COMPUTER-AIDED WIRE DESIGN USING SHEET METAL FEATURE FOR DENTISTRY APPLICATIONS

R.A. Hamid[1, 2] and T. Ito[3]

[1]Graduate School of Advanced Technology and Science,
Tokushima University, 2-1 Minamijosanjima-cho,
770-8506, Japan.

[2]Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,
76100 Durian Tunggal, Melaka, Malaysia.

[3] Graduate School of Technology, Industrial and Social Sciences,
Tokushima University, 2-1, Minamijosanjima-cho,
770-8506, Japan.

Corresponding Author's Email: [1]c501542005@tokushima-u.ac.jp

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ABSTRACT: This study approximates a dentistry wire bending operation by means of sheet metal feature. In reality, the sequence of bending operation depends on the target shape and determined manually by the dental technician. Sometimes, the technician needs to perform multiple bends at several bend points to fit the patient's tooth morphology. These cumbersome procedures could be improved if the use of computer-aided design (CAD) and computer-aided manufacturing (CAM) is applied in this field, with the aid of a proper process planning in between. In order to do so, the wire design has to be established and subsequently utilized for the bending code (B-code) generation. Therefore, the recent study describes the bending operation for a selected dentistry wire, in relation to the bending points and bending parameters. Then, a 3D comparison between a digitized polygonal model and the sheet metal model was executed in Geomagic to inspect the deviation. The color-mapping result showed a clear divergence between the test model and the reference model as a result of design complexity. The limitation of this outcome could be further improved by designing the wire as detailed as possible towards the scanned teeth.

KEYWORDS: *3D Wire Bending; Sheet Metal Design; Dentistry Wire; Bending Code; B-Code*

1.0 INTRODUCTION

The wire is used in dentistry application for many reasons. In orthodontics, there were some inventions to automate the dentistry wire bending process by introducing robots and also Computer Numerical Control (CNC) machines. Details of these inventions were elaborated by [1]. However, those mechanisms [2-5] were focusing on the braces application whereas there are still many other dentistry wire-related treatments which are bent manually in both orthodontics and prosthodontics applications. Due to some deficiencies of the manual operation as discussed by [6-7], automation of the wire bending process is beneficial for both patients and dental technicians. In addition, this innovation in technology provides a digital workflow which changes the collaboration between the lab and the doctor, increase the productivity and open the door for faster turnarounds coupled with reliable quality [8]. In order to develop a new wire bending mechanism to fill in the existing gap in the industry, the overall procedures, starting from a 3D scan of the patient's teeth towards the automated wire bending mechanism must be thoroughly considered. This present study aims to understand the wire bending sequential operation by adopting the sheet metal feature in CAD software to simulate the bending operation. The adoption of this feature was considered since the acquired wire bending machine is not established yet. Therefore, the manipulation of the sheet metal feature was somehow executed in order to identify the important parameters for this wire bending operation, so that the significant mechanisms to be included in the wire bending machine could be pre-identified.

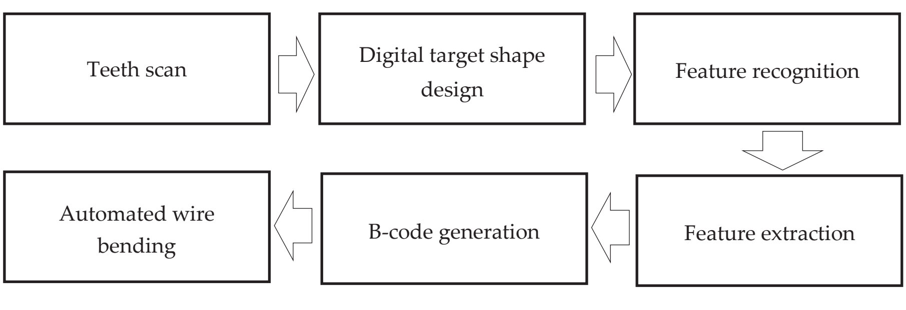


Figure 1: General procedure to bend a wire with the CNC wire bender

Figure 1 shows the idea of the required procedures for the CNC wire bending operation. Initially, the intended digital wire shape has to be designed in the digital software before a feature recognition and extraction to generate the B-code for the CNC machine operation could be executed. Generally, a 3D optical scan of the teeth is conducted by the dentist during the chairside treatment by using the optical 3D scanner. The scanning process produces the STL file of the patient's teeth which could be subsequently utilized for the appropriate wire-shape design, required for the treatment. Then, the suitable wire design could be translated into the machine language, referred as the Computer-Aided Manufacturing (CAM) data. This CAM data, preferably known as B-code would control the movement of the CNC machine in a specific way so that the final part could be produced. The transformation from the CAD data into the B-code requires several additional processes [9], such as the feature recognition, feature extraction and also the mathematical formulae to generate the code, which are still unclear. However, before these procedures could be considered, the bending operation has to be studied.

