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Beyond Range Sensing: XYZ-RGB Digitizing and Modeling

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Abstract

This talk will review the progress and the evolution of the development of range sensing techniques at the NRC laboratories. Essentially a 3D imaging project at the beginning, it has evolved to a new media project which requires the development of new tools for 3D modeling, editing, database searching and visualization. Generic applications related to documentation, inspection, target tracking and visual communication will be discussed.

1 Introduction

The surface shape of objects can be imaged and digitized using the following basic components: a light source to define a specific pixel(s), such as an encoding-decoding process (triangulation, fringes and patterns projections and time of flight are examples), a sensing device composed of a collecting lens and a photodetector that convert light energy to an electrical signal, an analog to digital converter and finally a computer to process, display, and store the raw data.

Conventional light sources can and are used to digitize shapes, but laser sources have unique advantages for 3D imaging. One of them being its brightness, which cannot be obtained by incoherent emitters. Another feature is the spatial coherence, which allows the laser beam to "stay in focus" when projected onto the scene.

Upon scattering, the spatial coherence of the laser light is lost, which means that the depth of field used at the projection can be useful only if we close down the lens aperture at the collection, otherwise the focused laser spot is imaged as a blurred disk of light on the photodetector. A solution to this problem is to modify the conventional imaging geometry to conform to the Scheimpflug condition[1]. Essentially, this geometry allows the position-sensing detector surface to "stay in focus" with the projected laser light.

Figure 1 shows on top the first prototype build in 1982 and an illustration of the scans produced at that time. Most of the design including visualization was based on analog electronics. Below is a photograph of a Virtual Reality theater installed at the Canadian Museum of Civilization located in the Ottawa area. Also a photograph of a multimedia document which is integrating computer graphics, photographs, a 3D scan of a replica of the Tutankamon mask, narration and music. This interactive virtual visit of the Tutankamon tomb has been shown for an Egyptian exhibit which ended spring 1999. Since 1982, the whole process has evolved to digital, from scanning to display.

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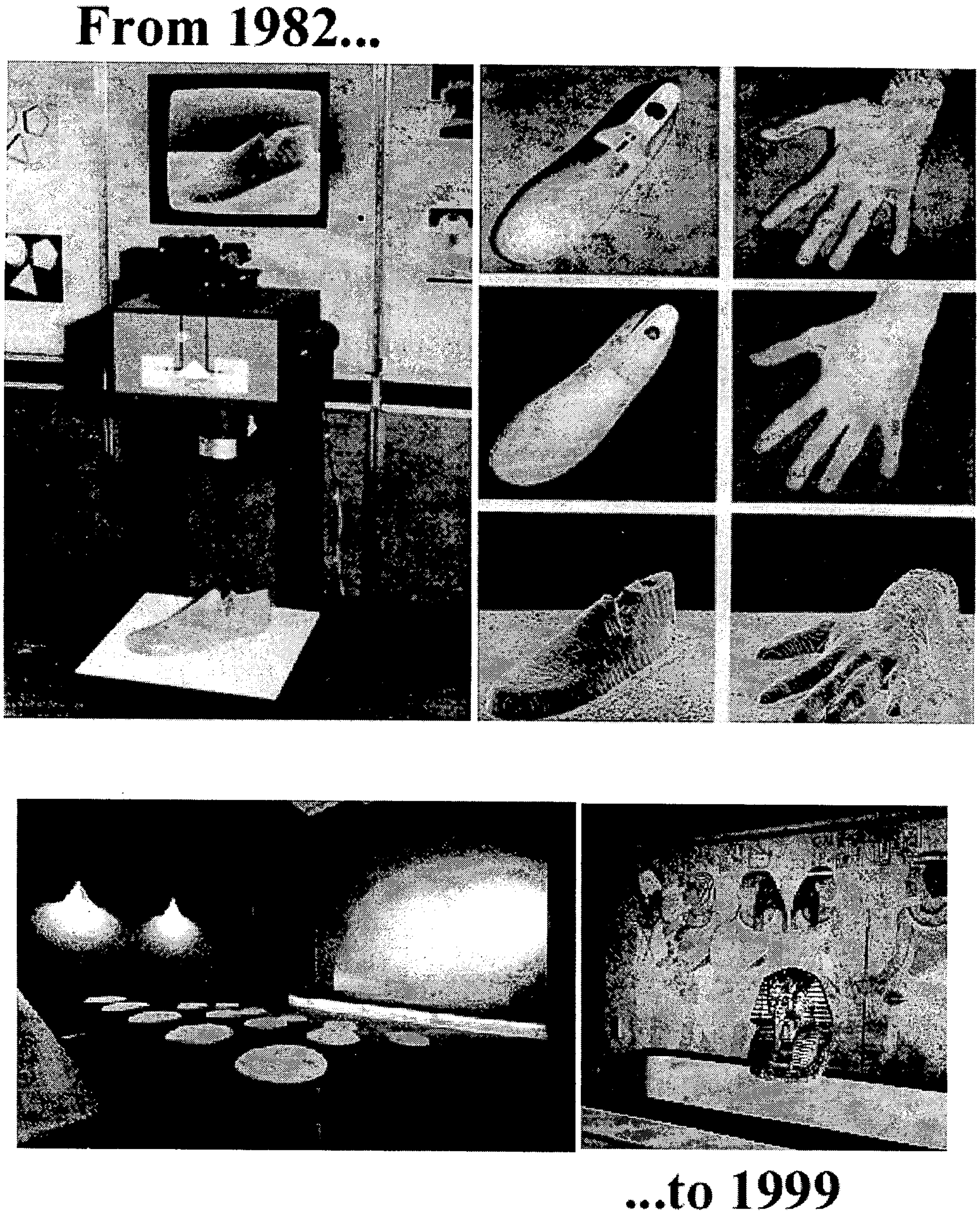


