision, LiDAR systems gather dense data with minimal space between points, resulting in exceedingly accurate outcomes. As for adaptability, there are various alternatives to consider in regards to land surveying with LiDAR. LiDAR systems can be installed on different platforms depending on the application's requirements (Karataş et al. 2022). For small-scale measurements, a fixed tripod may suffice, but aircraft, helicopters, or unmanned aerial vehicles are necessary to gather the data for larger areas. As light is used as the measurement tool, LiDAR data can be collected 24/7. First, LiDAR abbreviation used in this text stands for Light Detection and Ranging. LiDAR systems, in terms of safety, operate at a higher speed than their counterparts and can be controlled from remote locations. This enables their deployment in hazardous locations where extended operator presence may prove risky. LiDAR surveying devices, which have been in use since the 1960s, have transformed into handheld surveying systems. The coordinates in the resulting dense point cloud data structure offer spatial information in areas that are hard to reach and measure, including confined spaces (Nocerino et al., 2017). Handheld LiDAR presents numerous opportunities. It is effortless to operate both outdoors and indoors, lightweight, and handheld, gathering and exhibiting your exact 3D point cloud data in just a few minutes. Thanks to its feature of simultaneous imaging, the scanned or overlooked places in the work area can be viewed, and control can be exercised before completing the scan. Additionally, 3D modelling can be accomplished within minutes (Zeybek, 2021; Özdemir et al., 2022).

The study employed the FARO Freestyle 3D Handheld Laser Scanner. This device boasts high-quality and high-precision features, rapidly and accurately capturing 3D images and generating high-resolution point clouds. It can document rooms, structures, and objects with reliability (Andersson and Hedlund, 2016; Cheng et al., 2018; Rua, 2018; Memduhoğlu et al., 2020). This scanner is a handheld laser scanner that needs to be manually operated and aimed by the user at a maximum distance of 1 meter from the targeted object.

3. Results

In reverse engineering procedures, a product is initially scanned using laser scanning instruments and the resulting data is then sent to a software integrated with the scanning device (Çelebi et al., 2017). The point cloud data captured by the software is later transferred to the computer environment, where they are organised. Finally, the edited point cloud data is used to generate a solid model of the product. If a solid modelled product is to be manufactured, it can be achieved through either rapid prototyping or conventional methods, with reverse engineering processes being necessary. The initial step of this study involves scanning, also termed digitisation, where the model surface is scanned using optical laser scanners. Optical scanning devices are the preferred choice for parts without small holes and fewer surface details, whereas laser scanning devices are more suitable for scanning intricate parts (Yılmaz & Yakar, 2016). A study on the viability of reverse engineering applications in 3D CAD programmes used for design was conducted. Industrially chosen sample components undergo scanning, and the solid model of the point cloud derived from the scan is generated using reverse engineering procedures in design-appropriate software. These applications enable the conversion from a point cloud to a solid model.

The size details of the objects utilized in the research can be found in Table 1. The laser scanning point cloud are presented in Figure 1, alongside the 3D model in Figure 2 and the solid model for reverse engineering in Figure 3.

Through the use of reverse engineering, practical data can be collected to determine detailed and accurate dimensions of parts that may not be available for supply, in development, or currently in production. This information can be directly transferred to the computer environment, allowing for easier analysis and specificity. In addition to the 3D visualization provided by the point cloud, this approach enables designers and technical personnel to extract actual length and measurement values of desired parts from the database. For the reverse engineering study, handheld laser scanners were utilized to scan the selected application objects. Due to the scanner's capacity to record all objects within its 360-degree range, it was discovered that numerous unwanted data were generated. Therefore, purging the 3D point cloud of data contamination was necessary. The importance of cleansing these data cannot be over emphasised, as it ensures simple, high-quality data without contributing to an unnecessary load in file size. The Scene software, a point cloud processing software, was used to conduct this data cleansing.

