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Invited Paper

3D surface digitizing and modeling development at ITRI

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ABSTRACT

This paper gives an overview of the research and development activities in 3D surface digitizing and modeling conducted at the Industrial Technology Research Institute (ITRI) of Taiwan in the past decade. As a major technology and consulting service provider of the area, ITRI has developed 3D laser scanning digitizers ranging from low-cost compacts, industrial CAD/CAM digitizing, to large human body scanner, with in-house 3D surface modeling software to provide total solution in reverse engineering that requires processing capabilities of large number of 3D data. Based on both hardware and software technologies in scanning, merging, registration, surface fitting, reconstruction, and compression, ITRI is now exploring innovative methodologies that provide higher performances, including hardware-based correlation algorithms with advanced camera designs, animation surface model reconstruction, and optical tracking for motion capture. It is expected that the need for easy and fast high-quality 3D information in the near future will grow exponentially, at the same amazing rate as the internet and the human desire for realistic and natural images.

Keywords: 3D, surface digitizing, surface modeling, range image, reverse engineering

1. INTRODUCTION

The Industrial Technology Research Institute (ITRI) of Taiwan has been devoting to the research and development of 3D surface digitizing and modeling for almost a decade. As a major technology and consulting service provider of the area, ITRI has developed 3D laser scanning digitizers ranging from low-cost compacts, industrial CAD/CAM digitizing, to large human body scanner, with in-house 3D surface modeling software to provide total solution in reverse engineering. The core abilities to acquire 3D information from sophisticated-shaped objects and to process and manipulate its large number of 3D coordinate data have enabled the applications in reverse engineering, body scanning, and 3D animation.

2. METHODOLOGIES

2.1 3D laser stripe digitizer

The concept of ITRI's non-contact 3D digitizer is illustrated in Figure 1. A stripe of laser is projected onto the surface of an object, and the reflected light is captured by either of the CCD cameras to avoid occlusion. Based on optical triangulation and camera calibration parameters, the 3D coordinates of the illuminated data points on the object surface can be calculated as shown in Figure 2. Integrating the digitizer head and a four-axis translation-rotation stage, as shown in Figure 5, can fully digitize a 3D object automatically. The digitizer head has a depth of field of 170 mm, and the system scans at speeds up to 3,000 points per second and precision up to 50 μm. The digitization generates a large number of 3D coordinates from different viewing angles. Figure 4 illustrates the surface modeling process to make these unorganized 3D data useful. (See Section 2.2 for details.) Thorough discussion of the design and analysis of the digitizer can be found in [3][7][8].

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A low-cost compact version with only one CCD camera for triangulation in PC-based applications is shown in Figures 3 and 6. It is designed so that one CCD retains the information of two fields of view of the original two-CCD design to account for occlusion issues without compromising precision and accuracy [2]. We further design the scanner to equip with a color CCD camera for building a complete color 3D model.

2.2 3D surface modeling

As illustrated in Figure 4, after acquiring large number of 3D coordinates from many viewing angles, registration and merging are two fundamental steps to create a useful 3D surface model. A polygon-based method for describing a complete object is proposed [6]. Multiple range images are integrated into a single polygonal, usually triangular, mesh. Registration is to align the multiple range images into the same coordinate system. Merging then removes redundant data and stitches these images to a single mesh. Our program needs no additional information from the digitizer. Figure 7 shows the reverse engineering surface modeling result of an impeller and its rapid prototyping replica.

Surface modeling from 3D laser digitizer enables the capture of detailed description of the object surface, but the large number of 3D coordinates or polygonal information hinders efficient usage and effective applications of the surface models. We proposed a sequential decimation process to reduce the number of polygons in a triangular mesh after the registration and merging of multiple range images are performed [12]. An iterative vertex decimation method is used to remove vertices with minimum re-triangulation error. To reduce the distortion resulting from polygon reduction, vertices are characterized by local geometry and topology before the re-triangulation error is evaluated. This algorithm can be applied to not only triangular meshes generated from 3D digitizer, but also general volume meshes and terrain meshes. Figure 8 demonstrates results from our polygon reduction algorithm.

One other common issue in 3D digitizing is finding the next best view to efficiently digitize the object by calculating the next best position or a working path of the sensor, which has been well addressed by peers. In developing our low-cost scanning system that has significant less degrees of freedom in movement, however, we tackle a similarly important issue of deciding the best positions of the object for efficient scanning in building an effective 3D surface model. A low-occlusion approach is proposed to find the best viewing position for scanning by considering the position of the object instead of the sensor [1]. The efficiency improves significantly by combining carefully planned working path of the sensor and optimum positions of the object.