Figure 1. Top: The first 3D digitizer built in 1982. Bottom: A VR exhibit using a color scan based on a 3D color digitizer.

2 From B&W to Color

A very simple way to add color to the 3D digitizer is illustrated in figure 2. Here, at the projection level, the single wavelength laser is replaced by a RGB laser which projects a "white" laser spot on the object's surface[2]. RGB stands for red, green and blue wavelengths, which are simultaneously combined in a single mode optical fiber.

The second modification is made at the detection level. A prism (or a wedge) is used to disperse the RGB laser beam in 3 separate beams, each of them having an amplitude related to the spectral component of the illuminated point on the surface of the object.

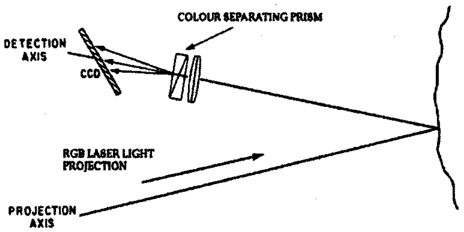


Figure 2. Geometry for the simultaneous recording of geometry and color.

An interesting feature of this geometry is that the shape and color are digitized simultaneously, thus allowing a perfect registration of geometric and color data. This is essential for effective reflectance modeling.

3 From 3D Data Points to Geometry

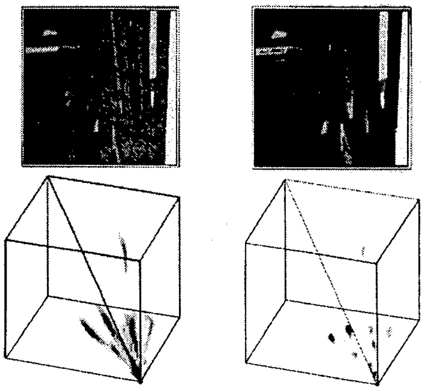
As in the OCR (Optical Character Recognition) case, the geometric recovery is noise sensitive. The process of recovering the geometry from the scanned data is known as reverse engineering, and the geometric primitives [3] are those supported by CAD software, such as cylinders, spheres, lines, circles, splines, NURBS and others.

When using an image of a manufactured part, which has been designed using the known CAD geometric primitive, the complexity of process is the lowest, yet, as in OCR, substantial user interaction is needed in order to fully recover the original file. The level of user interaction increases with the image noise.

4 From Geometry to Reflectance Modeling

One can approach this problem from two directions. Color modeling using the 3D raw data (with noise) as the shape input, or physical modeling using combined geometric and color modeling. In reference[4] the first approach has been reported. Surface orientation information are obtained from the 3-D image file and reflectance properties of the object's surface are reconstructed using a Torrance-Sparrow[5] model. As in the above case of geometric modeling, user interaction is needed to recover the desired information. The user input here, is the proposed model for reconstruction and the validation of some segmented areas when a variety of materials are in the field of view.