CAD/CAM technology has been widely applied in multiple oral disciplines [10-12], especially in the field of fixed denture restoration [13-14]. However, the application of CAD/CAM in the design and development of a dental wire is still unexplored [15]. Computer-aided wire design is well established in the industrial wire bending industry [16], but it is considered new for the dentistry application. Till recently, no work related to digital wire design in CAD for the dentistry wire has been found. The wire design for dentistry application is more critical than the wire design for the industry in terms of the design complexity and accuracy. The target shape for industrial use is simpler and involves a mass production for each design. Therefore, the process planning is less onerous since, with a single wire design, many wires output could be generated at a time. The wire design in dentistry, however, requires a more detailed design due to customization. In short, the process planning is challenging since the procedures need to be repeated for each patient. This is very crucial since each bend must be accurately placed on the right bend point, with the appropriate bending parameters. Otherwise, a maximum retention of the wire could not be achieved and bring discomfort to the patient.

Computer-aided wire bending system must be able to receive a different B-code for each bending operation and perform the wire bending operation successfully according to it. The CNC machine, unfortunately, cannot actually bend a wire without the B-code. In order develop an algorithm that is capable of processing the input file resulting in the operational bending sequence generation for the machine, an analysis of the input shape has to be carried out.

Therefore, the objectives of this present study were to design the target shape in CAD and subsequently to perform a 3D digital comparison between the designed wire and the digitized ones. The 3D modeling was executed by means of sheet metal feature. Sheet metal feature was adapted to design the wire, in consideration to the 3D linear segmentation algorithm, introduced earlier by [17]. This could theoretically demonstrate how the proposed bending mechanism works. Furthermore, it has the capability to determine the number of bends required for the model. Since there are many wire appliances for both orthodontics and prosthodontics applications available in the industry, an orthodontic retainer as indicated in Figure 2 was selected as the target shape for this study.

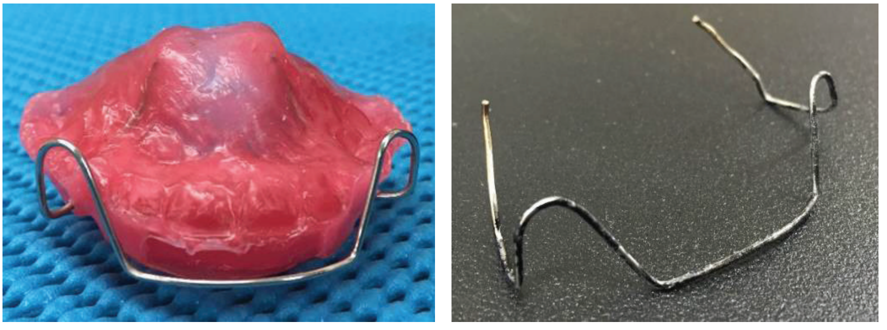


Figure 2: The target shape used in this study

2.0 3D SCANNING PROCESS

3D scanning is normally used to digitize the required shape which is subsequently employed to construct a digital 3D model. In this study, a Makerbot digitizer was utilized for the scanning of an orthodontic retainer while a MakerWare for Digitizer created the industry standard stereolithography (STL) file. The MakerBot Digitizer Desktop 3D Scanner creates a digital 3D model of a physical object by taking a rapid sequence of pictures as the object rotates on the MakerBot Digitizer turntable. Firstly, laser lines were created with two lasers that outlined the profile of the object, while a camera concurrently took a series of photographs. Those lasers were mounted on the left and right corners of the MakerBot Digitizer and the scanning process employed one laser after another until the whole image was generated. Secondly, MakerWare for Digitizer software took the photographs of the laser lines and combined them to create the point cloud data of the digitized object. Then, a MakerBot MultiScan™ Technology was executed for the scanning improvement where the MakerWare for Digitizer rescanned the wire from a different angle and combined the two sets of scan data. Afterwards, the editing of the STL file was performed in Geomagic where the deletion of unwanted noise near the desired shape was executed and a mesh of the point cloud data was generated, as depicted in Figure 3b. The raw scanned data acquired the feature of the target shape, but the appearance was not so good for the subsequent 3D comparison. Therefore, in order to increase the accuracy of the 3D comparison result, a new shape was created based on the scanned image. In order to do so, several points were selected according to the STL file. Later, a curve through points was generated with a b-spline and a sweeping tool was applied to make it resembled a wire, as depicted in Figure 3c, with a diameter of 0.5 mm. The diameter was chosen in regard to the actual reference wire.

