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Journal of Dental Specialities

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Review Article

Robotic wire bending in orthodontics -A review

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ARTICLE INFO

Article history:
Received 11-08-2023
Accepted 20-12-2023
Available online 04-04-2024

Keywords:
Archwire
Robotic
Orthodontic treatment

ABSTRACT

The foundation of orthodontic treatment is the orthodontic appliance, therefore improving it would change the requirements for oral health while also improving general orthodontic treatment. From the traditional methods to the modernized world, dentistry has undergone enormous advancements and movements that have increased the scope of dental treatment and frameworks. By improving treatment accuracy, efficacy, and efficiency while reducing treatment time and patient discomfort, robotic archwire bending can address the drawbacks of manual bending and enhance orthodontic treatment. Robotic archwire bending can overcome the shortcomings of manual bending by increasing the treatment accuracy, efficacy, and efficiency, also decreasing the treatment time and patient discomfort thus improving the orthodontic treatment in general. Because of the robot's advantages in standardization, industrialization, and intelligence, prosthodontics and orthodontics have undergone a significant revolution from qualitative to quantitative, and this has been a key area for medical robot development.

1. Introduction

The third most common oral condition worldwide is malocclusion. Fixing your teeth with braces is now the most efficient way to treat malocclusion. One of the most important aspects of orthodontic therapy is arch wire bending. Due to the great stiffness and extreme elasticity of orthodontic wire, it is a very tough task. The conventional method of obtaining the formed archwire curve relies on manual labor, which will erroneously introduce several mistakes brought on by human factors. For lingual orthodontic treatment in clinics, specialized archwires are required. Traditionally, only skilled orthodontists could manually bend these archwires. This pattern necessitates extensive chairside time, precision, and specialized skill training, but it cannot guarantee appliance accuracy. What new developments have been made recently to address the drawbacks of archwire bending?.[1]

Robotic archwire bending can overcome the shortcomings of manual bending by increasing the treatment accuracy, efficacy, and efficiency, also decreasing the treatment time and patient discomfort thus improving the orthodontic treatment in general.[2]

The most successful method for treating malocclusion now is the fixed orthodontic approach. In this therapy, the force produced by the distortion of the archwire is restored in order to straighten the misaligned teeth. Therefore, the procedure of archwire bending is crucial to orthodontic therapy. A robot is a device that can automatically do a complex series of tasks, particularly one that can be programmed by a computer. Robots are used nowadays for manufacturing purposes, medical care, and military applications.

Wire bending for dental work has historically been done by hand until recently. Robots are used to carry out the desired wire bending operation in new developments in

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orthodontic archwire bending On the other hand, not all of the potential of CNC wire bending technology has been discovered. In this regard, the production workflow that incorporates CAD/CAM into the system is recommended. A variety of interfaces are also introduced for the purpose to construct bend points for different situations. The material qualities were not taken into account when developing the B-code generation system, which automatically translates the XYZ Cartesian coordinates for each bend point into the necessary theoretical wire bending parameters. An example that starts with bend point design, proceeds on to extract XYZ coordinates, and ends with developing the B-code serves as an example of the viability of this process. Additionally, a visual representation of the mechanism's use in the process of bending wire is also supplied.[3]

2. Various Robotic Wire Bending System

2.1. The bending art system

It is the first CAD/CAM system to be created for the purpose of creating specific orthodontic arch wires. This was created in 1984 by Professor Helge Fischer-Brandies and a colleague, together with the assistance of an engineering firm. BAS's initial prototype was produced. It is employed in the production of orthodontic wires for the labial and lingual arches.[4]

2.2. Motoman UP6

A different kind of MOTOMAN UP6-based robot that is employed in the bending of orthodontic archwires. It is made up of a computer and an archwire-twisting apparatus. The robot end needs to be flexible while bending the archwire because of the intricate shape of the archwire. And the six-freedom MOTOMAN UP6 robot can accommodate the need for flexibility made by the archwire bending.[3]

2.3. LAMDA system

LAMDA system or a lingual archwire manufacturing and design aid is a system for rapid and exact bending of the archwire. Developed by Alfredo Gilbert (2014), the system uses a robot that can bend the archwire in two planes which restricts the applications of the system.[5]

2.4. Cartesian type archwire bending robot

This system of archwire bending uses a robot that has multiple components. The bending procedure is examined and the structure of the archwire is designed with the included software. This cartesian orthodontic archwire bending robot comprises of the support mechanism, archwire posture control mechanism, archwire rotating mechanism, archwire support block, archwire rotary die, archwire fixed die, archwire rotary die posture control mechanism, blocking mechanism.

