

## COMPUTER VISION APPLICATIONS IN MECHANICAL SYSTEMS INNOVATIONS

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**Abstract:** Computer vision is a scientific subject that includes methods for acquiring, processing, analyzing, and understanding real-world images in order to produce numerical or symbolic information so that they can be processed by a computer. The set of computer vision techniques are part of the enabling technologies of the so-called Industry 4.0. A group of the computer vision techniques are the 3D reconstruction techniques which are an optimal solution for many fields of industry such as assistive technology, medicine, agriculture, agribusiness, among others. 3D reconstruction is used for estimating measurements, robotic navigation, geometric feature abstraction, 3D scanning, reverse engineering and others applications. The main goal of this document is to develop a technological map of the software and hardware for 3D reconstruction tasks, based on the followings techniques: stereo vision, photogrammetry, profilometry and topogrammetry. Photogrammetry consists of methods for acquiring and interpreting images in order to determine the shape and location of an object from two or more photographs taken from different angles. The technique converts two-dimensional information, contained in images, into three-dimensional object information. The self-referenced laser profilometer can use the fusion of two principles in a single portable system, stereo vision (passive triangulation) associated with laser triangulation (active). Stereo vision fuses object distances and features (depth), providing positional data that can be found in the geometric relationships between several unique viewpoints. then, a disparity map is generated in which each positional data is correlated with depth. The topogrammetry technique results from the combination of topometry techniques, where spatial shapes are measured by the oblique projection of fringes, and the stereoscopy technique – where images from two cameras are combined to, by triangulation, determine the 3D coordinates of the observed points. The methodology to follow consists of a review of the literature for identify the hardware and software used in 3D reconstructions researches from 2018 to today. Through the analysis it is possible to find some cheap cameras and free software that could potentially become an affordable solution for small and medium businesses. Opening the possibility of greater use of enabling technologies that are part of the fourth industrial revolution (I4.0), as currently only companies with ample purchasing power make use of these technologies in the world.

**Keywords:** Technological Map, Computer Vision Technologies, 3D Reconstruction techniques.

### 1. INTRODUCTION

Computer vision is a scientific discipline that includes methods for acquiring, processing, analyzing, and understanding real-world images in order to produce numerical or symbolic information so that they can be processed by a computer. Computer vision is part of the enabling technologies of Industry 4.0 and its applicability in production processes is increasing. The main goal of this article is to develop a technological map of the hardware and software solutions currently used for 3D reconstruction. 3D reconstruction is the process of constructed 3D representations of the 3D appearance of objects from the outputs of data acquisition equipment (Ma and Liu, 2018). The inputs of 3D reconstruction techniques are the outputs of data acquisition equipment (Ma and Liu, 2018). The commonly used data as inputs of the techniques are monocular images, stereo images, video frames and point clouds, corresponding to monocular cameras, binocular cameras, video cameras and laser scanners (Ma and Liu, 2018). This work grouped the 3D techniques in four groups: 1. Photogrammetry, 2. Stereo Vision, 3. Profilometry and 4. Topogrammetry -also known as fringe projection- based on (Figaro Da Costa Pinto, 2010), these techniques are classifies as Noncontact techniques (An et al., 2022).

Photogrammetry consists of methods for acquiring and interpreting images in order to determine the shape and location of an object from two or more photographs taken from different angles. The technique converts two-dimensional information, contained in images, into three-dimensional object information. The self-referenced laser profilometer can use the fusion of two principles in a single portable system, stereo vision (passive triangulation) associated with laser triangulation (active). Self-referencing is associated with not using auxiliary external systems for the global referencing of measurements, allowing its use with the flexibility of manual movement (Figaro Da Costa Pinto, 2010). Stereo vision fuses object distances and features (depth), providing positional data that can be found in the geometric relationships between several unique viewpoints. then, a disparity map is generated in which each positional data is correlated with depth. Thus, from a disparity value, the depth information that corresponds to it can be estimated so that a simple two-dimensional feature can be projected in a 3D space (da Silva Vieira et al., 2021). The topogrammetry technique results from the combination of topometry techniques, where spatial shapes are measured by the oblique projection of fringes, and the stereoscopy technique – where images from two cameras are combined to, by triangulation, determine the 3D coordinates of the observed points (Figaro Da Costa Pinto, 2010).

Several works propose hybrid techniques, for example combinations between LiDAR (LiDAR is an active remote sensing technique that is similar to RADAR but, instead of using radio waves as a radiation source, it uses laser pulses) and stereo vision (Chen et al., 2019; Cholakkal et al., 2020; Suvei et al., 2018; Wang et al., 2022) or sonar sensor and photogrammetry (Brown and Snyder, 2018; Paixão et al., 2018) in order to optimize 3d estimation processes. This work presents a technological map for the implementation of 3D reconstruction techniques through a systematic review in the IEEE and ScienceDirect databases from 2018 to the present. This document is organized as follows: it presents the development of 3D reconstruction works in Section 2. Section 3 lists the hardware and software tools found in the literature review carried out in this document (Technological Mapping). An application of the technology use map is presented in section 4. Finally, the conclusions and the focus of future research are presented in Section 5.