3. APPLICATIONS

3.1 Reverse engineering

An important and original application of the 3D digitizers is in reverse engineering as already illustrated in Figure 7. We have consulted a wide range of traditional to hi-tech industries that adopts 3D digitizing as an indispensable tool for computer-aided design, manufacturing, and inspection, including applications in parts design, industrial design, tooling, sculpture, ergonomics, textile, and foot wear.

A good example is in the measurement and inspection of tires [10]. A 3D digitizing sensor is installed on a 4-axis mechanism to scan the whole tire surface in radial and circumferential directions. The laser stripe generates a section curve in the radial direction. The 3D coordinates of a series of points along the curve can be measured with an accuracy of 0.05mm. The scanned result is shown in Figure 9. The geometry of the tire can thus be evaluated, including width, diameter, circumference, arc value, and roundness. The dimensional error is always less than 0.15mm. Tread wear can also be quantified by comparing the digitized surface data to its original data, and the resolution is up to 0.1mm.

3.2 Body scanning

It is only natural that 3D scanning find applications in uman-related measurements because of the abundant information 3D digitizers are able to provide dealing with biologica. :md highly diversified subjects compared to the limited data from using conventional meters. As shown in Figure 10(a), our human body scanner consists of six 3D digitizers and three vertical translation axes. The range of measurement is 1900mm in height, 900mm in width, and 500mm in depth. It takes approximately 8 seconds to capture whole-body data of a 180-cm tall subject with a per-4 mm profiling, a horizontal resolution less than 2 mm, and a range resolution less than 1 mm. The body scanner satisfies the requirements for speed, safety, comfort, and efficiency, and has been used in consumer-product design and health care applications. Figure 10(b) illustrates the rendered results of scanning of a human subject [13].

3.3 3D animation

To obtain realistic visual effects, more and more motion picture and animation productions adopt reverse engineering technologies. 3D digitizers and motion capture systems are two important tools in this domain. Manipulating large quantity of scanned 3D data, however, is highly inefficient and difficult for animators when using 3D digitizer to build models. In the 3D modeling animation process, two issues are of major concerns: fast surface reconstruction and easy surface structure manipulation. Fast surface reconstruction saves time and thus cost. Easy surface structure manipulation asks for continuity maintenance and flexible orientation of coordinate system for merged surface reconstruction. We proposed a fast surface reconstruction pipeline of the 3D digitizer and used a motion capture system to integrate surface modeling technologies [9]. Figure 11 shows the results after clustering, surface reconstruction, and motion capture integrated animation rendering.

4. OUTLOOK

It is expected that the need for easy and fast high-quality 3D information in the near future will grow exponentially, at the same amazing rate as the internet and the human desire for realistic and natural images. 3D imaging can be achieved from many sources, including active scanning for model-based 3D and passive capture for vision-based 3D. Either one has its advantages, and integration at some level is expected to be a certain route towards advancement of the technology. The requirement of performances will certainly go in the direction of real-time, dynamic, high-resolution, and high-accuracy 3D imaging.

Based on both hardware and software technologies in scanning, merging, registration, surface fitting, reconstruction, and compression, ITRI is now exploring innovative methodologies that provide higher performances. A project involving hardware-based speckle image correlation algorithms with advanced camera designs [4][11] wishes to provide high-speed 3D imaging capabilities. Effort in animation application will continue with integration of capabilities in high-speed tracking for motion capture. Acquiring 3D information from vision-based cameras will also be pursued. Topics in creating natural 3D color will be explored. Integration among 3D input, processing, display, and human interface technologies to spawn more innovative ideas in human-centered technologies is underway.

5. ACKNOWLEDGEMENTS

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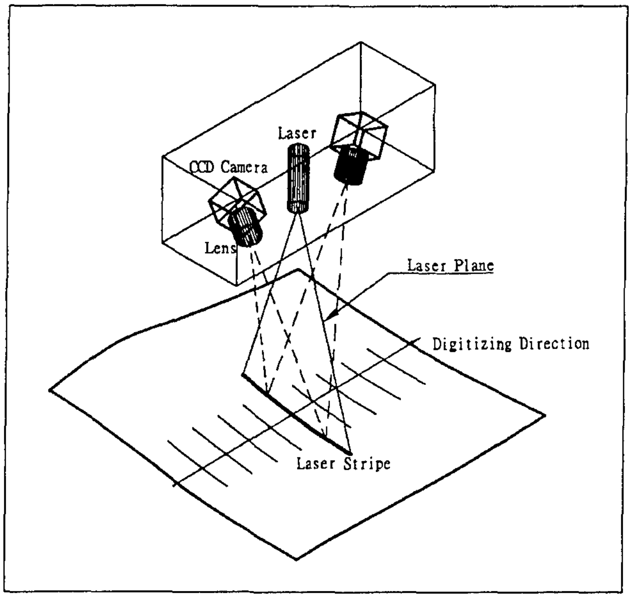


Figure 1. 3D laser stripe digitizer schema.

