Motorized low-cost 3D structured light scanning system for reverse engineering

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Abstract: *Recently, development in the 3D technology is becoming more evident. 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. This paper is focused on the development, implementation and testing of an automated low cost motorized active 3D structured light scanning system (SLS). The scanner is based on the software platform of the DAVID Laser Scanner Vision Systems GmbH's. Advanced of basic technologies for comparing the scanned data, will show the differences in performance of the 3D data acquisition with a test to reference approach with a commercial scanning system.*

KEYWORDS*: 3D SCAN, STRUCTURED LIGHT SCAN, REVERSE ENGINEERING, OPEN-SOURCE, CODED STRUCTURAL LIGHT*

1. Introduction

Nowadays, 3D technology has gained attention in different areas. The main scope is creating a replica of the 3D object. The generation of 3D CAD models is usually the first step in a rapid prototyping (RP) system [1]. The term rapid prototyping (RP) refers to a class of technologies that are used to produce physical objects layer-by-layer directly from CAD data [2].

There are various scanning systems used for 3D scanning. 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 [3]. Of the many available techniques, Structured-light Scanning (SLS) systems have emerged as the most cost-effective and accurate method to capture the 3D geometry and appearance of a real object [4]. Structured light triangulation has become the method of choice for shape measurement in several applications including industrial automation, graphics etc [5]. Scanners that use structured light are in general faster than laser based devices but require longer signal processing [6]. In these systems, specific light patterns are projected onto the object and at least one camera in applied to observe these distorted patterns of object surface [7]. Different calibration approaches have been developed for this type of systems, which computes the intrinsic parameters of the perspective camera and light emitter as well as the relative position with respect to one another [8].

Compared to passive image-based approaches, active sensors provide directly and quickly 3D information of the surveyed object in form of range data (point clouds) [9].

2. Materials and methods

Structured light systems are used for different type of 3D object reconstruction. The scanning systems used in our work, use the triangulation principle for capturing scan data Fig. 1. David structured light scanning system (SLS) use Binary code and Phase shifting. It projects multiple phase shifting patters of a single frequency. David we use the Random Sample Consensus (RANSAC) based algorithm for coarse registration combined with a subsequent ICP for fine registration (optimizing the coarse solution). In coming sections, we are going to present a more detailed explanation of the possibilities that David software has for individual customizations.

3. Experimental work

Our scanning system consists of a low-cost 3D structured light system (SLS) based on the software platform of the DAVID Vision Systems GmbH's DAVID-Laser Scanner. The shelf hardware and equipment's as light projector, web camera and also open-source software can be used for 3D scanning systems [11]. The video projector TOSHIBA TDP S8 (resolutions 1400x1050) was used to project a number of stripe patterns onto the object. To obtain a higher resolution of single scans, we used "Default" pattern parameter, with 26 number of patterns both horizontals and vertically. The camera used has a CMOS sensor model uEye UI-1480-C (5MPixel, 6f/s, CE class A of regulation) and the optic lenses used is Fujinon 1: 1.4/12.5 mm HF12.5HA-1B. Once, the camera and structured light emitter (projector) is calibrated, the field of view of the sensor remains fixed by maintaining constant the distance R from the object Fig. 1. This range will be always in the depth of field of the sensor.

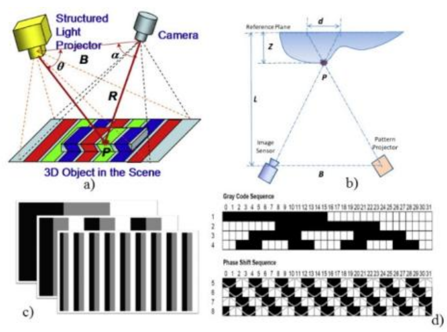


Fig. 1. *a) Illustration of structured light; b) calculation of the Z depth; c) gray level coding patterns; d) combining gray code with phase shift [10]*

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 special codes represented by letters identifying various commands [3] Fig. 2.