The cartesian orthodontic archwire bending robot can bend larger angle, and mainly make use of screw nut movement platform and stepper motor, non-standard parts are relatively small. It is easy to mass product and control. However, its end actuator structure is single, so it is difficult to meet the bending requirements of the individual archwire.[6]

2.5. Suresmile

Suresmile is an all-digital system that uses cutting-edge 3-D imaging technology and computer systems for diagnosis and treatment planning and uses robotics to create fixed orthodontic appliances that are uniquely tailored to each patient. Using a white light scanner or cone beam computed tomography, the orthodontists first create digital images of the patient's mouth and teeth. The technician then positions the teeth in their perfect location. After that, a computer makes a few minor tweaks to the data. The dentist inputs information into the system and sends it to the suresmile headquarters with the placement and tension of the brackets and wires. The archwire is now grasped by two mechanical grasping pliers, which bed the wire into the desired shape, as the use of the robots begins.[7]

3. Methodology

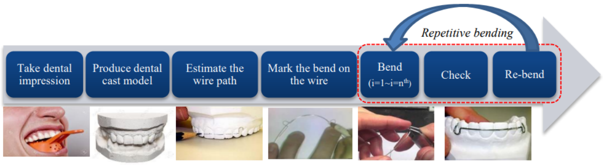


Figure 1: Shows the conventional manufacturing process for bending wire by hand.

Figure 1 depicts the standard production process for bending dental wire. The traditional method involves repeatedly bending to make a single bend, tiring the bender out in the process. The preferred bend point on the wire is often marked by the orthodontist or prosthodontist in accordance with the pre-planned wire path on the dental cast model. The bending procedure will then be carried out utilizing a human hand and a particular pair of pliers. This hand wire-bending process greatly depends on the bender's skill. The pre-bent wire typically needs to be bent again a few times before the proper shape is obtained. Due to certain significant changes, this lengthens the bending time and exhausts the bender (Ito et al. 2016). Additionally, it has a strong propensity to make mistakes, which reduces the effectiveness of the wire for the intended treatment. Therefore, to create high-quality dentures with a low revision rate, collaboration between an experienced dental professional and a qualified technician is frequently required.[8]

3.1. *Mathematical formulae to calculate the bending code (B-code)*

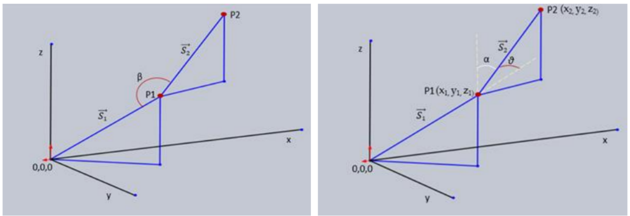


Figure 2: Definition of the bending parameters between two adjacent 3D linear segments, where S1 and S2 stand for the first and second segments, respectively, and where denotes the bend angle, included angle, and plane rotation angle.

Figure 2 Demonstrates the relationship between adjacent 3D linear segments' spatial properties. The intended wire bending parameters are represented by this data, which should be generated to instruct the machine on how to carry out the desired wire bending operation. For the situation of freeform target forms, a theory of 3D linear segmentation as described by Zhang (2013) is applied in this current work. According to this theory, the final shape is made up of a collection of 3D linear segments, indicating that the wire had to be bent several times to produce the desired shape. Hamid and Ito (2016) proposed this theory. According to the relative spatial parameters between adjacent linear segments in this situation, known as the B-code, each line segment can be bent one at a time. The concept of 3D vectors is extensively studied and adapted to theoretically establish the desired parameters. In this approach, each 3D linear segment represents a 3D vector and by using the 3D vectors concept, each parameter (L, β, θ) could be theoretically calculated by using the XYZ Cartesian coordinates between adjacent 3D points (P1, P2, P3), as shown by Eq. 1 – Eq. 4. The verification of these spatial parameters has been conducted by Hamid and Ito (2016).[8]

3.2. *Bend points planning*

Figure 3 shows the suggested manufacturing process from the time the desired bend points are planned until the B code is generated. It is hoped that this work will serve as a springboard for further investigation by other researchers in this area. Many cases have been taken into consideration in this process. First, if we already have a pre-bent physical wire from the dentist's office, we could scan it and utilise the scan to calculate the bend spots in CAD. Second, in the absence of a physical wire, 3D digitising tools could also be used to estimate the feature line of the target shape.[9] Thirdly, a 2D image of the patient's teeth might be used to prepare the bending points planning data. As a result,