## 2. LITERATURE REVIEW

The reconstruction process is mainly divided into image acquisition and model construction, as Figure 1 (Hou et al., 2020).

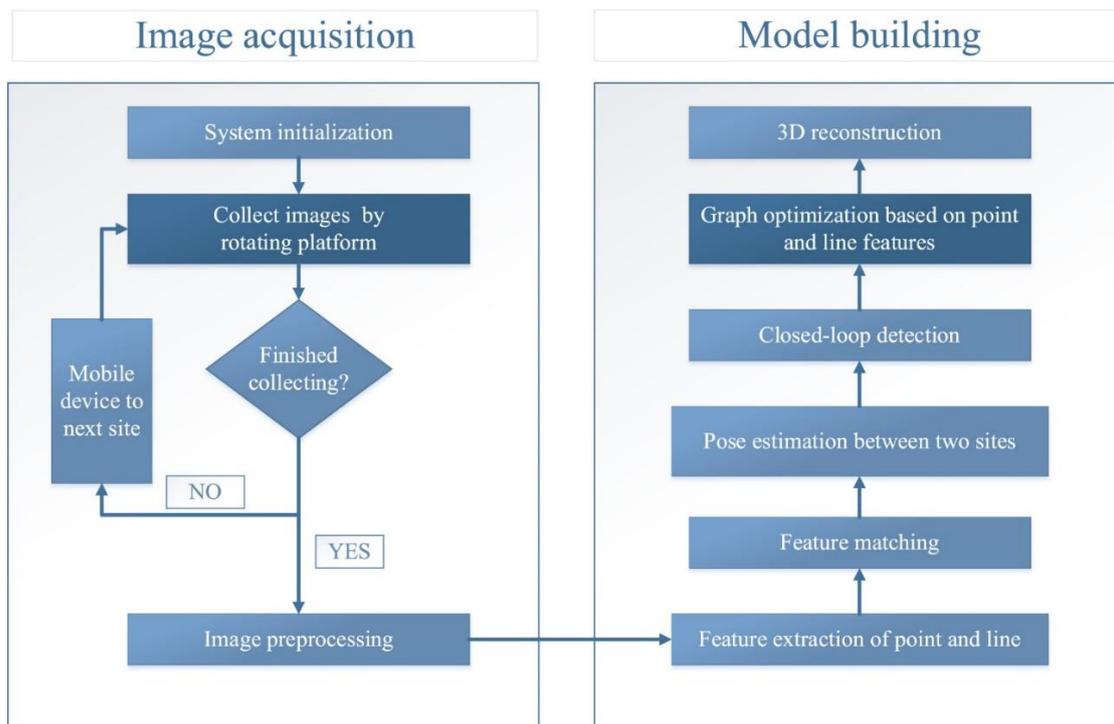


Figure 1. Block diagram of proposed system. Source: (Hou et al., 2020).

Research published in recent years is presented below. The articles were found in the IEEE and ScienceDirect databases, the keywords were: 3D reconstruction, Mechanical applications and computer vision. Most articles were selected that had information on the hardware and software platform used in the investigation. The objective is to identify the software and hardware tools to feed the technological mapping proposed in this work. It is also important to mention that papers published before 2018 were not considered.

The work by Xu et al., (2018) proposed a reconstruction method to improve the measurement of binocular vision. (Xu et al., 2018) based his method on stereo vision integrated to LIDAR systems for the detection of humans and other obstacles in agricultural scenarios. Randil and Mallikarachchi, (2018) establish a method in measuring displacements in a 3D environment, using stereo vision technique. Suvei et al., (2018) proposes a fusion method which uses the depth information collect from a LIDAR sensor to guide a block matching stereo algorithm for obstacle detection. In Brown

and Snyder, (2018), a camera and stroboscopic system attached to an interferometric sonar aboard an underwater vehicle have been used to create bathymetric reconstructions of the seafloor from photogrammetry.

In Han et al., (2019), a lightweight 3D reconstruction algorithm framework is projected for scene objects implemented on the Raspberry Pi 4. Han et al., (2019) used a RGBD camera. Pan et al., (2019) integrate a LIDAR sensor in a drone to analyze the growth of wheat crops through 3D reconstruction. In Chen et al., (2019), a 3D reconstruction framework based on multiple sensors is designed for intelligent vehicle to be aware of driving environment.

