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論　文　内　容　要　旨

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学位論文題目	Theoretical approach of computer-aided shape design and manufacturing simulation to dental wire bending (歯科用ワイヤー加工に対するコンピュータ援用形状設計と製造シミュレーションの理論的取り組み)		

内容要旨

Dental wire bending in orthodontics and prosthodontics applications are traditionally performed in the hand-made operation. Recent advancements in the field of arch-wire bending point to several attempts to automate the dentistry wire bending operation through Computer-Numerical Control (CNC) dental wire bending machine and robotic device. Automated dental wire bending system helps to eliminate all the drawbacks associated with manual wire bending operation, and at the same time offers some advantages over the traditional approach. The review related to dental wire bending systems for the past two decades illustrates that all of the reported inventions have focused on arch-wire bending for both labial and lingual orthodontic. This highlights the demand for a more flexible dental wire bending system which could be used in other wire-related dentistry treatments, not just to bend a flat arch-wire or the customized arch-wire. For this reason, the present study tries to propose the concept of a flexible dental wire bending system by choosing a CNC dental wire bending machine to execute the desired 3D wire bending tasks, as the first objective of the study.

In order to get started, a theory of 3D linear segmentation algorithm is introduced. Digital wire design in dentistry is complicated due to freeform shapes which make them difficult to be predefined generically. As a result, the conversion process from Computer-Aided Design (CAD) to Computer-Aided Manufacturing (CAM) data would be impossible. Therefore, in this theory, the freeform shape is segmented into multiple 3D lines, where the XYZ Cartesian coordinates of the start and the end point in every line segment are used for the generation of wire bending parameters, known as the bending code (B-code). In theory, the bending of a 3D real curve is made based on the relative spatial parameters (L-the length, β-the rotation angle, and θ - the bend angle,) of the adjacent 3D line segments. B-code controls the bending operation of the CNC machine in this way; L tells the feeding mechanism the desired bend length to be fed, β instructs the turning mechanism to rotate if there is a change of plane in the subsequent bending while θ controls the bending mechanism to create the desired bend angle in each bending operation.

For the purpose of understanding the theory of B-code shape definition, a 3D simulation using a sheet metal feature is carried out by reverse engineering

approach. The actual pre-bent labial bow is re-constructed in this feature and the simulated relative spatial parameters are compared with the calculated B-code parameters for validation. As a result, the mathematical formulae proposed in the theory of 3D linear segmentation are relevant for the subsequent development of the B-code generation program. In addition, the manufacturing workflow to process the initial digital teeth data towards the automated 3D wire bending is proposed which consists of 3D data digitizing, digital shape generation, XYZ coordinates extraction, B-code generation, and 3D dental wire bending. In the first stage, different types of 3D digitizing methods have been considered which led to different types of input data for the subsequent digital shape generation process. This refers to the digital wire design in the computer, in relation to the planning of bending points' algorithm. Therefore, some interfaces to process the variation of input files towards the XYZ coordinates extraction have been discussed, in terms of the stereolithography (STL) file, the 3D point cloud data and the 2D image file. Also, an automatic XYZ coordinate' s extraction program which is capable to extract the XYZ coordinates from the Initial Graphics Exchange Specification (IGES) file has also been established. In the fourth stage of the manufacturing workflow, an automatic B-code generation program has been developed to automatically produce the B-code data from the XYZ coordinates data. This reflects the second objective of the study.

Additionally, the implementation of the B-code is demonstrated through a case study which simultaneously tested the IGES-XYZ coordinate extraction program and the B-code generation program. Furthermore, 3D wire bending simulations of the generated B-code which are initially processed by the 3D point cloud data filtering and the 3D point cloud data selection programs are executed in order to check the reliability of the introduced programs. Consecutively, the generated B-code from the 2D image input file has also been examined. These have proven the ability of the B-code generation program to provide the required B-code regardless of the type of input data. Finally, the feasibility of the generated B-code towards realizing a successful 3D wire bending operation has been validated, as the third objective of the study.

Other than that, a mathematical definition of human dental arch form has also been additionally investigated, in an attempt to design an optimized arch shape for the braces treatment. This could improve the theory of the 3D linear segmentation into a more semi-optimized curve. However, the actual arch-wire bending operation to realize the semi-optimized arch shape has not been studied, which remains as the recommendation for future work. To conclude, the research objectives in this study have been achieved, focusing on the introduction of bending points' algorithm and the theoretical manufacturing of personalized target shape. As for future work, the interface to directly integrate the B-code generation program to the CNC wire bender has to be developed, so that they could work consecutively to perform the desired wire bending operation. Also, the planning of wire spring back algorithm towards the theoretical bending angle (θ) could also be scrutinized.