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Semi-Automatic Low cost 3D Laser scanning systems for reverse engineering

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Abstract

This paper is focused on the development, implementation and testing of a semi-automated low cost motorized active 3D slit laser scanning system. The scanner is based on the software platform of the DAVID LaserScanner Vision Systems GmbH's. The authors implemented motorized movements on a CNC milling machine, controlling the systems by the Mach3 CNC software. The authors have combined and personalized different software, mainly low cost or open-source: a specific program was written and compiled for processing; establishing communication between the scanning software (David-Laserscan) and control software/hardware of the milling machine (Mach3) throw two double virtual communication ports.

Keywords: 3D Laser scaner; Range image; David software; Computer-aided Reverse engineering; Rapid Prototype;

1. Introduction

The diffusion of the acquisition systems is helped from the rapid evaluation of the information technology and Mechatronics, permitting low cost system by using off-the-shelf hardware (webcam, projectors, etc.) for 3D scanning [1-3]. Nevertheless, the accuracy of these systems has to be taken in consideration when affording in metrology. Depending from the interaction of the sensor and the surface of the object, the systems can be divided in contact and non-contact 3D scanners. In this work the focus is on the active scanning systems, where a well-defined light source (typically a laser, coded light patterns, etc.) interacts with an object, and this interaction is captured by a sensor (web camera, video camera equipped with optical lenses, etc.).

The term passive stereo indicates that the sensor on the system does not rely on active forms of illumination, except ambient light. The main approaches to illumination control are: (a) continuous wave modulation, (b) time-of-flight (TOF) and (c) structured light triangulation [4]. Most of the active systems are based on geometric triangulation. Those techniques require that angles and distances between sensor, light source and object must be recognized from system calibration.

The Computer-aided Reverse Engineering (CARE) creates a computer model of an object by converting in digital form real object geometry, and the fine scale texture surface properties throw measurements of the object, as it exist in the real world [5]. The accuracy and the resolution of the computer model obtained is determined by many factors. CARE, with some pipeline can permit technical and nontechnical individuals to generate, quickly and automatically, medium-high accuracy engineering CAD models of existing objects. As part of reverse engineering process, since 1970s, laser scanner principles, using fast scanning mirrors were introduced by National Research Council of Canada (NRC) and other Laboratories [6]. Slit scanner is the most widely used triangulation based 3D laser camera, because of its optical and mechanical simplicity and cost. Many authors have created simple low cost efficient hand held 3D scanner for acquisitions of point

data of object in short distance [7]. Using a non-real-time servo motion system, equipped with two Charge-Coupled Device (CCD) cameras and a laser [8], the response time of ensuring the distance within the range of the depth of field for the camera matches the relation between image sampling and data processing. The proposed solution keeps the distance between the cameras and the measured object fixed, and moves the laser in horizontal or vertical direction. In this way the image is always in the depth of field of the camera. For acquiring a complete model, it is necessary to scan the object from different viewpoints, by rotating the fourth A-axis of the CNC machine, which is the platform of the object. The last versions of David scanning software (3.9.1) give the possibility to align the scans (point clouds) automatically after each scan is taken. The proposed approach extend the possibility of the scanning software by creating a program, written in processing language, which controls and communicates with the motion control of the CNC and with the scanning system, as explained more in depth as follows.

2. Slit laser system implemented for 360° data acquisition

To create a semi-automatic 360° system, a 4 axis CNC machine (FCN 500,4-axis milling machine) was used, with an active sensor (Logitech web camera Orbit/Sphere AF with CMOS sensor, 2MPixel, 30fps), and a tracking device (Opt. Power = 5mW, wavelength 532nm, linear green laser beam Class 1).

Different software were used, mainly low cost and open source, such as Processing and Virtual port monitor (evaluation version), Mach 3 and David laser scan. The software operate in a desktop and Dell Precision 340 PC with Pentium 4 CPU 2.4 G GHz and 1GB of Ram.

The system can be classified as semi-automatic because of the necessity of some preparatory setup, needed before starting the scan, as described in next paragraphs. Once these modification are made, the system runs a 360° automatic scanning, without the necessity of user intervention.

The heart of this system is the algorithm code used in Processing software, which communicates (send and receives commands) with David and Mach 3 software, controlling in the scanning system and the movements of the CNC machine by the virtual ports created earlier. The logic schema of this process is shown in Fig. 1.