Liu et al., (2020) proposed a, high-precision 3D mapping method for drones using high-precision-real-time kinematic Global Positioning System (RTK-GPS) data and RGBD (red-green-blue-depth) camera. An automatic monitoring platform for plant breeding is built by Liu, to provide accurate environmental parameters and phenotypic parameters for agronomic researchers during breeding experiments through RGBD camera and LiDAR implementation. Parr et al., (2020) presents the design and development of a 3D scanner based on a set of microphones and a depth camera as main components. In Li et al., (2020), a nondestructive detection of masson pine seedlings morphological indexes based on 3D-Reconstruction through stereo vision was proposed. Hou et al., (2020) proposes a highly robust automatic 3D reconstruction system based on integrated optimization by point line features for reconstruction of various complex large scenes based on three RGB-D cameras collaborative (SLAM (Simultaneous Localization and Mapping)). Y. Wang et al., (2020) proposed a 3d reconstruction scheme for micrometer-level scanning of decimeter-scale objects, with both real-time efficiency and high accuracy, using Kinect sensor for the data acquisition. Demoulin et al., (2020) presented a method to improve photogrammetry-based 3D estimation of wing deformations in real flight conditions.

In Isachsen et al., (2021), a system for robotic food handling is proposed by implementing an Intel Reale SR300 sensor. This system aims to optimize robotic food handling through 3D reconstruction. Cao et al., (2021) built a multi-sensor system composed by a long-wave infrared camera, a RGBD camera, and a digital projector for multimodal data acquisition, real-time 3D thermographic reconstruction, and projector-based spatial augmented reality. Duan et al., (2021) integrate dense SLAM and deep learning into the new monocular 3D reconstruction pipeline, which can perform high-quality 3D reconstruction of large-scale scenes using only RGB images.

Gholami et al., (2022) used an ultrasonic sensor and stereo system for obstacle detection for mobile robot navigation. Kim et al., (2022) suggests of stereo vision in which the cameras have two different focal lengths, offering improved performance for both crack localization and characterization. Chiang and Lin, (2022) proposes a stereo vision system for to reconstruct 3D objects. In Kang et al., (2020), a neural network based visual perception framework for autonomous apple harvesting is proposed. Nguyen et al., (2022) presents an approach integrating a fringe-to-phase network with a fringe projection profilometry (FPP) technique to achieve 3D reconstructions with high accuracy and speed performance. Hou et al., (2022) used an RGB-D camera named KINECT V.2 and Visual Studio to provide a good starting value for 3D reconstruction, the branch and bound method is adopted, which can quickly obtain high-precision camera pose estimation. Cheng et al., (2022) implemented a photogrammetry system for 3D reconstruction in the construction sector. In Yang et al., (2022), an oblique photogrammeter with five high-precise measuring cameras is developed, which can be controlled by a microcontroller, positioned by a GNSS system (Global Navigation Satellite System), and accessed through narrowband internet of things (NB-IoT) module interface. GNSS is a broad term encompassing different types of satellite-based positioning, navigation and timing (PNT) systems used globally. GPS (or Global Positioning System) is one such type of Global Navigation Satellite System.

Through the bibliographic review, it is possible to appreciate the various fields of action of mechanical engineering where 3D reconstruction techniques are used. 3D reconstruction of objects, large scenarios, distance measurement, robotic navigation, robotic food handling in terrestrial, aerial and aquatic environments, among others. Which allows visualizing the importance of these computer vision technologies to optimize processes. Also, it is possible to observe that the current works propose hybrid techniques such as combinations between lidar and stereo vision, laser triangulation and photogrammetry, photogrammetry and stereo vision, laser triangulation and stereo vision and others. The next chapter presents the technologies identified in the literature review carried out here in order to develop a technological map that provides the reader with different hardware and software tools currently used in 3D reconstruction projects.

### **3. TECHNOLOGICAL MAP OF THE HARDWARE AND SOFTWARE SOLUTIONS**

Initially, 100 articles were chosen, which were listed in a table describing the title of the article, software and hardware used in the 3D reconstruction project, reconstruction techniques addressed, and research objective. In the first filter, 43 articles were discarded because they did not mention hardware or software. From the remaining 53 articles, the information for the elaboration of the technological maps was extracted. Each hardware and software tool were classified into 4 groups according to the reconstruction technique. Finally, the prices were estimated from the investigation of the sales pages of the listed tools. Figure 2 present the review methodology used in this research.