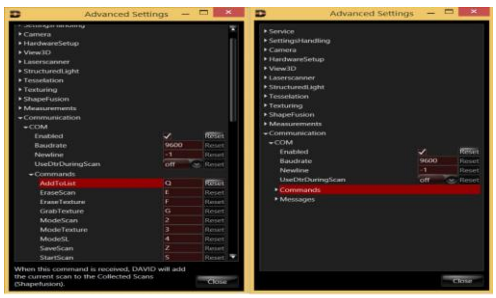


Fig. 2 *Advanced setting in David software*

The setup performed is:

1. Enable the port communication and the "Baudrate" to 9600.

2. Define in "Commands"

a. the letter code "Q" to perform "AddToList"

b. the number code "4" to prepare the system for structured light scanning (SLS) in "ModeSL"

3. Define in "Message"

a. "N" code letter the field "NextSLPattern"; this is necessary for the counting of the number of patterns that David send out for scanning.

Before starting the scanning process, we need to choose the resolution and the parameters in the hardware setup. For having a full scan, we need to rotate the motor 6 time by 60 degrees. For our scans we used a non-standard calibration board with 108.233 mm calibration scale.

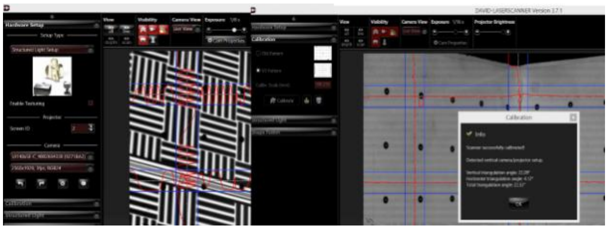


Fig. 3 *Hardware setup and calibration procedures*

After the calibration process results successfully completed, we are ready to perform the full scans process. The schematic setup and the real scanning process of David laser scan is show in Fig. 4 .

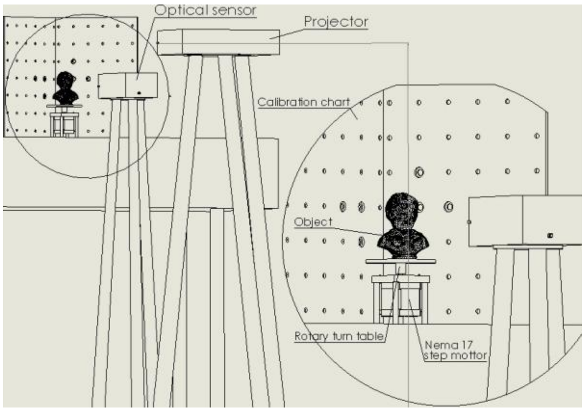


Fig. 4 *David SLS schematic view*

3.1 Rotary table configuration and setup

For performing a full scan, we have built a simple computer controlled rotary table, based on a stepper motor and an open-source Arduino single-board microcontroller. The hardware Arduino Mega 2560 can take inputs from a variety of switches or sensors, and controlling a variety of lights, motors, and another physical sensor. Arduino projects can communicate with software running on the PC [12]. We need to use a breadboard for circuit designed, a L293D quadruple high-current half-H drives for driving the stepper motor. A NEMA 17, 2 phase step motor power 5VDC 0.5A with a steep angle 3.75° was used to rotate the object on the turntable. For a 360° full scan we need 96 steps. As a power source, we used of the shelf hardware, an old PC power supply unit. The schematic connection with all input and outputs pins are shown in Fig. 5. For communicating and controlling David SLS scan and the motor a program inside the Arduino has been compiled.

