Towards A New Generation Dental CAD/CAM System

(Preliminary Proposal)

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1 Introduction

The dental CAD/CAM system invented by Dr. Francois Duret involves in the following 3 steps in creating a complete restoration:

1) Data acquisition and processing,
2) Restoration design, and
3) Milling.

The first step can be further divided into the following parts:

a) Range image acquisition,
b) Registration and data integration, and
c) Range image processing.

The current system can be improved in many of the above mentioned areas by adapting recent research results in machine vision and image processing conducted here by the USC-IRIS group, and by further research conducted specially for the dental CAD/CAM system, as will be described below. Based on our expertise and our experience, we are proposing to conduct research on the dental CAD/CAM system in the first two areas mentioned above, namely, the data acquisition and processing, and the restoration design. Our emphasis on this research are accuracy, autonomy and user-friendliness for a new generation of dental CAD/CAM system.

2 Building a next generation range sensor

Range sensors have been successfully used in the industry as demonstrated in the current dental CAD/CAM system by Sophia Bioconcept. However with the new development the restoration design research, the system may benefit from a new range sensor system. At this time, we need further information on the current system to discuss possible improvements. Our group has built a few range sensors over the years ([7]).

3 Registration

After the range images of the plaster models are taken, the 3-D information from different viewpoints must now be combined to provide an integrated data set as the basis for the restoration design. The most important issue is the precision of the integration because the restoration design depends directly on the measurements obtained from the range measurements and any misalignment among the range image views will result in loss of significant clinical landmarks and errors in the measurements thus compromising the accuracy of the restoration design. This brings up an important issue of sensor system calibration which provides necessary information for the data integration process.

In a conventional system, calibration is done once before system is in operation. More advanced systems need to be able to calibrate the system on-line, or in other words, the system needs to be able to perform self-calibration during operation. There is also an issue of open-loop versus closed-loop calibration. Our purpose for the system calibration is to acquire necessary information for data integration. Even with a carefully calibrated system for range image acquisition, errors can still occur in every stage of the acquisition, which can not be corrected by an open-loop system itself. Thus a closed-loop calibration system is needed to verify the calibration by examining the quality of the integration.

We propose to achieve this closed-loop self-calibration through range image registration. This range image registration process is to match between a pair or more range images in the overlap regions of the images and compute the exact 3-D transformation that can precisely align the set of images to provide a complete set of data for the model. This registration process can ensure the quality of the data integration and is carried out for every set of range images. The Computer Vision group in USC-IRIS has conducted extensive research on range image registration in recent years and our findings are widely cited in the literature [1]. The algorithms in our research are very suitable for the type of application for the dental CAD/CAM environment. Some highlights of our range image registration algorithm can be described as follows.

- The algorithm works on raw range images, thus eliminating the need for feature extraction, and also allows us to achieve highest registration accuracy possible with the input data.
- No correspondence between range image segments is needed to achieve registration. The registration is achieved by exploring the geometric constraints between the range image segments and by minimizing a viewpoint invariant distance measure between the range images. Our formalization of the minimization process results in a very fast convergence compared with the methods used by others (e.g. [6]).
- The algorithm allows registration to proceed incrementally one view at a time and optionally integrate the views into a single object oriented representation.

Figure 1 shows a plaster tooth model we used in our experiment. Figure 2 shows the result of registering and then combining a set of 18 range images of the model tooth.

It is clear that significant amount of research is needed in order for our registration system to work in the dental CAD/CAM environment and to take the advantages of the known environment to achieve the best possible results. Among them are the coordination between the registration system and the range imaging device so as to perform sensor planning or to utilize sensor