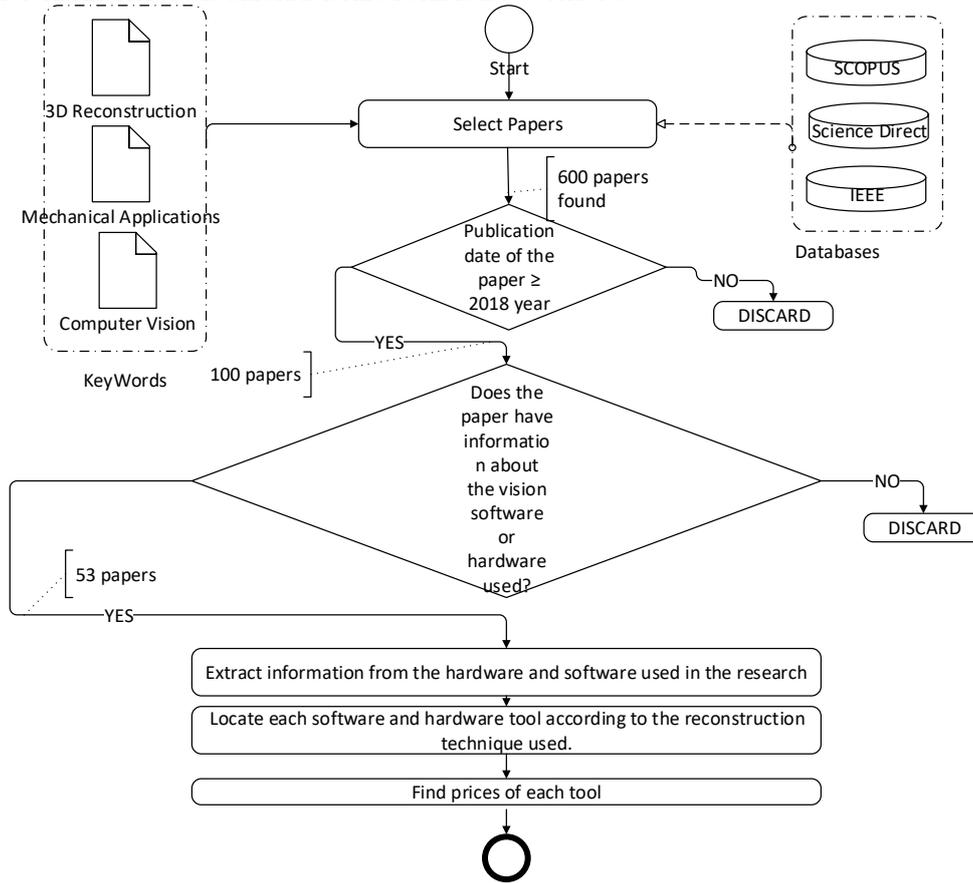


Figure 2. Review methodology

Trough the study on (Brown and Snyder, 2018; Cao et al., 2021; Chen et al., 2019, 2020; Cheng et al., 2022; Chiang and Lin, 2022; Cholakkal et al., 2020; Demoulin et al., 2020; Duan et al., 2021; Figaro Da Costa Pinto, 2010; Gholami et al., 2022; Han et al., 2019; He et al., 2022; Hou et al., 2022, 2020; Isachsen et al., 2021; Kang et al., 2020; Kang and Chen, 2019; Kim et al., 2022; C. Li et al., 2019; P. Li et al., 2019; Li et al., 2022, 2020; Lin et al., 2020; Liu et al., 2020; Ma et al., 2020, 2018; Masuk et al., 2019; McCord et al., 2022; Minos-Stensrud et al., 2018; Paixão et al., 2018; Pan et al., 2019; Parr et al., 2020; Pinto and Janeiro, 2021; Randil and Mallikarachchi, 2018; Renaud et al., 2022; Rode et al., 2021; Suvei et al., 2018; Triputen et al., 2018; Wang et al., 2022; Y. Wang et al., 2020; Y. C. Wang et al., 2020; Xu et al., 2022, 2018; T. Xu et al., 2021; Y. Xu et al., 2021; Yang et al., 2022; Zabatani et al., 2020; Zhang et al., 2018) papers, the hardware and software technologies were identified and are presented in Figure 3 and Figure 4, consecutively, as mind map representation.

