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Collaborative Design and Manufacturing of Prosthodontics Wire Clasp

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Abstract. The core idea behind the concurrent engineering is an integration of upstream and downstream activities of design/manufacturing in order to produce better products in a timely manner. Digital engineering is one of the critical approaches towards this integration, and this approaches enables the promising area of digital dentistry. Digital dentistry is defined as a dental technology or device that incorporates digital or computer-controlled tools, for example, dental CAD/CAM systems. This research focuses on the area of dental wire clasp, which has been manufactured by manual bending operation performed by the skilled dental technicians. Normally, a team of dental doctor and dental technician works collaboratively to design and manufacture the dental wire clasp. However, the accuracy of the bending operation is inconsistent and depends mainly on the expertise of the technicians. This paper describes the current situation of dental wire clasp manufacturing, reviews some of the innovative computer-aided wire bending systems, and proposes a framework of collaborative prosthodontics wire clasp design and fabrication using an idea of virtual engineering approach in digital dentistry.

Keywords. Digital dentistry, Dental wire clasp, CPS, IoT, CAD/CAM

Introduction

The core idea behind the concurrent engineering is an integration of upstream and downstream activities of design/manufacturing process in order to produce better products in a timely, and effective manner. Digital engineering is one of the critical approaches towards this integration, and its promising areas are commonly manufacturing industries. However, thanks to the advancement of CAD/CAM technologies [1], digital dentistry could be another promising area of this integration. Digital dentistry is defined as a dental technology or device that incorporates digital or computer-controlled tools, for example, dental CAD/CAM systems [2].

When we look at the dental wire clasp manufacturing, it has been traditionally performed in hand-made operation by skilled dental technicians. One of the critical issues of manual bending is that the accuracy of the bending operation is inconsistent and depends mainly on the expertise of the technicians. Therefore, some CNC-based wire bending systems for dental arch wires have been proposed as an innovative approach to digital dentistry. However, these machines are mostly based on flat shape

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bending, which is not compatible to fabricate the 3D shape of dental wire clasps. The first issue of this study is to design and develop a computer-controlled dental clasp bending system.

It is true that dental CAD/CAM systems technically support the dental treatment in these days in an effective manner. However, their objective is not on the integration of upstream/downstream activities, but mainly focuses on manufacturing of dental restorations. Since network-based technologies, such as Internet of Things (IoT) [3] and Cyber-physical systems (CPS) [4] have been available these days, these technologies could also be applied to digital dentistry to implement a cyber-dental system, which is the second issue of this study.

Reviewing these two issues mentioned above, this paper proposes an idea of cyber-physical dental wire bending system, which integrates an idea of 3D CNC wire clasp machine and an idea of collaborative working for the integration of upstream/downstream activities of dental treatment.

1. Dental CAD/CAM system using digital manufacturing

Digital dentistry technology is attracting the attention not only of the dental technicians and dental doctors, but also of patients for its emerging technology towards an innovative dental treatment [5]. Dental CAD/CAM system is one of the promising fields of digital dentistry, of which process flow is shown in Figure 1, where a dental CAD system and a dental CAM system play the two central modules in the process.

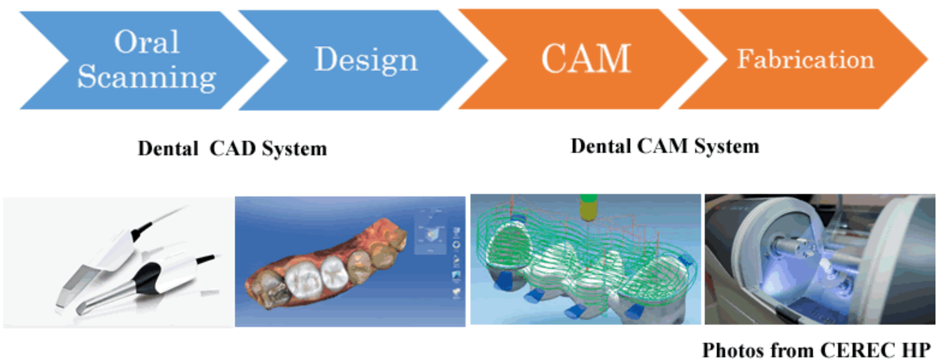

Figure 1. A typical process flow of dental CAD/CAM system.

Initiated by the first commercialization of Cerec system [6], several dental CAD/CAM software products are on the market, such as ISUS, Delcam, Renishaw, SUM3D, MillBox, WorkNC, etc. As for the manufacturing processes in CAD/CAM dentistry, just like industrial CAD/CAM fields [7], subtractive processes such as CNC milling as well as additive manufacturing processes such as 3D printing are used.