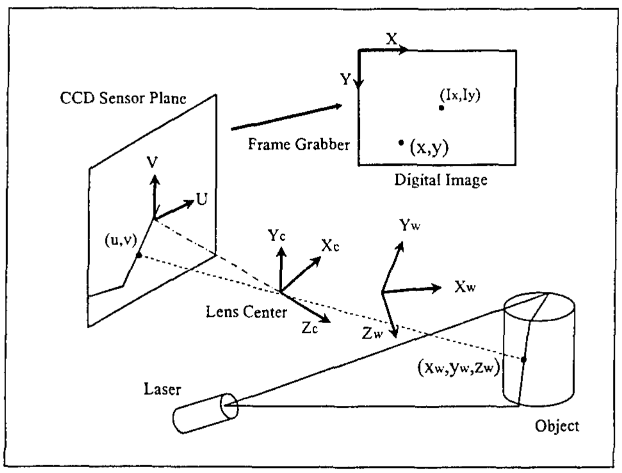


Figure 2. 3D image formation.

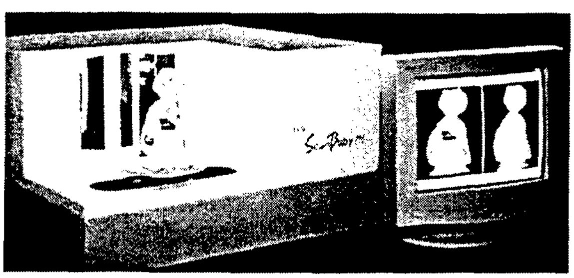


Figure 3. ITRI low-cost 3D scanner.

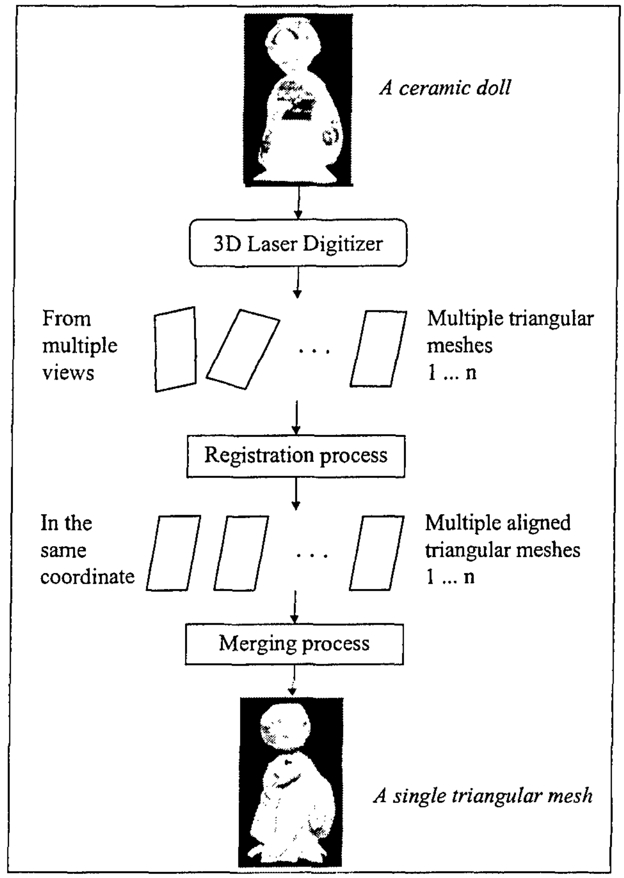


Figure 4. Procedure of surface model integration.

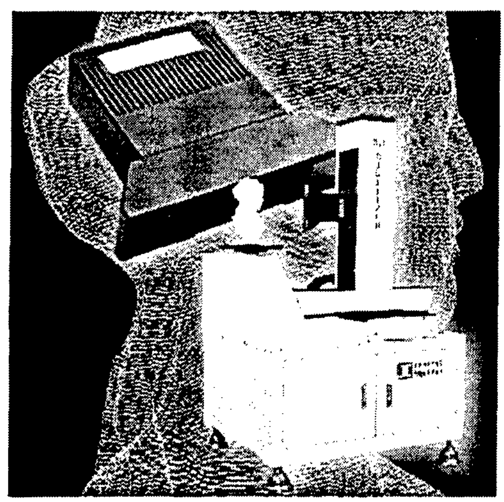


Figure 5. ITRI 3D laser digitizer.