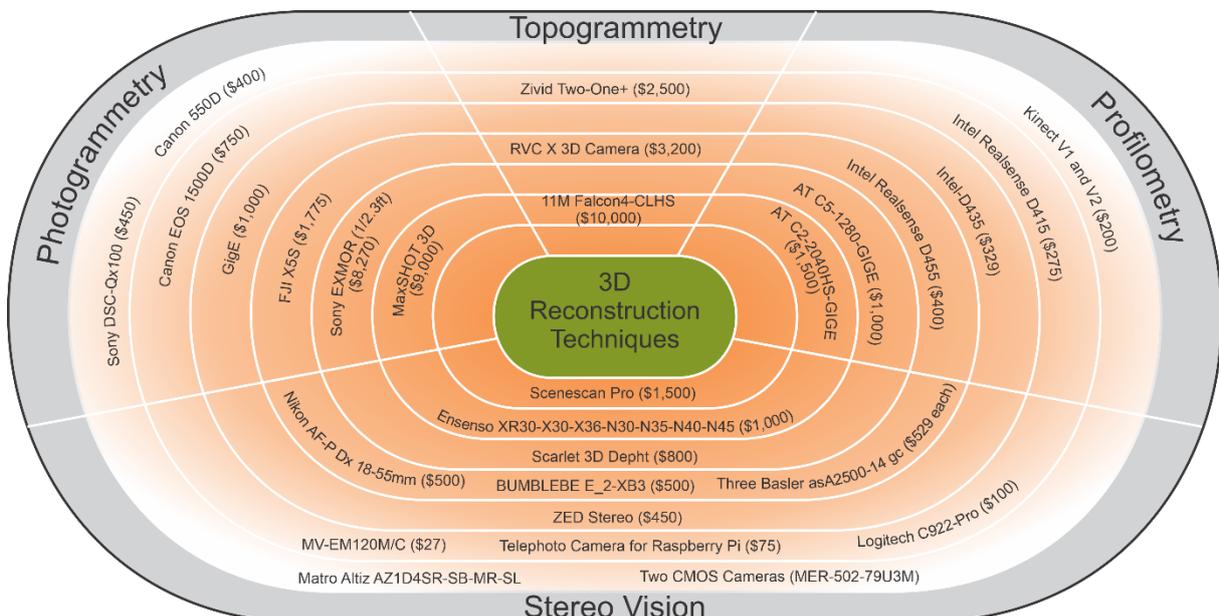


Figure 3. Mind map of Hardware for 3D reconstruction (Technological map).

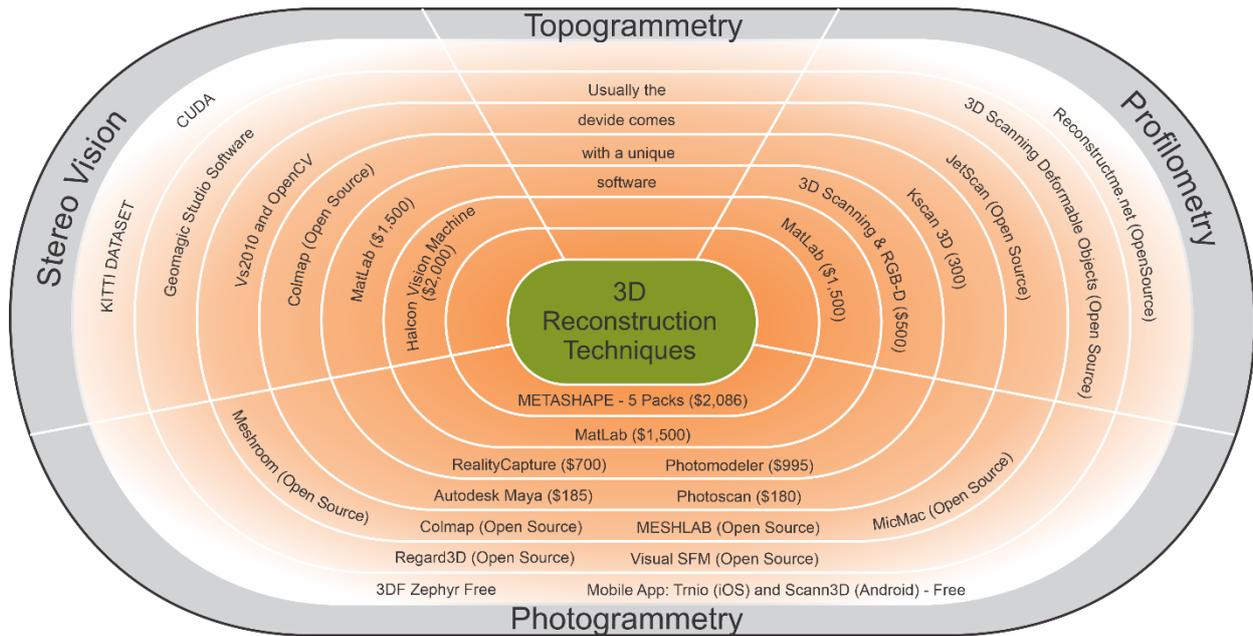


Figure 4.. Mind map of Software for 3D reconstruction (Technological map).

Figure 3 shows that the most expensive equipment is linked to topogrammetry technology. Hybrid techniques that use LIDAR sensors, GPS and IMU sensors, sonars, laser sources and projectors that make experiments more expensive are also found in the literature review. In said investigations, these devices were much more expensive than image acquisition systems. Table 1 presents prices of some LIDAR sensor prices found in the literature review.