Figure 3 illustrates the reflectance modeling process. The color image as digitized is shown on the upper left. An RGB plot of all the pixel values can be seen below this image. On the upper right is a corrected image using reflectance modeling. Below is the corresponding RGB plot. We can see that the reflectance modeling has successfully found the normal reflectance of the objects in the scene. Indeed, the distributions of color in the RGB space are now invariant to object's shape and to the geometry of the illumination.



a) b)

Figure 3. Reflectance modeling of 3-D color data. (a) Original color distribution in the RGB space. (b) Same color distribution after reflectance modeling.

In other words, because we know the geometry of the illumination and also the surface orientation (here computed directly from the 3-D color portion of the data), it is possible to recover the normal reflectance value at each and every pixel of the scanned image. Instead of spreading, the color distribution now clusters in small spherical distributions. The "intrinsic color" of each individual object in the scene can now be recovered by segmentation of the clusters and by centroid calculation.

5 Target tracking

The geometry consists in a two axis synchronized scanning[6], both controlled by galvanometer-driven mirrors. Essentially this 3D digitizer has random access digitizing capability over a field of view of more than 4K pixels along each axis x, and y. When mounted on a rotating platform it is used to digitize 3D panoramas over 360 degrees.

6 Automated Digitizing and Modeling

An experimental set-up for the automation of the digitizing and modeling process has been built in the laboratory[7]. The objective is to develop practical automated and semi automated methods of acquiring complete dense samplings of the surface of objects for model building and inspection applications.

The setup consists of two sensing platforms. The first platform comprises a Biris[8] range profile sensor mounted on a translation stage. The stage sweeps the sensor perpendicular to the orientation of the profile to generate a single range image. A rotary index table, on which the sensed object is placed, provides an additional degree of freedom. By indexing the rotary table to various positions, a set of overlapping images of the work piece is acquired. Each image is taken from a different vantage point and, as the table is instrumented, the entire set of images can be directly composed into a registered set which completely covers the object.

The objective of the first platform is to completely automate the acquisition process. This platform is appropriate for objects which are small enough to fit on the rotary index table and within the sensor's field-of-view, and are convex enough to not present significant self occlusions.

For larger and more complex objects, the second platform is more appropriate. A Biris range profile sensor is mounted on the end of a CRS A465 6 degree-of-freedom robotic manipulator. The manipulator is used to position the sensor in space, and the most distal joint is used to enact a cylindrical scan. A graphical user interface has been developed as a user aid to plan semi-autonomous scanning processes. Also, a fully automatic system based upon next-best-view planning is under development.

7 Geometric inspection

A reference part is scanned as a "gold standard" and the production parts are compared against it. The technique named differential inspection consists in subtracting the two 3-D images and by tresholding the result. Any deviation larger than the specified tolerance level can also be color-coded to visualize the location defects on the object's surface. The reference shape can also be a 3D CAD file[9].

8 Reflectance inspection

For each x y z coordinate, we have a registered spectral component (s) which can be calibrated and compensated to describe the normal reflectance at this specific spatial coordinate. Then, the same strategies used above for geometric inspection can be used here for reflectance inspection.

9 Future Directions

Multi-spectral 3D digitizing is not limited to three values in the visible part of the electromagnetic spectrum. A choice of laser wavelengths is available from the ultraviolet to the infrared. Some lasers emit simultaneously many lines in the visible or in the infrared. Any combination of these wavelengths can be used to design a specific 3D digitizing system.

When an ultraviolet laser light is used at the projection, fluorescence 3-D digitizing can be made using the arrangement shown in Figure 2. As in the case of reflectance measurements the fluorescence values can be calibrated to compensate for the geometry of illumination and the geometry of the object to be digitized.

Polarization of laser lights has also much potential for the analysis of specular reflection in order to identify and measure material properties such as surface finish and glossiness.

Translucence is typical of many plastic used in the molding industry. Such a property can easily be monitored by analyzing the laser spot profile detected by the position-sensing unit.

In the long term though the technology should lead to the measurement of the BRDF (Bi-directional Reflectance Distribution Function). Such a distribution could prove to be very useful for the quality inspection of not only manufactured parts but also for food products.

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