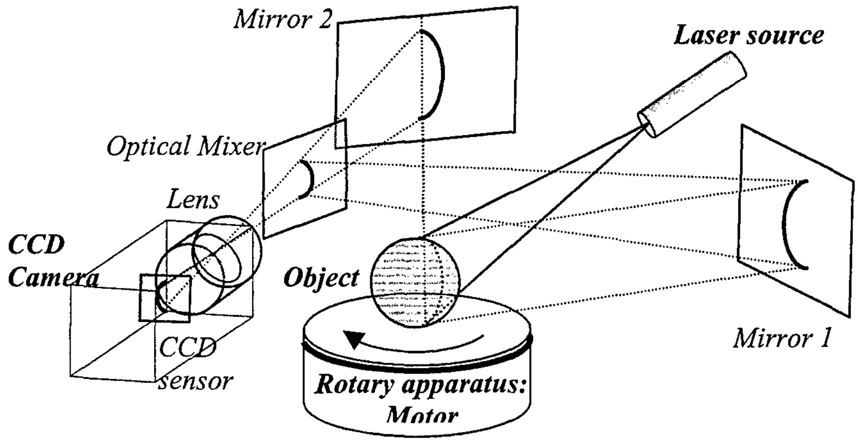
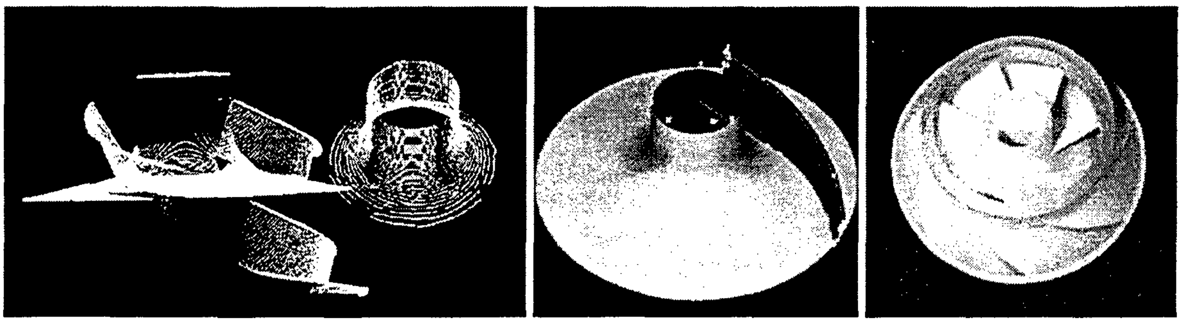
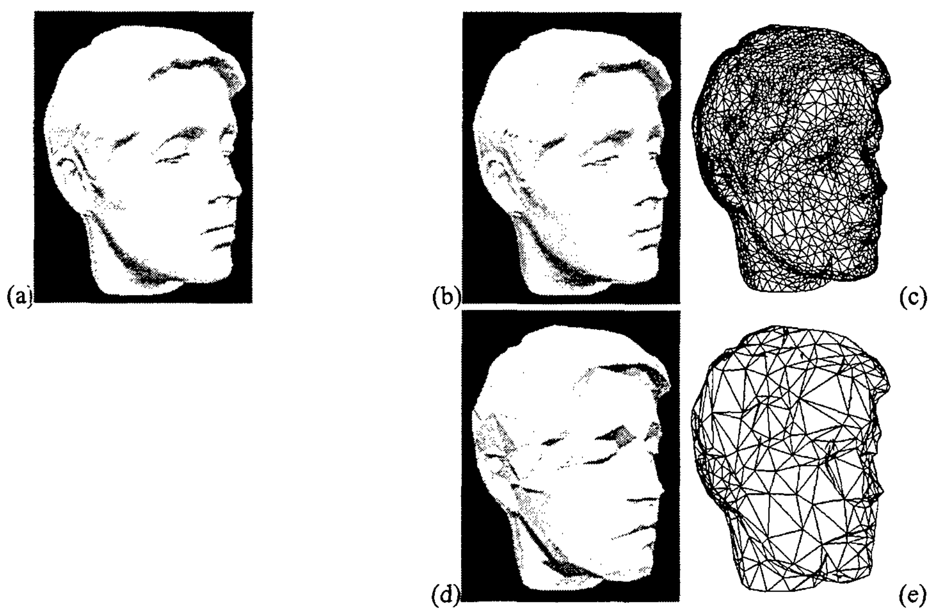


Figure 6. Low-cost scanner schema.