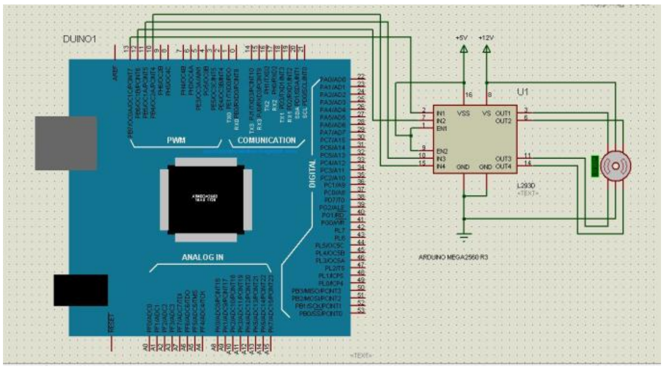


Fig. 5 *Schematic connection for controlling the turntable by Arduino Mega*

4. Results

A qualitative analyze, based on indirect comparison shows the performance of our implemented scanning systems. A test-to-reference data analyze is performed for two complex parts. The first model used for data comparison is a small medium size artistic ceramics statue with 100 mm height, representing freeform geometry Fig. 6 (A). The second model used, is pyramid 60x60x32mm made by resin for molds, and produced in a CNC milling machine, by having same incorrectness from production Fig. 6 (B). Its geometry represents plane parallel surfaces, holes, step planes, end gauges which are some of the main characteristics of artifacts for reference objects used in metrology.

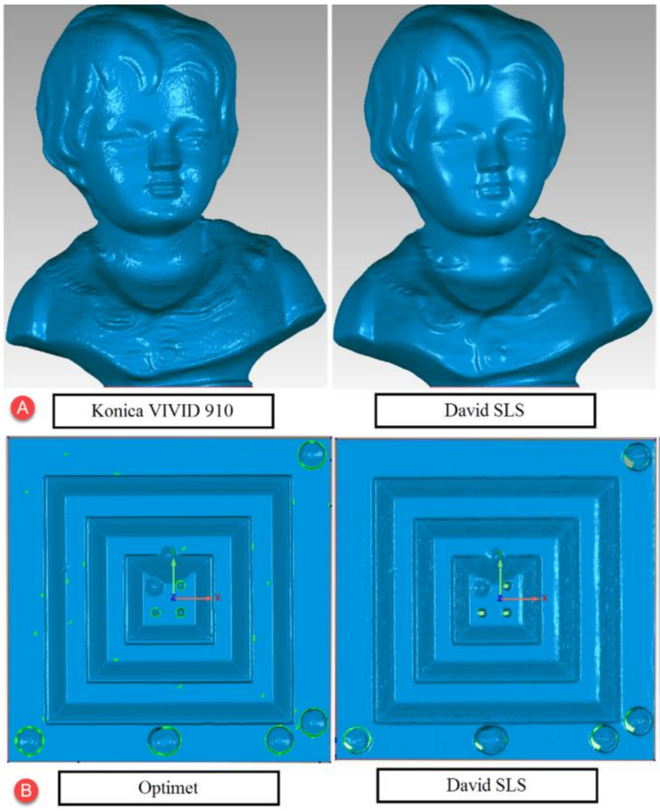
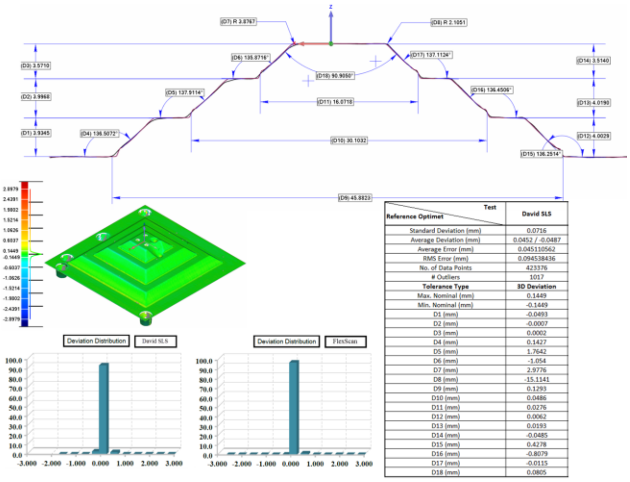