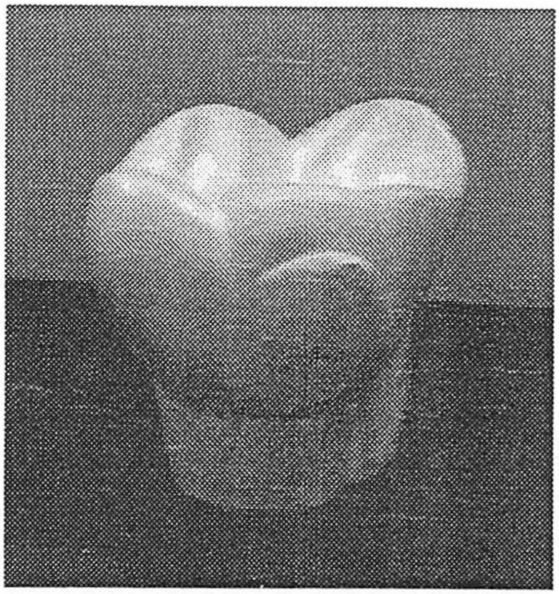


Figure 1. A plaster tooth model.

calibration for initial registration estimate; registration error analysis and performance analysis; data integration and representation to facilitate data processing and restoration design (see below).

4 Range image processing

Processing the acquired range images includes two steps. One is the integration of the registered range images. The second is to perform noise filtering and feature extraction. Noise is inevitable in any process requiring data acquisition. There are two purposes for integrating multiple range images. One is to obtain a complete set of data covering the entire surface of the plaster model. The second is to reduce the effect of noise that may exist in the individual range images. By merging more than one range images, a smoothing effect can be achieved. This smoothing, however, may have the undesirable side effect of blurring sharp geometric features, such as the margin. To preserve the features while further smoothing out the remaining noise, we