As opposed to the conventional method of dental impression, a dental CAD/CAM system enables to process a more accurate, quick and flexible dental treatment [8]. However, the dental CAD/CAM system requires extra time and work on the part of dentist, and the manufacturing cost is much higher than conventional restorative treatment, which may be one of the issues remained to be solved.

One of the potential advantages of dental CAD/CAM system, however, would be the availability of virtual cyber-dental space, where patient, dental technician and dental doctor could share treatment information and virtually work together. The current dental CAD/CAM system, however, mainly focuses on the design and creation of dental restorations such as crowns, crown lays, veneers, inlays and onlays, bridges, dentures, etc. Therefore, the potential usage of cyber-dental space still remains unused.

2. Cyber-physical dental system based on virtual operation

One of the approaches of cyber-physical dental space can be seen in the application of guided surgery of implant operation. A computer guided implant treatment system offers dental doctors a comprehensive 3D system for accurate and predictable implant treatment[9]. Dental implant operation can be manipulated in virtual space, its surgical template guide can be virtually designed, and physically manufactured to be used in the actual implant operation.

The authors have proposed an idea of collaborative framework using cyber-dental space for implant operation simulation. Figure 2 shows an image of dental implant operation using the collaborative cyber-dental space, where dentist and patient share the treatment information and work together in a collaborative cyber-dental space.

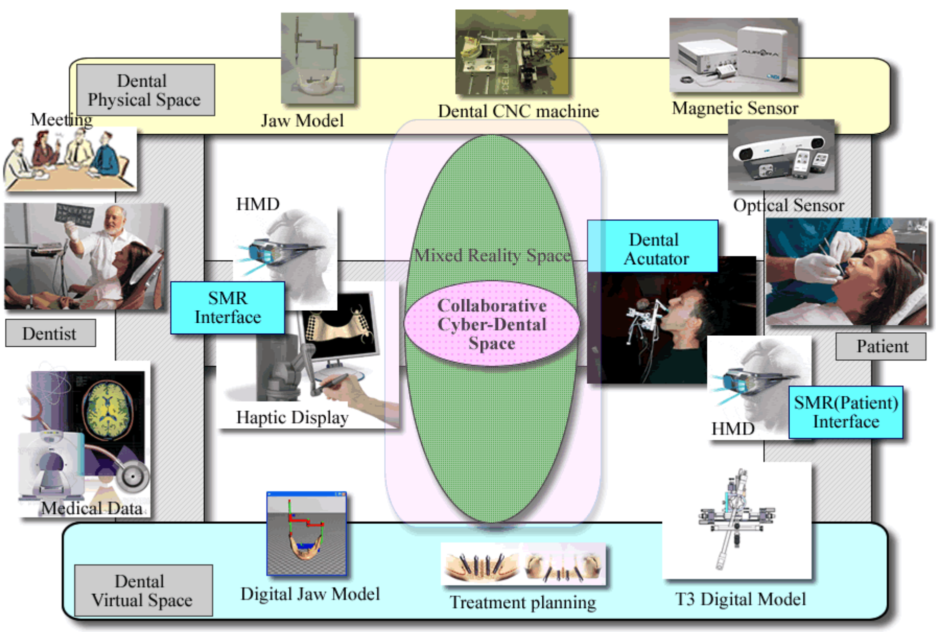

Figure 2. A framework of cyber-physical dental system for dental implant treatment.

In this framework, a dentist and a patient share information in the mixed reality-based collaborative working space. Prior to the actual treatment of implant operation, a dentist prepares a dental treatment design and shares it with a patient so that the patient could understand how the operation is supposed to be performed. The collaborative working space also functions as a reliable space which enhances the feeling of trust between the patient and its doctor.

This framework is based on an idea of implant operation, where digital engineering could offer substantial benefits to both dentists and patients. Based on the idea of this framework, this research applies it to dental wire clasp design [10] and manufacturing using a new type of CNC wire bending system of which process flow will be presented in Section 3, and proposes a collaborative framework for prosthodontics wire clasp design and fabrication, which will be presented in Section 4.

3. A process flow of CNC dental wire bending system

Industrial wire bending machines [11] are available on the market to fabricate bended wire products with different materials, size, diameter, etc. Several types of CNC wire/pipe/tube bending machines are developed by industrial bending companies [12]. For example, tube bending machines can make automatic bending operation based on the CAD/CAM design data [13]. These bending machines, however, are basically heavy and big because they are made for industrial applications. Incidentally, the technology in those industrial bending machines could be applied for denture fabrication in dentistry. However, these machines are too big in their size and not suitable for dental applications.