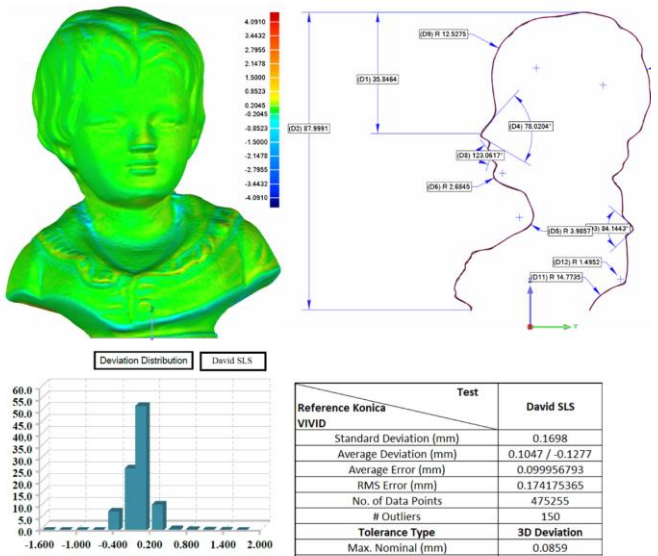
Fig. 6 *A) David Statue figurine; B) Pyramid*

A quantitative comparison of 3D models of the same objects taken by reference systems Optimet ConoScan 3000 and Konica VIDID 910 , was done using Geomagic Studio™ software [13]. The results of the Pyramid comparison between David SLS and Optimet are shown in Fig. 7 and data comparison for the David statue figurine in Fig. 8.



Test / Reference Optimet	David SLS
Standard Deviation (mm)	0.0716
Average Deviation (mm)	0.0452 / -0.0487
Average Error (mm)	0.045110562
RMS Error (mm)	0.094538436
No. of Data Points	423376
# Outliers	1017
Tolerance Type	**3D Deviation**
Max. Nominal (mm)	0.1449
Min. Nominal (mm)	-0.1449
D1 (mm)	-0.0493
D2 (mm)	-0.0007
D3 (mm)	0.0002
D4 (mm)	0.1427
D5 (mm)	1.7642
D6 (mm)	-1.054
D7 (mm)	2.9776
D8 (mm)	-15.1141
D9 (mm)	0.1293
D10 (mm)	0.0486
D11 (mm)	0.0276
D12 (mm)	0.0062
D13 (mm)	0.0193
D14 (mm)	-0.0485
D15 (mm)	0.4278
D16 (mm)	-0.8079
D17 (mm)	-0.0115
D18 (mm)	0.0805

***Fig. 7** Data analyze for pyramid*



Test / Reference Konica VIVID	David SLS
Standard Deviation (mm)	0.1698
Average Deviation (mm)	0.1047 / -0.1277
Average Error (mm)	0.099956793
RMS Error (mm)	0.174175365
No. of Data Points	475255
# Outliers	150
Tolerance Type	**3D Deviation**
Max. Nominal (mm)	0.0859
Min. Nominal (mm)	-0.0859
D1 (mm)	0.1119
D2 (mm)	-0.186
D3 (mm)	9.4251
D4 (mm)	3.9571
D5 (mm)	-1.513
D6 (mm)	-0.0267
D8 (mm)	33.8588
D9 (mm)	0.3206
D10 (mm)	0.412
D11 (mm)	2.4596
D12 (mm)	1.3841

***Fig. 8** Data analyze for statue figurine*

5. Discussion

The creation of semi-automatic low cost SLS system based on open-source hardware/software can permit users to create powerful algorithm codes for fast data capture and why not to be fully automatic process. David software is user friendly and can be modulated in different ways regarding its possibilities of sending and receiving command to different hardware/software connected to the systems. The time needed for David SLS system for data acquisition and processing (in default mode) is more than 90 sec. Especially when a high level of smooth average and quality check is chosen in David the tame for data processing can be higher. The time needed by our semi-automatic system for six single scans data acquisition and processing was 6.5min. The system resulted to have no problems working in laboratory condition with normal lights illumination.

6. Conclusions

The scope of our work was creation of semi-automatic low cost SLS system based on open-source hardware/software. In further publication by author David laser scan scanning software resulted do integrate very well with not only open-source software but even with standard equipment which have a motorized movement system as CNC machines [3]. Using low-cost systems for digitizing 3D object offer the potential for users to construct and implement a scanning system which has good performance with semiprofessional ones. These to be clear not that these user-build system are going to substitute the commercial scanning system in the dedicated areas. But with a good know-how experience users can obtain adequate results in the range of microns to millimeters.

From the results taken, we did not encountered problem with medium reflective surface, but problems can occur when dealing with metallic objects because of their higher reflective surface.

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