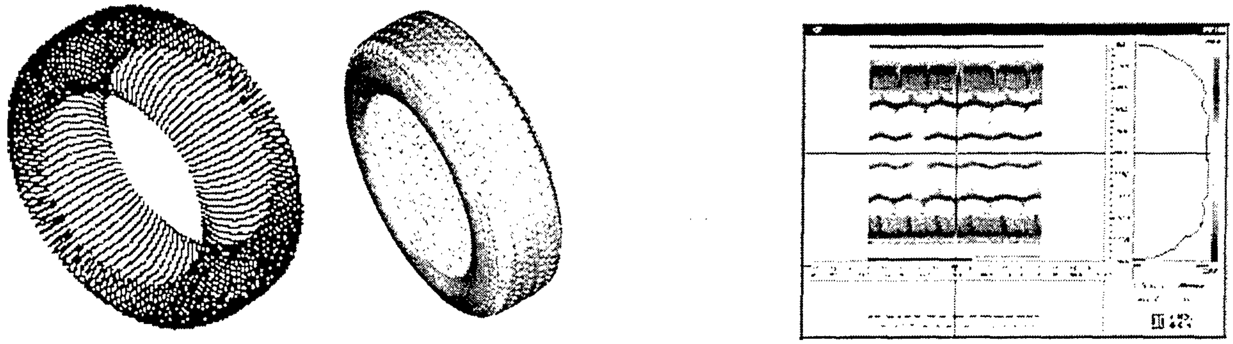
(a) (b) (c)

Figure 7. Impeller surface modeling. (a) Multi-view range data, (b) fitted impeller vane surfaces, (c) rapid prototyping.



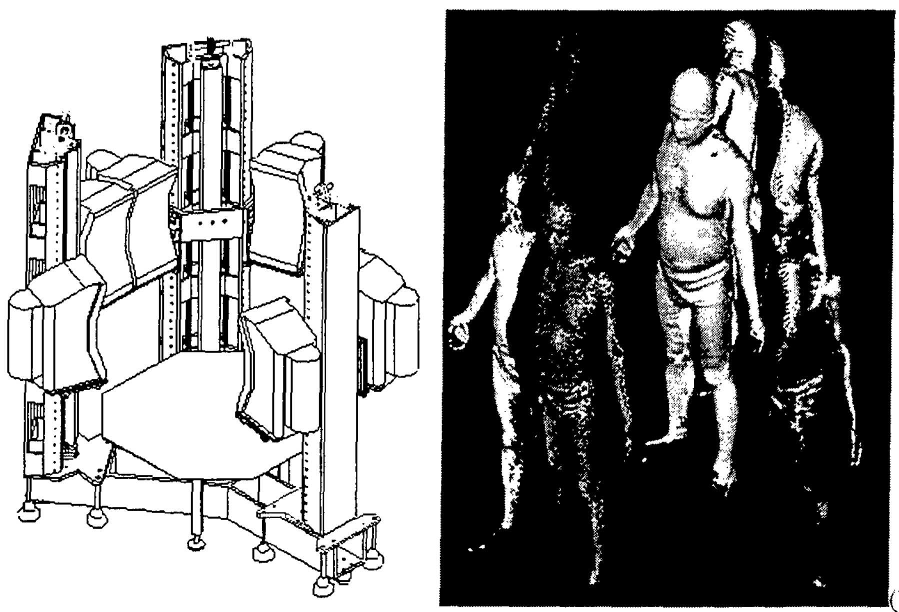
(a) (b) (c) (d) (e)

Figure 8. Polygon reduction of a human head model. (a) Original flat-shaded model from 3D digitizer (43,359 triangles), (b) 75% polygon reduction (10,795 triangles) flat-shaded, (c) wire-frame, (d) 97% polygon reduction (1,262 triangles) flat-shaded, (e) wire-frame.



(a) (b) (c) (d)

Figure 9. Application in reverse engineering for tires. (a) Measured 3D profile, (b) shaded image of tire, (c) radial section profile, (d) wear inspection.



(a) (b)

Figure 10. ITRI whole body scanner. (a) System schema, (b) multi-view merging and rendering of measured human body 3D data.

(a) (b) (c)

Figure 11. Application in 3D animation. (a) Clusters in a facial model, (b) surface patches, (c) rendered images of facial animation.