Table 1. Lidar Sensors prices

Device	Average price (dollars)	Paper
Velodyne HDL-32E	\$18000	(Suvei et al., 2018)
RPLIDAR A2	\$ 319	(Pan et al., 2019)
OUSTER OS1-128	\$22799	(Cholakkal et al., 2020)
LEICA BLK360	\$16000	(Wang et al., 2022)
Velodyne VLP-16	\$8000	(Cholakkal et al., 2020)

It can also be observed in the works read, that several authors build the photogrammetry or stereo vision system more commonly, making use of 2,3,4 or more cameras, for example (Chiang and Lin, 2022; Kim et al., 2022; Suvei et al., 2018; Xu et al., 2018; Yang et al., 2022). Some works used phone' cameras for the researchers, this case appear in (An et al., 2022; C. Li et al., 2019; Minos-Stensrud et al., 2018; Suvei et al., 2018; Yang et al., 2022).

Figure 4 shows that there are several software for each 3D reconstruction technique, these software help the calibration of the cameras and the point cloud registration to generate the 3D scene or object.

This work presents software and hardware technologies for 3D reconstruction. It can be seen that there are ready-to-implement technologies, but their costs are high. There are also cheaper technologies but with performance limitations, both in hardware and software. However, several works can be seen today that are using sensors such as Kinect or Intel that are not so expensive and still provide solutions in the proposed investigations. It is also relevant to mention that an important step for obtaining good results is defined in the calibration of the vision system, but systems such as Kinect or Intel are already calibrated from the factory. The resulting unknown is, is it possible to use the cheapest existing 3D reconstruction technologies to propose solutions (high performance) for the development of mechatronic or vision systems in an I4.0 environment?

In a world where approximately 70% of robot sales are made in China, Germany, Japan, the Republic of Korea and the United States ((WEF), 2018), it is necessary to bet on cheaper solutions that are affordable for small or medium-sized companies, taking into account the current state of technological production in Latin American countries. This technological map provides several alternatives for the development of a 3D reconstruction system, ranging from cheap devices and "open source" software to much more expensive technologies.

#### 4. METROLOGY APPLICATION

From the map of technologies presented, 2 solutions were chosen, a software and a hardware to analyze the result of the combination in the field of metrology. The chosen software was MESH LAB and the hardware was the Kinect V1 RGB-D camera. The reasons for these choices are: the price of the Kinect V1, in this case less than 100 dollars, and in

the case of the software, MESH LAB was used, due to the easy access to the free trial version for one month. The setup of the scene is presented in Figure 5.