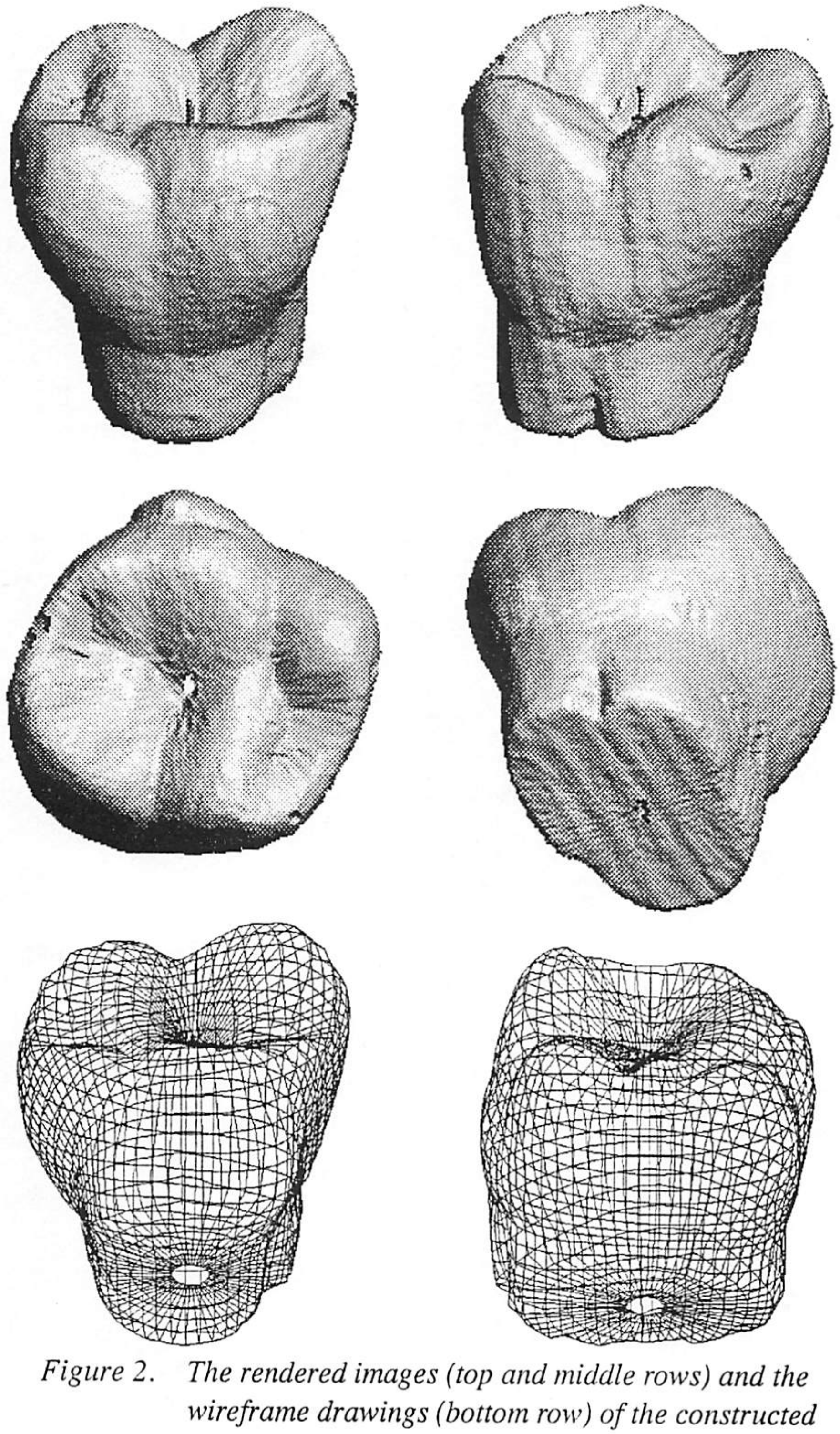
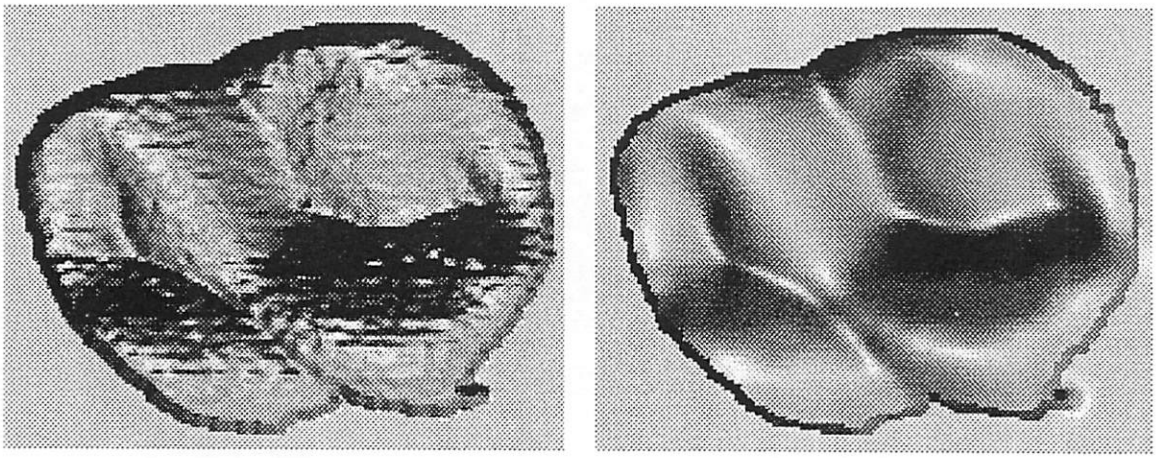


Figure 2. The rendered images (top and middle rows) and the wireframe drawings (bottom row) of the constructed model for the tooth model in Figure 1.



(a) (b)

Figure 3. Adaptive Filtering. Shown here are the range images of the occlusal surface of a tooth before (a) and after (b) smoothing.

propose to use a special filtering algorithm developed at USC-IRIS, called Adaptive Filtering [8]. Conventional filtering technique is a linear process that smooth out both noise and valuable geometric features that might be crucial to the successful restoration construction. The Adaptive Filtering scheme, on the other hand, automatically preserves significant geometric features such as creases. An example of the Adaptive Filtering is shown in Figure 3.

Feature extraction is to extract clinically significant geometric features such as the margin lines. Feature detection theories are well established in the field of (range) image processing. Detecting features automatically not only reduces the chance of error involved during human operation, it also increases the accuracy and reliability of the detected features while reducing processing time.