2.1. Preliminary setup and modification

Only the main steps, needed to be followed by the user to obtain a 360° scanning system, are here explained and focused, without making deep explanation of each software package used in this work.
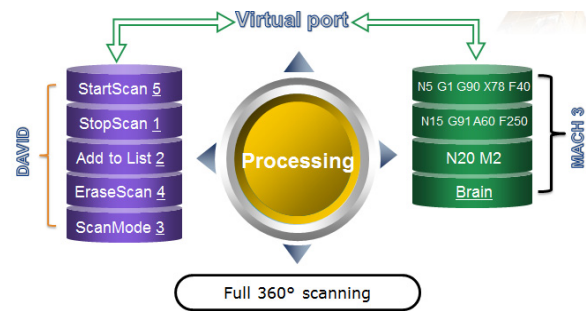

Fig. 1. Logic schema of the laser scanning system

2.1.1. David laser scanner software

David 3D scanning software has the capability to send and receive commands through a serial port using letters or numbers. This allows to simply create different inputs and outputs for the other control software. Customizing the Command options, it is possible to execute by David software an action connected with that command sending to the serial port a special letter identifying that command (Fig. 2-4).

For this scanner a virtual port (COM4) was created and the port number was enabled in advance setting.

In the Hardware setup menu of the David software platform, an hand-held laser setup is chosen. In this case, the options are modified as:

- *Commands*
  - ○ *StopLaserScan*   *1*
  - ○ *Add to List*   *2*
  - ○ *ScanMode*   *3*
  - ○ *EraseScan*   *4*
  - ○ *StartScan*   *5*
- *Messages:*
  - ○ *StartLaserScanning*   *2*

After that, the software needs to be calibrated, and then it is ready for scan, as explained in the software manuals [9], waiting only for the start command.

It is important to underline that for this system the calibration angled background must be present during laser scans.

2.1.2. Milling machine and Mach 3 preparation

To motorize the movements of the scanning system, an existing 4 axis CNC machine was used (3 linear X,Y,Z axes, with Z as the vertical axis, and an A rotation one - Elettronica Veneta FCN 500) controller by an 8-Axis Ethernet Motion Controller (VITAL Systems Inc DSPMC/IP pn7761S). The software that controls in real time every operation and the working parameters of the machine is ArtSoft Mach3. This software is widely used in custom made and retrofitted CNC machines.
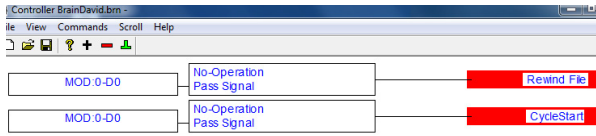
Fig. 2. Brain of Mach3

Table 1. Part program for starting/stopping the Mach3 brain.

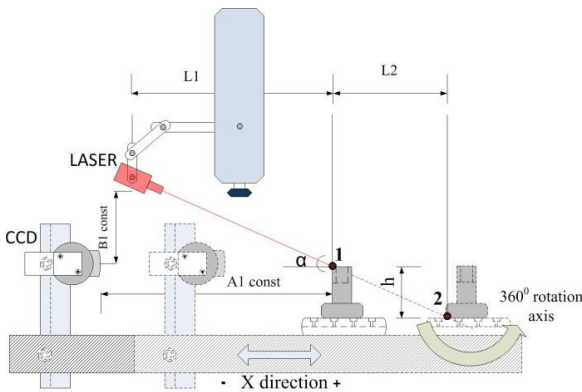| Syntax in processing algorithm	Description
if (myPort.available() > 0 && start == 1)	// function for the control of Mach 3
if (time < 100){	// Launch the logic output 1 in Mach3 for the execution of the moving program by the CNC machine motion control
delay(2000);	
for (int i=0; i < 7; i++)	
myPort.write(reply_1[i]);	
println("go");	
delay(2000);	
else	
for (int i=0; i < 7; i++)	
myPort.write(reply_0[i]);	// put the Mach3 in Standby

Fig. 3. Scanning in X direction

Below, only the main procedures needed to set and operate with this scanning system are explained.

First, the communication port is prepared in the advanced options (Function CFG's, then ModBus Status and control), to send commands to the milling machine. A virtual port - COM2 – is activated for the communication with the machine (the creation of these virtual ports COM2, COM3, COM4 and COM5 will be explained in next paragraph).