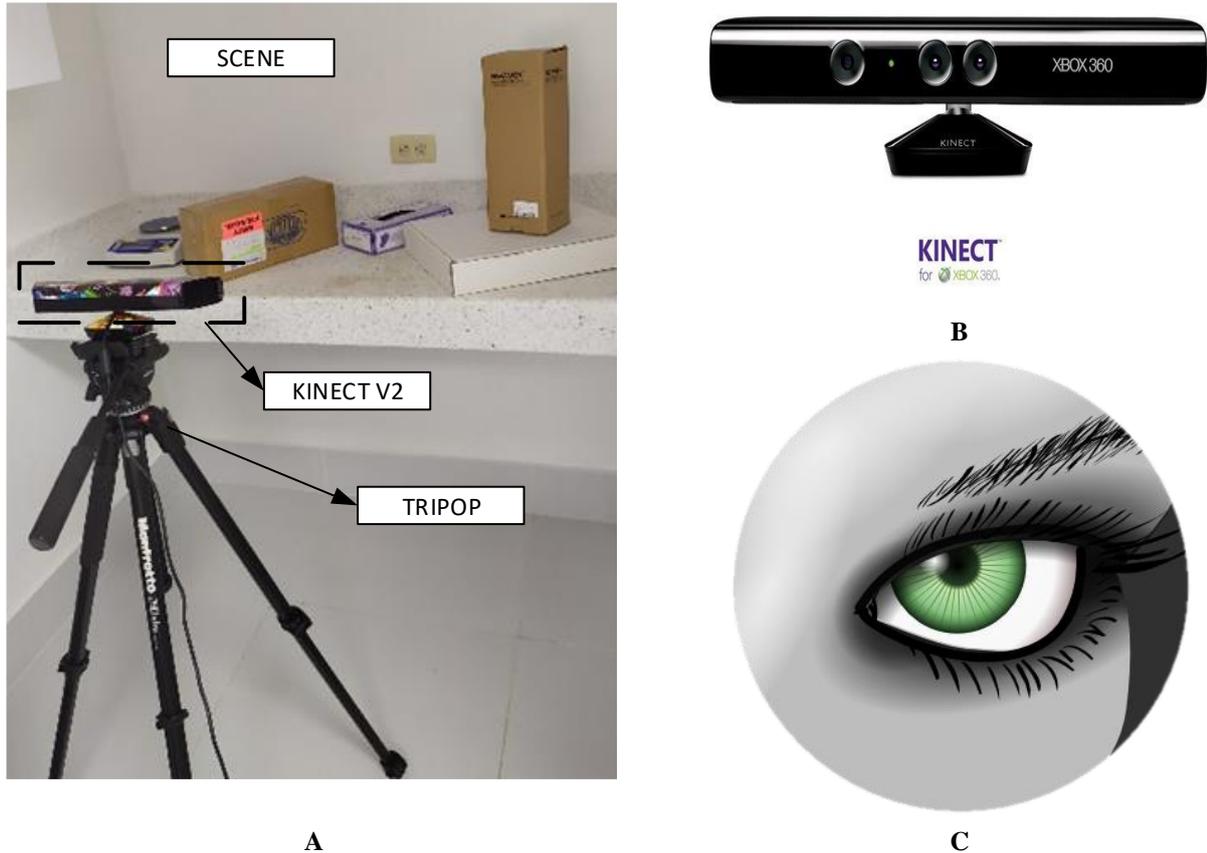


Figure 5. A Setup Scene for 3D reconstruction Source: Author, B. Kinect V1 RGBD camera, C. Logotype of MeshLab.

For this experiment, the height of the camera is kept fixed, then to capture the point cloud of the scene, the camera angle is changed vertically and horizontally. Figure 6 illustrates the vertical and horizontal variation of the camera angle with respect to the scene.

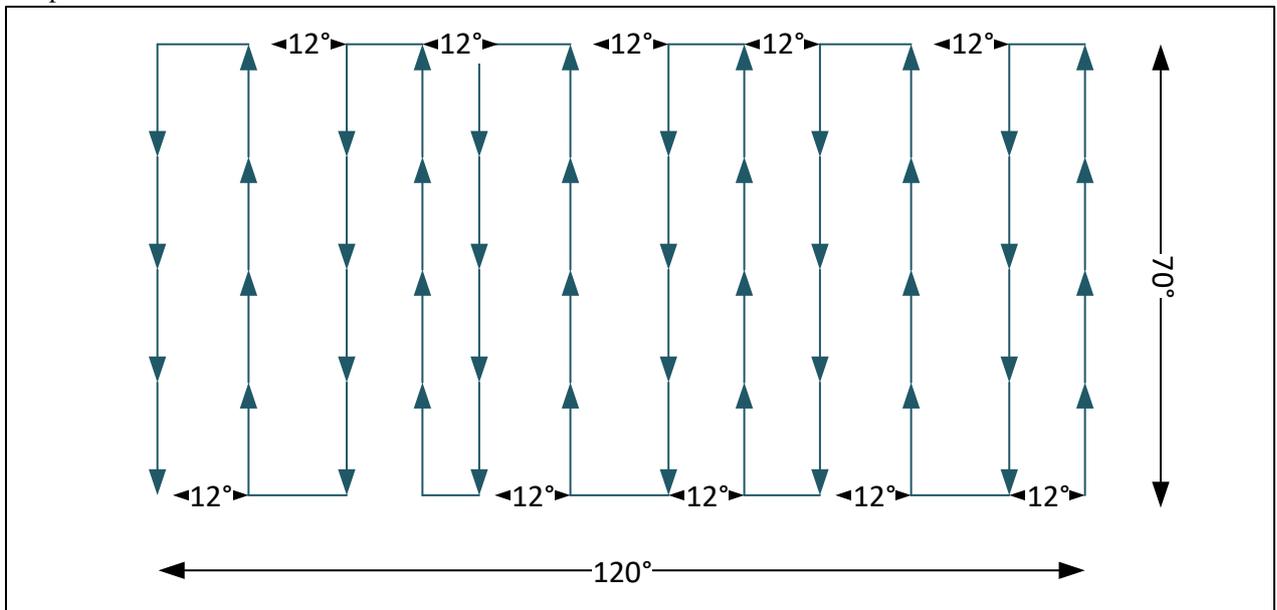


Figure 6. Tripod Angle Variation

The variation of the image acquisition angle is possible thanks to the tripod mechanism. the angle varies 70 degrees vertically and in steps of 3 degrees horizontally, until completing 120 degrees. For the acquisition of the point cloud, the free Reconstructme software was used. Then the point cloud is inserted in the MeshLab software (in charge of the concatenation of points through the Iterative Closest Point ICP algorithm). Figure 7 presents the result of the 3D reconstruction of the proposed scene.