(a) (b) (c)

Figure 3: Transformation of the scanned wire: (a) point cloud data, (b) mesh data and (c) created wire

3.0 3D DIGITIZING PROCESS

In the real application, a straight wire is bent with undetermined parameters that depend on several factors, like the feature of the bending plier, the method of bending and most importantly, the expertise of bender. Normally, the bender could not envisage the final outcome before the operation or foresee the consequence of diversifying the bending parameters. However, with a sheet metal feature, CAD model is converted directly to sheet metal model and the sequence of bending could be visualized in a 3D design environment. The modifications of some bending parameters are also possible to foresee the effect of changing some parameters to the designed shape. Therefore, to what extent the 3D sheet metal model could represent the real target wire was investigated in the present study.

Sheet metal parts constitute a very specific type of solid model. The wall thickness is constant throughout the model and the bends are applied using a selected bend radius value. The fundamental sheet metal feature is a flange. SolidWorks sheet metal has four different types of flanges that can be used to create parts. The flanges add material of predefined thickness in different ways. The base flange was employed to create the base feature for the sheet metal part. The added bending parameters are editable and could be modified according to the preference of users. Therefore, the bending procedures required for the target shape would be discussed, elaborating on the bending sequences, bending points and also the bending parameters applied for each section.

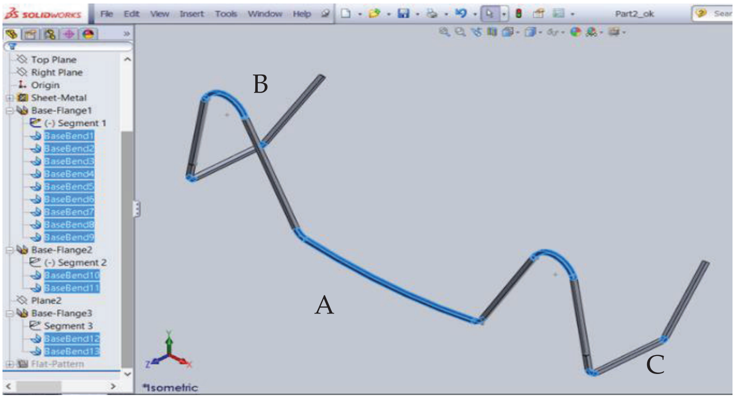
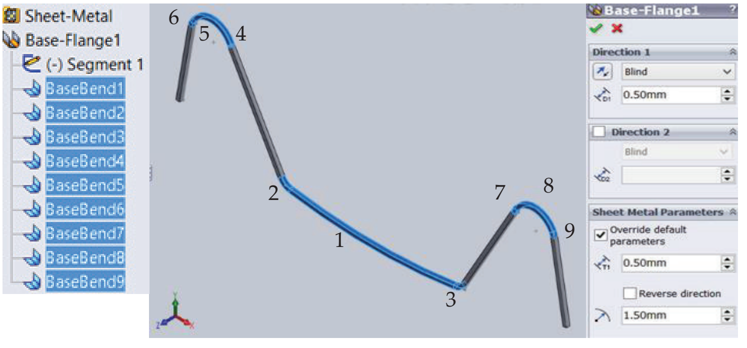


Figure 4: The constructed sheet metal model

The sheet metal model comprises of three sections in three different planes as illustrated in Figure 4, which were completed consecutively. In reality, section (B) and (C) do not have the same measurement due to customization, but for this study, those two sections were assumed to be equal. In addition, all segments were sketched on a normal plane, even though the actual wire was bent on several inclined planes. The manipulation of a sheet metal feature helps to visualize the bending operation, but in order to do so, a 2D sketch of the target output needs to be designed first. In the sheet metal feature, the 3D sketch is not available and hence, the user has to imagine the most straightforward way to bend the wire. For instance, in this example, section (A) is drawn and bent first, followed by the other two sections. The logic behind this is that the first section contains some complicated features such as an arc and loops, in comparison to the other sections. The sequence of bending in the autonomous mechanism is crucial since a collision might occur between a wire and the bend tool during the bending operation if the sequence is not properly planned. In other words, the bending sequences must also consider that the target shape will not conflict with the wire bend tool and the wire holding device, before and after the bending operation.