After discarding excess points, we obtained the point cloud and solid models in ".LAS" format. These models underwent several processing steps in other software. It was established that Geomagic Wrap CAD software's module can be used for reverse engineering operations on scan data of industrial parts obtained via laser scanning devices, also in ".LAS" format. The study showed that CAD data of the parts could be created without difficulty, albeit with minor details (Figure 3).

Table 1. Object dimensions

Scale	Width (cm)	Length (cm)	Height (cm)
Small	0.30	0.20	0.40
Medium	0.40	0.30	0.60
Large	0.60	0.40	1.70

Figure 1. Point cloud of objects on a small, medium, and large scale from left to right.

Figure 2. 3D model of objects on a small, medium, and large scale from left to right.

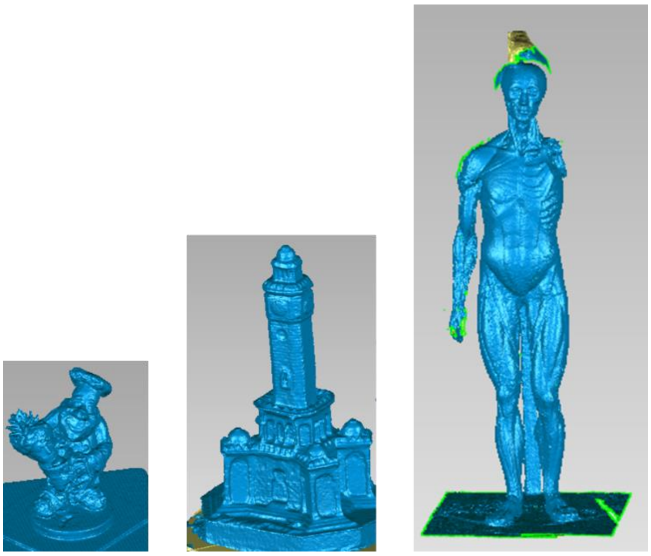

Figure 3. Solid model of objects on a small, medium, and large scale from left to right.

4. Conclusion

The laser scanning method has proved successful in reverse engineering for the design and production of small objects, utilizing three-dimensional modelling. The current study applied this method to objects of varying lengths. The following factors were determined to be crucial for successful implementation using Geomatic Wrap software.

Reverse engineering refers to the method of creating a collection of characteristics following a systematic analysis of a complex hardware system. This procedure is performed by individuals who were not involved in the original design process and must work without the benefit of original drawings, documentation, and operating manuals. Contemporary production methods encompass the procedures that commence with the product's design in a digitized environment, and culminate in the production phase employing industry-appropriate techniques. The deployment of contemporary technology in the data acquisition phase of reverse engineering expedites subsequent stages, culminating in production. Converting objects into CAD models by digitization poses a challenging and intricate issue. Fully automating the creation of a comprehensive and coherent computer-aided design model remains an ongoing research effort. In this regard, besides automation and pace, it is critical to achieve accurate and precise access to the fundamental data. One popular approach to 3D modelling is utilizing the LiDAR method, which is proffered as an alternative solution for acquiring data in reverse engineering applications. The resultant point cloud was then processed in Scene software. The 3D model was transferred to the Geoamgix Wrap software, and technical drawings were carried out on the 3D CAD data. This research investigated the potential of handheld laser scanners as an alternative method for reverse engineering applications. Today's dynamic industrial environment necessitates companies to adopt and integrate new technologies continuously. The utilization of modern communication and information technologies is of great importance, particularly in industries such as automotive manufacturing that cater to large and multinational corporations. Handheld laser scanners confer numerous benefits and enhanced flexibility in reverse engineering applications, such as enabling reproducible measurements and time savings. Handheld laser scanners, according to the authors, may serve as a viable alternative method for data collection in reverse engineering activities.

Acknowledgement

This research was funded by project 1919B012206671 as part of the Tübitak 2209-A University Students Research Projects Support Programme.

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