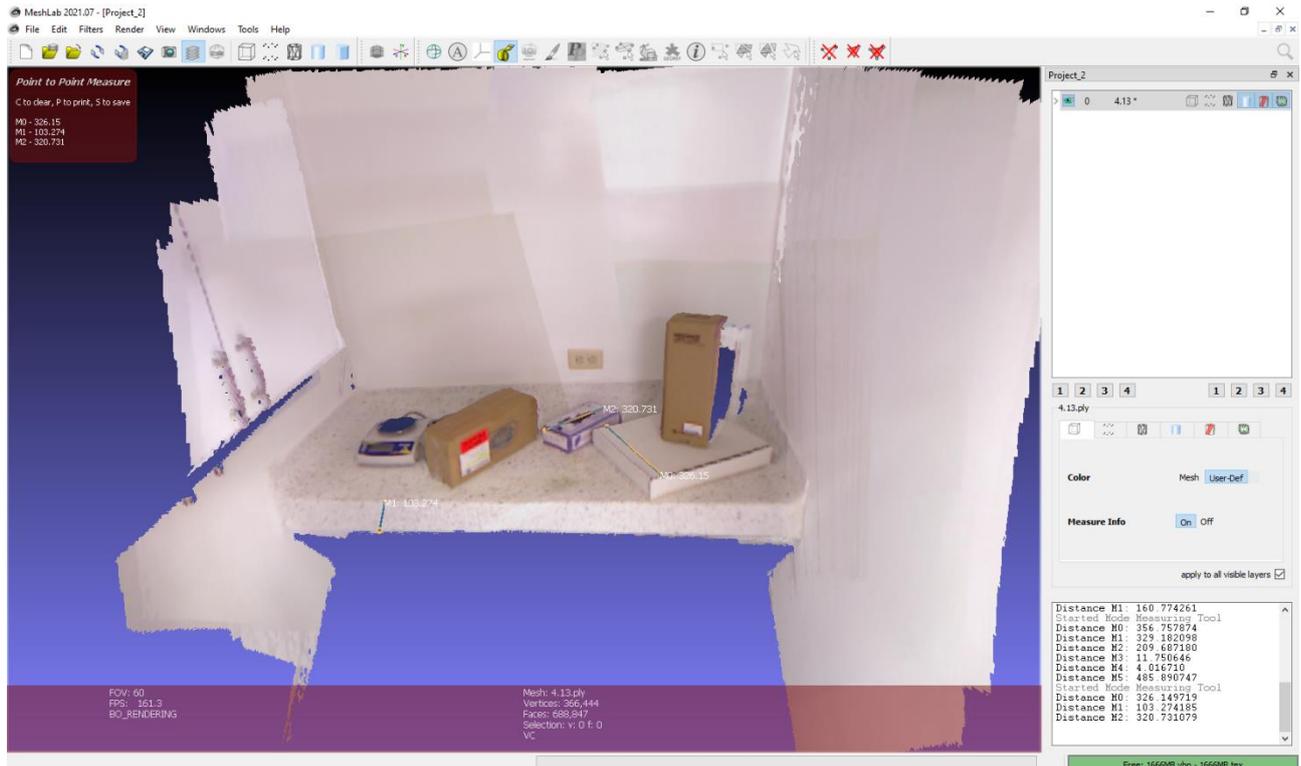


Figure 7. 3D reconstruction result (MESHLAB).

The objects in the scene were measured before the 3D reconstruction process, with which the measurements produced by the MESHLAB software were compared and a measurement error of  $\pm 4$ mm was calculated.

## 5. CONCLUSION

This research provides an overview of the 3D reconstruction techniques and technologies to choose for implementation of computer vision. The technological map exposed in this work brings software and hardware tools that were found in the bibliographic review. The technological map also offers an approximation of the prices of the tools in dollars. In order to facilitate the visualization of the technological map, it was represented in the form of a mental map, where more important information can be added during the design process of mechatronic systems.

It can be seen that there are several inexpensive cameras and free software that can potentially become an affordable solution for small and medium-sized businesses. Opening the possibility of greater use of enabling technologies that are part of the fourth industrial revolution (I4.0), because currently only companies with ample purchasing power make use of these technologies in the world.

This article provides information on cheap technological alternatives to develop cheap solutions in artificial vision, thus aligning itself with the current research trend according to (Bolaños et al., 2022) “the trend in research on the development of mechatronic and technological products is to lower prices while maintaining high performance”.

It was demonstrated through the use of low-cost hardware that a 3D abstraction very close to the real environment is possible, obtaining a measurement error of  $\pm 4$ mm. This error is considered acceptable for applications that do not require a high degree of precision. Answering in the first instance, that it is possible to implement a low-cost vision system for applications in the mechanical sciences as agriculture machinery, assistive technology and industrial automation in context of Industry 4.0.

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