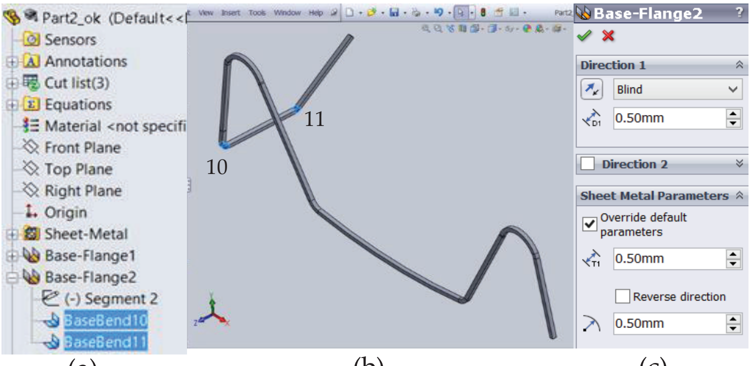


(a) (b) (c)

Figure 5: The first section: (a) number of bending, (b) bend points and (c) bending parameters

Specifically, section (A) contains an arc and two loops while section (B) and section (C) consist of right-angled bends only. In general, the number of bending for the whole target shape was 13. For section (A), 9 bends were required, as illustrated in Figure 5, started with the arc shape in the middle. The arc was counted as one single bend, instead of multiple line segmentation as discussed in the 3D line segmentation algorithm. Since the present work was aiming to estimate the operational sequence at first, therefore this simplification was made.

The segmentation of this arc according to the theory was discussed in [18]. Then the right-angled bend for both sides (bend 2-3) were executed. Later, the loop for each side was bent consecutively until the first section was completely bent. The reason why every loop was bent individually according to bend (4, 5, and 6) and bend (7, 8, and 9) is due to customization. Thus, in reality, the dimension of each loop differs conforming to the patient's tooth size.



(a) (b) (c)

Figure 6: The B section: (a) number of bending, (b) bend points and (c) bending parameters

Furthermore, section (B) and section (C) require two bends for each, as depicted in Figure 6 which makes the total number of bends for the whole target as 13. The type of bend for this section is a right-angled bend, where the straight wire is bent conforming to the 3D linear segmentation algorithm. For these sections, the bend radius chosen for bend points 10 and 11 is 0.5 mm. The blue highlight indicates where the bending points are and with this, a clear visualization of bending operation could be perceived. The modeling of a more complicated shape which possesses many different planes might be more complicated with this feature. The sequence of bending order might diverge with the manual application. In this sheet metal feature, the sequence of bending operation is generated based on the sheet metal bending algorithm and hence is inappropriate to be adopted in the real wire bending operation.

4.0 SCAN-TO-CAD COMPARISON

This section describes the difference between the scanned model and the drawn sheet metal model in Geomagic environment. 3D compare tool was used for the comparison analysis where it generates a 3D, color-coded mapping of the differences between the reference object and the test object. The reference object is the object that is selected in the model manager. The test object is chosen from a dropdown list in the 3D compare dialog. In addition, the test object can be points, polygon, or CAD while the reference object can be polygons or CAD. Therefore, in this study, the reference object of the scanned image was wrapped as a polygon data, while the sheet metal model was chosen as the test object. A polygon data was chosen over the CAD data for the reference object since the CAD and polygon models act as very different reference objects. When an Initial Graphics Exchange Specification (IGES)-CAD model is toleranced with the points, the software goes back to the CAD engine to get the exact deviation of the point. However, once the model is converted to a polygon that information is lost and the points are toleranced to a faceted polygon model.