Ideally speaking, the dental CNC bending machines should be compact as a table top in its size so that it could be used as a chair-side operation. Recently, a desktop size CNC wire bending machine [14][15] has been put on the market to work as if it were a 3D printer of wire bending to fabricate a variety of simple shapes by a simple operation. However, the wire clasp bending in dentistry is very much complicated in sizes and shapes, and requires a high degree of accuracy to ensure the perfect fixation of clasp to patient's mouth. Therefore, these machine are not suitable for dental wire bending applications.

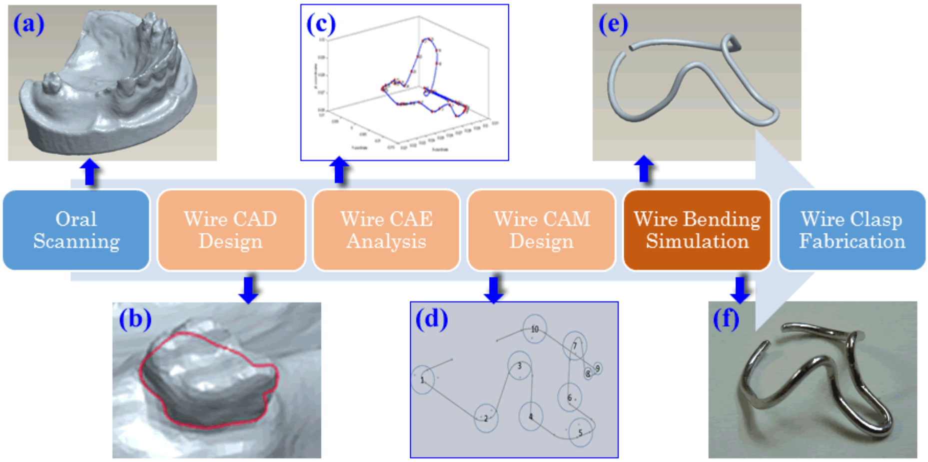

Figure 3. Process flow of dental clasp wire bending system.

In general, the accuracy of the bending operation is not always consistent and fundamentally is depended heavily upon the skills of the dental technician. Incidentally, innovative attempts to automate the wire bending process have been made in several projects which proposes wire bending machines, for example, LAMDA robot [5], endodontic micro robot [16], Cartesian robot, orthorobot [17][18], Suresmile robot[19][20], etc. However, all of these approaches are flat shape bending, which is not compatible to fabricate the 3D shape such as dental wire clasps.

Considering the above mentioned circumstances, this project proposes an idea of CNC dental wire bending machine system, which could design and manufacture a dental wire clasp based on the following process flow. A dental CAD/CAM system mentioned in the previous section enables design and fabrication of dental restorations such as crowns, bridges, etc. The CNC wire bending system in this research enables design and fabrication of tailor-made dental wire clasps. Figure 3 shows the overview of design and fabrication process flow of dental wire clasp bending system proposed in this study.

The bending process is performed in the following six steps (a)-(f). As the first step (a), oral scanning with a 3D digital scanner makes the raw shape data for design of dental wire clasp as shown in Figure 3(a). The target object in this figure is a dental impression created in a conventional dental impression technique, which could also be possible by a direct oral scanning using a handy digital scanner.

The second step (b), a dental clasp wire design can be made on the scanned digital model by a digital engineering approach [2]; For example, a dental technician traces the target clasp curve by a digitizer, a haptic device, or even a mouse as shown in Figure 3(b). However, the 3D curve is designed in a 3D virtual space where shape recognition is very difficult in general. Therefore, a haptic device is an effective tool to design/modify/finish the curve design in 3D virtual space [21]. The designed shape can be reviewed not only by the dental technician who designed it, but also by a dental doctor who uses the dental wire clasp.

In the third step (c), the designed curve is analyzed by an analysis tool which is under development in this study to generate the segmentation of the designed curve as shown in Figure 3(c). Based on the results of analysis [22], a bending operation process is calculated to generate G-code in the fourth step (d), or bending code for the CNC bending machine also under study in this research (Figure 3(d)). The generated G-code is evaluated in simulation model in the fifth step (e) to make sure the feasibility of fabrication as shown in Figure 3(e). The final result of the fabrication in the sixth step (f) is the targeted wire clasp as shown in Figure 3(f).

In order to implement these fabrication processes (a)-(f), design and manufacturing of the CNC wire bending machine as well as the CAM system to control the machine based on the CAD design of wire clasp is under study in this project.

