RAPID 3D MODELING AND RECONSTRUCTION

A white paper presented to
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by

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July 15, 1993

1 Summary

As FAX and Xerox machines are revolutionizing our ability to copy and transmit documents, we are beginning to consider technologies for copying and transmitting solid 3D objects. Such systems would require two phases: input of an accurate digital model of the original, and output of the digital model as a useful replica. For a stand-alone system, both phases must be rapid and accurate. Such a system would permit the remote design, expert analysis, and archiving of both manufactured and natural artifacts, thus making a profound impact on both the natural and artificial sciences.

For the output phase, tremendous progress has been made in the past 5 years in Rapid Prototyping, where a digital model is used to drive a laser deposition process that stacks slices of the numerical model to output a 3D solid. A variety of media with tradeoffs in accuracy and strength are currently being explored, ranging from liquid polymers to metal droplets. An alternative is to use computer-driven machine tools to mill solid objects. Note that for some applications, it may not be necessary to actually replicate the 3-D object, but only to transmit the 3D model for remote visualization on a computer screen.

The acquisition phase is currently performed either by contact probing, or by active range sensing methodologies, such as active triangulation, striped lighting, grid coding, laser time of flight or ultrasonic. Each of these methodologies comes with with its strengths and limitations. Some of the approaches in active triangulation are maturing fast and offer great hope for inexpensive, off-the-shelf range sensors with a wide application range. After a set of 3-D data points on the surface is obtained, it must then be integrated into a coherent 3D surface. Here again, new algorithms are maturing fast.

USC is in a unique position to develop such a 3-D acquisition, processing and analysis system; we have assembled a highly interdisciplinary team of researchers anchored in the School of Engineering and have identified an immediate demand for such a system in the medical sciences, specifically dental reconstruction: two world-class experts from the Dental School will play a critical role in the project.

For the input phase, we propose to design and build a high-resolution sensor capable of high-speed data acquisition. We will also continue to develop methods to transform the set of data points into a coherent surface model, similar to one generated from a CAD system. Prof. Nevatia's group has considerable experience in this area. Prof. Gaudiot has experience in parallel processing, a crucial necessity in a real time working environment. For the output phase, in addition to monitoring research in Rapid Prototyping, we will also explore NC machining, where a part is created by subtractive milling. This alternative is particularly suited to dental applications. The challenge is to automatically plan a tool trajectory that incorporates tool offsets, avoids collisions, and adapts tool velocities to avoid overheating (for example at points of high curvature). Currently there is no system capable of automatically planning tool paths. Profs. Goldberg and Requicha have expertise in the area of robot motion planning and solid modeling and will focus on this phase.

For the synthesis of both phases, Prof. Duret has 20 years experience building a system for computer-aided scanning and on-site manufacture of dental implants. Over these years, a multi-million dollar research investment in his group, based in France, produced 7 patents and a commercial product (see enclosed). Prof. Duret has an appointment at USC's School of Dentistry,

where he works closely with Prof. Jack Preston, Chair of the School's Department of Oral and Maxillofacial Imaging.

We propose to develop two working prototypes. Initially, we will design and fabricate a macro prototype for objects on the scale of 10cm to 1m. This will allow us to develop and test modeling algorithms at a scale that will not require special-purpose sensing hardware. We will concurrently study the unique requirements of dental applications and design a micro sensor that can be used in the mouth with an output system for objects on the scale of .1 to 1cm.

This project has strong potential for attracting industrial funding. Prof. Duret has made contact with four multinational companies (Masushita, Mitsui, Nikon, and Sopha) who have expressed interest in commercializing such a system.

If warranted, we will prepare a detailed review of the state of the art in both input and output phases of solid modeling and a detailed workplan with milestones and budgets. Prof. Jean-Luc Gaudiot of EE-Systems will coordinate this project.

Below, reconstruction of tooth geometry from a dense sample of data points (USC IRIS: R. Nevatia, G. Medioni, and CW Liao.).

(a) data points (b) shaded result 1 (c) shaded result 2