5 Restoration Design

A good restoration design system must be able to utilize all the available information. But it is unreasonable to expect a fully automatic system. Instead, human intervention is still needed and in many cases, human interaction is desirable. Thus providing a friendly graphical user interface (GUI) is highly desirable. Hence the design system is divided into two parts, the design system itself and a user interface.

The restoration design can be considered as a constrained model fitting process, where a reference restoration model is to be modified based on the input from the base (from registering and processing the range images discussed above), and constraints from the four sides and from the opposing teeth. These constraints and/or inputs have different relative importance and hence should be considered differently in the system. The users should also have the option of providing additional constraints or preference to the design and have different options in configuring the system to adapt to different tasks and specific needs. Research is needed in gathering and classifying these information and in integrating them into the model construction system.

Surface modeling has been a topic for the Computer Graphics community for years, but extensive research in automatic surface reconstruction have been carried out in the Vision community in recent years and USC-IRIS group has been an active player in this field ([2], [3], [4] and [5]). Our goal in this research is to provide a user-friendly GUI to a semi-automatic system for restoration design with emphases on autonomy, accuracy and flexibility in system design. A subsystem that allows the operator to verify the design either qualitatively (rendering of the model or cross-section examination) or quantitatively (checking the material thickness and other statistics) is also needed, although the design of the principal system should be such that design verification is automatically built-in and in case the system could not produce a satisfactory result, then the operator will be notified for intervention. An interface to the Dental Milling System (DMS) will also be developed.

6 Proposed Schedule

The research task in the proposed dental CAD/CAM system can be divided into three parts, i.e., registration and data integration, data processing and feature extraction, and restoration design and graphical user interface (GUI) design. A brief description of each of these tasks together with the sub-tasks involved and the estimated time needed is given below.

6.1 Registration and data integration

The main task in this research is to develop the self-calibration system for the dental CAD/CAM system and a system for integrating multiple range data sets acquired based on the self-calibration. The basis of the self-calibration is the range image registration system developed by the authors.

P11. Preliminary study (4 months)

Preliminary investigation of the application of existing range image registration techniques to the dental range images, study the constraints and conditions for the system and establish preliminary system specifications. To be conducted on conventional workstation environment.

P12. Target platform selection and evaluation (4 months)

Study the software and hardware requirements for the dental CAD/CAM system. Specify system performance requirements based on the preliminary algorithmic investigation. Perform evaluation studies in both hardware and software on the candidate platforms.

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P13. Environment setup (6 months)

Setup dental CAD/CAM development environment for the self-calibration system. Develop relevant software for the target dental CAD/CAM system. To be conducted on both conventional workstation and target platform.

P14. Evaluation and user interface (6 months)

Algorithm validation, error analysis, performance evaluation and improvements. Implementation of interactive user interface for the self-calibration system.

P15. Data integration (2 months)

Investigate appropriate data representation for integrating the multiple range images for use in processing and restoration design stages.

6.2 Data processing and feature extraction

The goal of this research is to develop algorithms for processing the acquired range data in order to perform noise filtering and feature extraction for automatic landmark detection and restoration design.

P21. Feature detection and noise filtering (5 months)

Develop noise filtering schemes suitable for the dental range images and design algorithms for automatic detection of landmark features such as margins, cusps and grooves. Carry out error analysis of the developed algorithms.

P22. Feature representation (2 months)

Develop appropriate feature representation for restoration design.

6.3 Restoration design and graphical user interface (GUI) design

This phase of the research is to develop the final stage of the CAD/CAM system: the restoration design. The emphases are on the design and on the user interface.