4. A collaborative framework of prosthodontics wire clasp design and fabrication

Computer-assisted collaborative framework of design and manufacturing draws attention in various fields, such as aerospace, automotive, chemical processes, civil infrastructure, energy, healthcare, manufacturing, transportation, entertainment, and consumer appliances. While the technologies behind these systems have potentials for industrial applications, they could also be beneficial to the application of digital dentistry. Using the example of laboratory collaboration in the authors' labs, this section shows it and proposes a collaborative framework for prosthodontics wire clasp design and fabrication based on the idea of CNC wire bending system.

DentLab is located at Kuramoto campus, whereas CELab is located at Josanjima campus which is about 7 km away from Kuramoto. In order to share the large size of data in a timely manner under secure environment, a private cloud server system called CEL-cloud has been installed based on ownCloud program [23] with some customization. A typical usage of this cloud server system is rapid prototyping test samples of prosthetic restoration, which is very beneficial to the lab members. Design data prepared at DentLab is transferred to CELab, where fabrication is processed, then its products are transferred back to DentLab.

Considering the current usage of cloud server system, this research proposes a collaborative framework based on a cyber-physical environment under the collaboration between DentLab and CELab. The framework is composed of private cloud servers which can be accessed by the members of each labs in a secure manner as shown in Figure 4. Data files are stored in these servers, and be shared among the members in a seamless manner with high security along the whole processes of dental wire clasp fabrication. The framework offers a cyber-physical environment to design and manufacture dental wire clasp based on the process flow of CNC dental wire bending system described in the previous section.

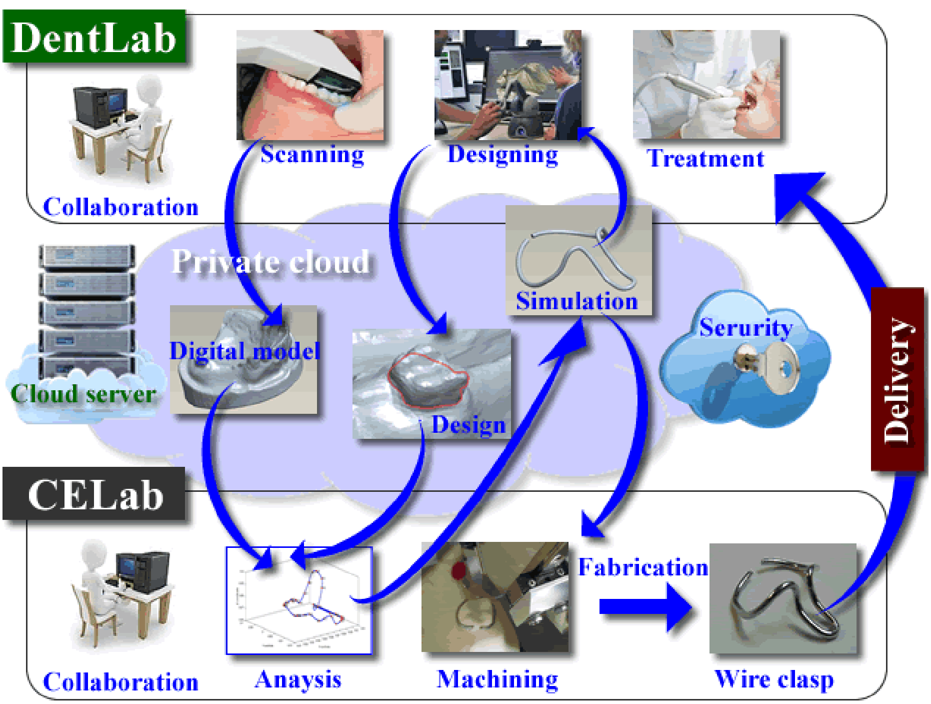

Figure 4. Process flow of cyber-physical dental wire bending system.

5. Concluding remarks

This paper focuses on the two issues in digital dentistry, namely, the integration of collaborative working environment based on the dental CAD/CAM systems and CNC wire bending manufacturing as a new approach of collaboration in digital dentistry.

First, this paper reviewed the dental CAD/CAM system, which is the core for complicated systems in digital dentistry. Integrating with virtual engineering technologies, a cyber-physical dental system based on virtual operation was presented as an example of the extension of dental CAD/CAM system.

CNC wire bending project presented in this paper is one of the application of cyber-physical system for design and manufacturing application. A process flow of CNC dental wire bending system was presented to show how the dental clasp could be manufactured by the CNC wire bending system. Then, the paper proposed a collaboration framework of prosthodontics wire clasp design and fabrication in order to integrate the upstream/downstream activities in dentistry as an approach to the two issues mentioned above.

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