Second, a "brain" file was created and loaded the in the brain directory of Mach3. "Brains" are logic functions created using the Brain editor part of the Mach3 software. These mini programs, created by the users, are software PLCs, that extend the possibilities to control and monitor directly the CNC machines, bypassing the usual way of controlling the machine by buttons (physical wheels or digital buttons), or command line inputs. The "Brain" written is a simple one, having only two steps (Fig. 2). The first step starts the moving cycle (which is created and loaded as a simple G-code file) when the logic output is sent from the processing logic (see Table 1) to the COM2 (which operates in parallel with COM3). The second step just rewinds the cycle every time it is needed. The file created is called *ControllerBrainDavid.brn*. The file is saved in the brain directory of Mach 3 and must be enabled.

A simple G-code file, written using a text editor, provides the commands for the main axes motors for all the movements needed for the scanning performed. In this study two types of object scans were tested. For the first type (Fig. 3) the web camera and the object are moved in the horizontal X direction (the A1 distance between them remain constant all the time, and the laser is fixed in the vertical Z axis, remaining static). The laser start the scanning by the upper point 1 of the object till end point 2, and it moves for the distance L2. The L2 distance must be physically known and written in G-code command line as the X movement value. This distance depends from the height of the object, and it cannot exceed the limits of the machine (in this case the MAX limit is 250mm). In this solution the distance needs to be done twice, so the second command line in G-code should bring the platform to the starting point of the scanning process. The optimal inclination angle of the laser (α) is ranged between 25-35°, and it was obtained testing many cases to have the better scanning results. The field of view of the sensor is fixed maintaining the A1 distance constant, chosen the optical lenses. This range will be always in the depth of field of the sensor. Using conventional geometry, the field of view of the sensor is [10]:

$$\Phi = 2 \cdot \tan^{-1}\left(\frac{P}{D \cdot f}\right) \qquad (1)$$

Where:
    f- is the focal length of the lens
    D- is the triangulation base (B1const, Fig. 3)
    P- is the dimension of the CMOS

To improve measurement accuracy, the baseline (D) can be increased, or a larger sensor used (P). These modifications sometimes are not possible, due to the optical system setup, in which the stability of the system decreases with the increase of (D), and for the shadow effect (self-occlusion problems increase with (D)). When the platform comes back to the home position, the fourth A axis is rotated.

The second setup of the laser scanning system (Fig.4) uses the same logic, the only difference is that it moves the laser along the vertical Z-axis for scanning.

2.1.3. Virtual Serial port monitor

For this scanner a virtual COM2 serial port was created and connected in parallel with COM3, COM4 and COM5. The evaluation version of Virtual Serial Port Driver XP4 software was used for this purpose (Fig. 5).

The first group of ports (COM2 and COM3) establishes the connection between Mach3 and the processing software, and the second group (COM4 and COM5) realizes the connection between the processing software and the David software.

The processing software executes the code and sends or receives digital inputs and outputs to COM3 and COM4. This software controls also the COM2 port, connected to Mach3, and the COM5, connected with the scanning software. A circular closed loop inside the Processing algorithm is created, to realize the timing, the control and the monitoring of all the operations.

2.1.4. Processing software

The leading part which controls the entire scanning process is done by the "Processing" software, an open source programming language and development environment, the Processing 1.5.1 (by Processing Foundation) [11]. It is compatible with all operating systems, and permits to create and build different algorithms.

The logic schema of the algorithm is shown in Fig. 6. The program is divided in three main parts.

The first part uploads the standard components of the library and set the variables for the scanning process, as:

- *timemax (//maximal time of scanning process, without the rotation of the A-axis)*
- *timescan (//variable for counting the number of scans)*
- *timescanmax (//max number of scans)*
- *in_buffer[] (//variable for the receiving buffer from Mach3)*

The second part of the program, called "void setup", determines the logic of inputs and outputs for the virtual ports, as:

- *myPort = new Serial (this, portName, 9600) (execution of the serial port controlling Mach 3)*
- *myPort2 = new Serial (this, portName2, 9600) (execution of the serial port controlling David laser scanner)*
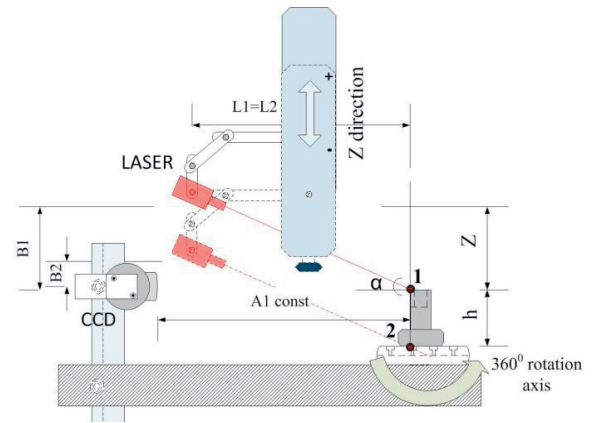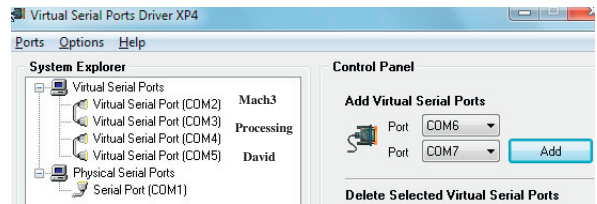

Fig. 4. Scanning in Z direction

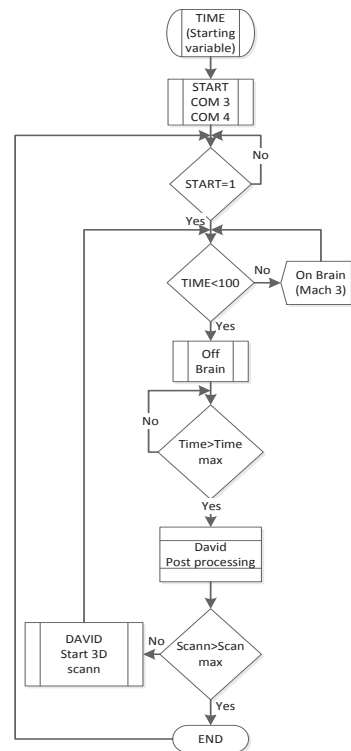Fig. 5. Software for creation of the virtual ports

Fig. 6. Logic schema of the program developed in processing

The third part, called "void draw", makes a repeated cycle till the variable *timescan* becomes equal to *timescanmax*. In this part the procedures for the controlling of the Mach3 and David laser scan software are all realized and executed, using each virtual port declared in the second part of the program.

After doing all the preliminary preparations in each step (as described for the setup of the Serial port monitor, the Mach3 brain, the David laser scanner, and after recalling the algorithm in Processing) the only need is to press the start scan button in the David scanner menu. By doing this, the process will make full 360° scans of the objects.

3. Scanning and monitoring different object scans

In Fig. 7 different scans made with this system are shown. In Table 2 are reported some process parameters for horizontal and vertical scanning types, performed on a 100 mm height sculpture.

In the David platform, after making some automatic individual scans and manual alignment, the full 3D object can be created. These steps, called "Data manipulation", are not part of this work.

Last version of David software (3.9) has the option for auto alignment of the progressive data captures. This means that in our algorithm the variable "*timemax*" needs to be higher, because it will include now the computing time for the alignment of scans.

For scanning reflective components, such as metals, it is necessary to coat the surface with an acrylic primer (Fig. 8).

Different tests were performed scanning also small objects, such as coins. This system uses a Dino-Light pro digital microscope (model AM413-T) as active sensor, having a resolution of 1280x1024 pixels, 10 fps, RGB24 colors. The movement of the laser is done in X direction, with a low speed of 3mm/min (Fig. 9).

In the Appendix A is presented a comparison done with the same 3D model obtained with the Optimet ConoScan 4000 confocal scanning system (with fine path as step along X=0.012 mm and step along Y=0.012 mm, 50mm lens for standard ConoProbe).

4. Conclusions

This work illustrates how a laser scanning system can be simply implemented using simple or retrofitted hardware for the motorized movement, interfacing different low cost or open source software modules.