P31. Restoration design (6 months)

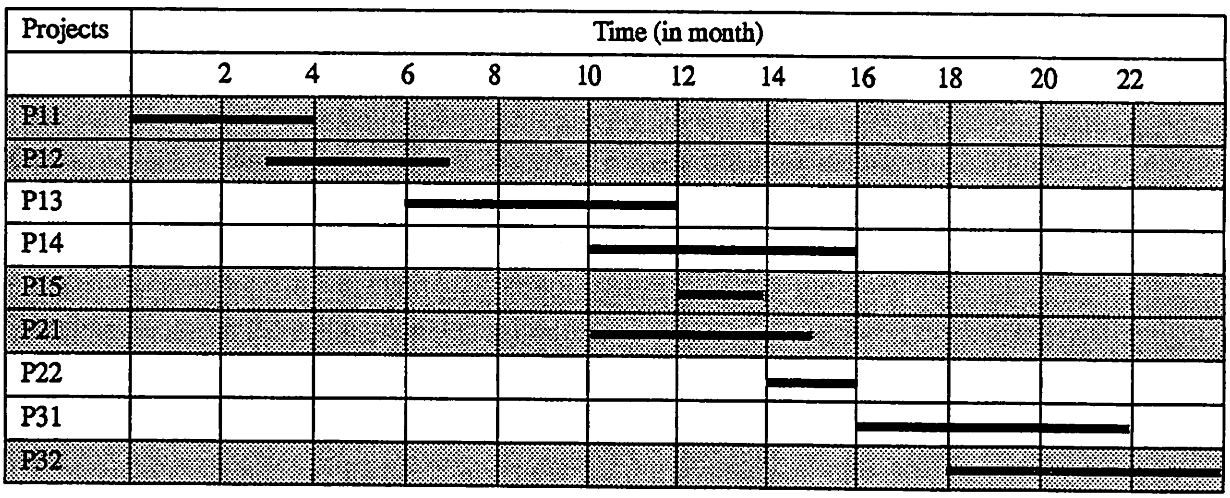
Study the different constraints and input data for the restoration design. Develop algorithms for fitting restoration text morphologies to input data under these constraints.

P32. GUI design (6 months)

Develop graphical user interface for interactive design and display of the restoration.

6.4 Schedule chart

Here is the time schedule for the various phases of the proposed research. The total time span of the project is two (2) years.



(Note the codes used for the projects are P11: preliminary study, P12: target platform selection and evaluation, P13: environment setup, P14: evaualtion and user interface, P15: data integration, P21: feature detection and noise filtering, P22: feature representation, P31: restoration design and P32: GUI design.)

Budget Estimate

		09/01/94- 8/31/95	09/01/95- 8/31/96	Totals
1	**SALARIES & WAGES**			
	Principal Investigator:			
	G. Medioni			
	10% effort, 9 acad. months	6,126	6,371	12,497
	100% effort, 2 summer months	13,612	14,156	27,768
	Base Salary 93-94: $58,900/9 months			
	Post-Doc (1)			
	100% effort, 12 mos.	40,267	41,878	82,145
	Base Salary 94-95: $40,000/12 months			
	Research Assistants-Level III (1.5 Graduate Students)			
	50% effort, 9 acad. months	18,116	18,841	36,957
	75% effort, 3 summer months	9,058	9,420	18,478
	Base Salary 94-95: $24,154/9 mos.			
	TOTAL SALARIES & WAGES	87,179	90,666	177,845
2	**FRINGE BENEFITS***	27,897	29,013	56,910
	32% of all S&W			
	Total Compensation:	115,076	119,679	234,755
3	**MATERIALS & SUPPLIES**	5,000	5,000	10,000
4	**TRAVEL**	5,000	5,000	10,000
5	**EQUIPMENT**	22,000	0	22,000
	Silicon Graphics - $15,000			
	Indigo - $7,000			
6	**TOTAL DIRECT COSTS**	147,076	129,679	276,755
7	**INDIRECT COSTS***	125,076	129,679	254,755
	(MTDC = Total Direct Costs less Equipment)			
	63.5% of MTDC, 24 months			
	Total Indirect Costs	125,076	129,679	254,755
8	**TOTAL COST TO AGENCY**	272,152	259,358	531,510

Note:

An annual 4% salary increase has been given to the Principal Investigator beginning Sept. 1, 1994.

An annual 4% salary increase has been given to Research Assistants beginning Sept. 1, 1995 .

An annual 4% salary increase has been given to Post-Doc beginning July 1, 1995 .