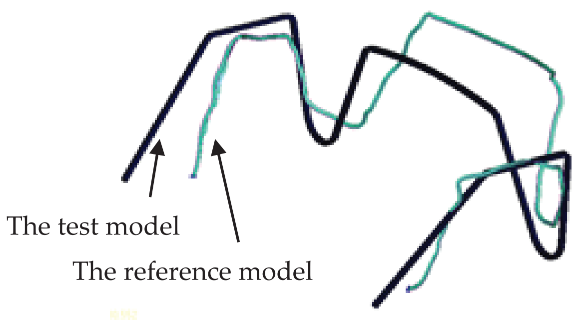


Figure 7: The best fit alignment between the reference model and the test model

Figure 7 shows the alignment between these models before a 3D comparison was conducted afterward. Figure 8 exhibits the color mapping result of this comparison on the reference object. This operation generates a color-coded spectrum model illustrating areas of correspondence and deviation between the two surfaces. The divergence is obvious, with some portions displayed in gray. The gray region shows insufficient data for valid comparison to the reference object. Areas of the resulting spectrum model that appear green illustrate regions of highest correspondence [19] and in this study, deviate less than ± 1.698 mm from one another. By default, surfaces at the higher end of the spectrum (yellows and reds) highlight areas in which the second model has positive relief, i.e., it is larger than the original. Those surfaces colored at the lower end of the spectrum (blues and violets) highlight areas of negative relief, or places where the second model is smaller than the original. The red circle shows the most critical point for the alignment.

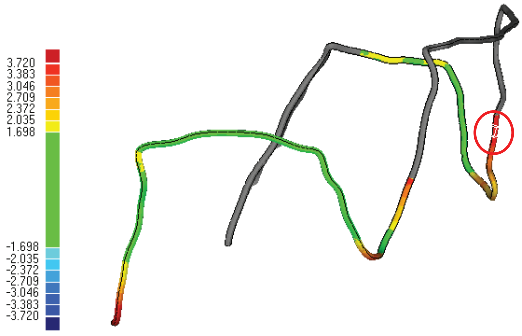


Figure 8: Deviation between test and reference model

The result demonstrates a clear deviation due to some limitations in this study. Firstly, the test model was drawn on some normal planes while in reality, the wire precisely follows the tooth contour which clearly involves multiple inclined planes. Secondly, section B and C were approximated to be equal, even though they were not. Thirdly, the scanned image was edited for the 3D compare, which contributes to a significant contrast towards the 3D compare result. A probe-digitizer was used to re-generate the scan image, but it did not drastically change the generated outcome. Therefore, these limitations could be improved by properly designing the wire in the beginning, which definitely consumes more time.

5.0 CONCLUSION

In a wire bending operation, a straight wire is bent according to the final target shape through a sequence of bending operation. In a manual wire bending operation, the bend point is marked on the wire and bent accordingly until the right length and bend angle have been obtained. In this wire bending simulation, the sequential operation was estimated. The actual target shape which was bent by the technician has a more complex shape which requires multiple bends and changing of working plane in order to digitally obtain the similar shape. The simplification of sheet metal model was done in comparison to the actual model for the sake of understanding the bending operation without spending more time on the details. As a result of this simplification process, the 3D comparison result has indicated a clear dissimilarity in terms of geometry between the designed wire and the reference wire. On the other hand, the objective to understand the bending operation has been achieved. Through this 3D simulation, some observations have been recorded. Firstly, a 3D non-planar target shape involves a different working plane. Therefore, the CNC machine needs to have a mechanism which can prepare the wire for the right working plane at each bend point. Secondly, the bending mechanism has to be able to bend the wire at a wide range of bending angle, if the machine is targeted for a multi-purpose bending. Therefore, the bending mechanism has to be able to move accordingly to perform the specified bending. Also, the radius of the bend point depends on the radius of the bending roller. In this matter, a flexibility of the bending radius dimension is only possible if the bending roller could be changed alternatively. If only the same radius of bending roller is designed for the machine, this means that the bend radius of all bend points would be similar. Thirdly, the sequence of the bending operation has to consider some other factors, like the collision of wire-machine, wire-tool, and also wire-wire. The decision of the bending sequence to produce the desired final target has to somehow consider all the stated factors in order to avoid bending failure. Finally, since the bending operation is all about changing the straight wire into a predetermined shape, therefore, another mechanism which could feed the straight wire into the bending mechanism has to be considered.

Sheet metal feature can be used to observe the bending operation for the required shape; however, the condition of using that feature depends on the complexity of the design. In this study, the adaption of a sheet metal feature in getting the number of bends required was accomplished, even though the sequence of bending was not accurately obtained. A comparison of the actual shape with the 3D sheet metal model has shown a clear dissimilarity in terms of geometry between the designed wire and the reference wire. Therefore, a modification to the sheet metal model has to be done for a better comparison result, which requires a very detailed CAD drawing in the future.

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