This scanning speed of these systems is lower, compared with other existing techniques [12], as Structured light (SL), although laser scanning can be more accurate than SL. A further work will be the optimization of the algorithms, for monitoring the

parameters of the system, to improve the communication with Mach3, and the increase of measurement accuracy with using different optics, sensors and geometrical setup. Via rapid prototyping method, based on additive manufacturing techniques, reverse engineering (RE) represents a fast developing business sector for cultural heritage as well as the manufacturing fields [13]. To close the RE cycle in Appendix A (Fig. 12.), are shown some of the scanned object used for these work. The production is made with a low cost 3D printer witch is not part of these work.

Table 2. Horizontal and vertical scanning types performed.

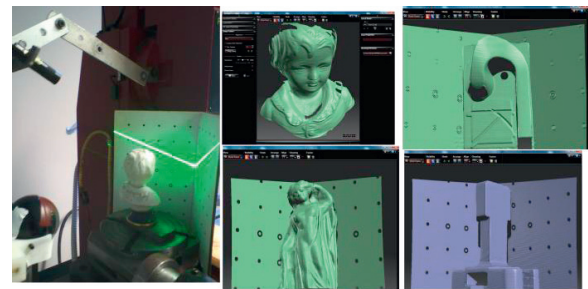| Data:	Scanning in X direction	Scanning in Y direction
Number of scans:	6	6
Angel of rotation individual scans(°):	60	60
Linear velocity (mm/min):	50	50
Inclination angle of laser(°):	30	25
Distance camera-object (mm)	200	200
Camera data:	960x720, 15fps,RGB24;	960x720, 15fps,RGB24;
Total time of scans (min)	40	36

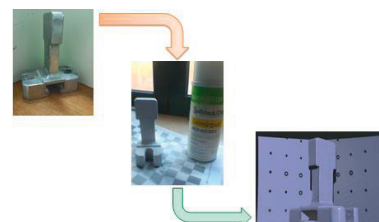Fig. 7. Some tests of semi-automatic scanning systems

Fig. 8. Treatment of metallic parts with primers

Fig. 9. Scanning coins with different systems

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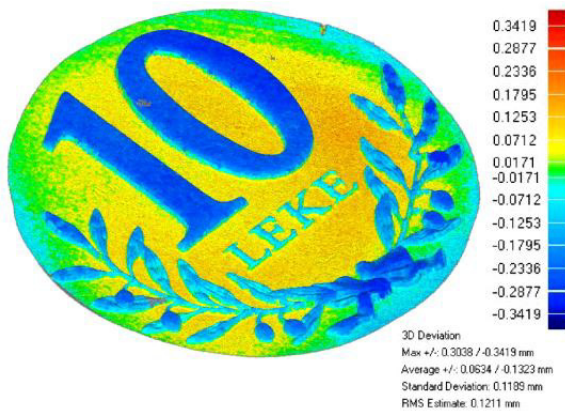## Appendix A. Comparison of scanning systems.

Fig. 10. Comparison of scans for a 10 Leke coin

Reference Model	10 Leke Optimet
Test Model	David Scan 10 Leke Res1280x1024
No. of Data Points scans	406865
Tolerance Type	3D Deviation
Units	mm
Min. Critical	-0.3419
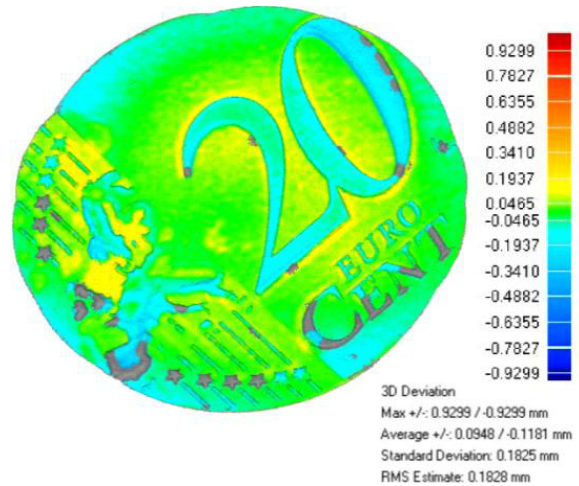
Fig. 11. Comparison of scans for a 20 Cent coin

Reference Model	20 cent Optimet
Test Model	LS 20 Cent Dino scale 34_15
No. of Data Points scans	173880
Tolerance Type	3D Deviation
Units	mm
Max. Critical	0.9299
Min. Critical	-0.9299

Fig. 12. Production with low cost 3D printer (FDM techniques) of scanned objects