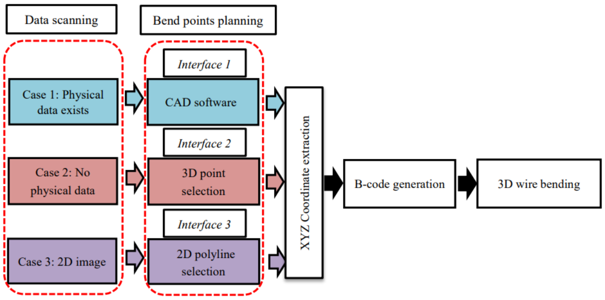


Figure 3: Workflow for manufacturing wire bending.

a few techniques have been investigated in regard to these kinds of cases. In this regard, multiple interface types have been established at the bend point planning stage. In the following sub-chapters, a quick overview of these interfaces will be elaborated through certain instances. Regardless of the interface utilised, this stage's ultimate goal is to obtain the desired XYZ Cartesian coordinates of each bend point.[10]

3.3. *Method 1: Physical data exists.*

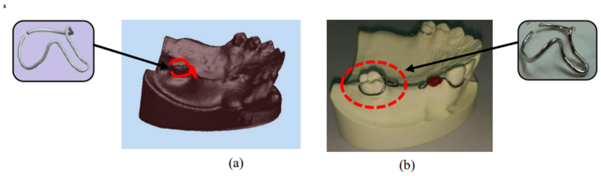


Figure 4: a: Digitized dental cast and the produced wire clasp model; **b:** Dental clasp fitting.

The first approach used CAD software for establishing the bend spots. The guiding idea behind this strategy is depicted inFigure 4. In this technique, a laser scanner was used to first digitalize the wire clasp. To replicate the intended shape, the bend points of the wire clasp were then plotted on the scanned wire clasp. In what is more comparable to a reverse engineering process, the pre-bent physical wire of the dental clasp was employed to directly help the bend points designing. This technique may be employed if it was planned to carry out the enhancement of the initial target shape.[10,11]

3.4. *Method 2: No physical data*

In the second method (Figure 5), a magnetic sensor was used to digitally estimate the target feature line, creating a collection of 3D point cloud data. Before physically bending the wires, a dental technician draws the desired wire outline with a pencil on top of the patient's dental cast. The idea of digitizing that line has thus been explored, leading to the adoption of a few more techniques to filter the noise created

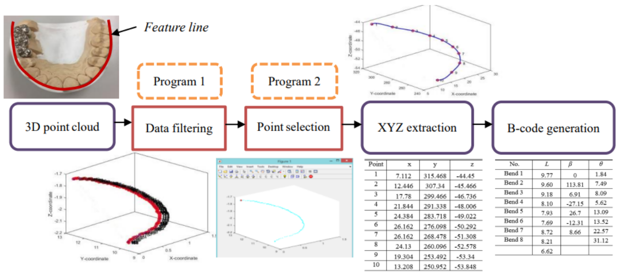
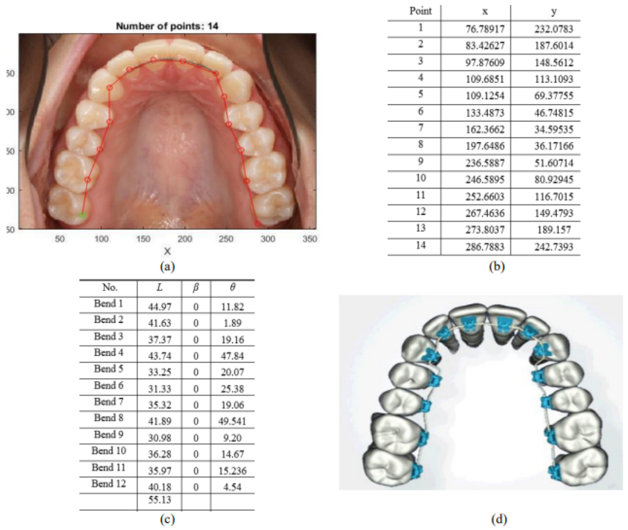


Figure 5: The method used in manufacturing to process 3D point cloud data.

and to choose the proper 3D bend point. These sounds are typically made by adjacent objects like fixtures, a measuring table, or another assembly part that the digitised part is attached to (Igor, 2012). Such noise needs to be reduced to maintain the surface reconstruction's quality. The red line in this illustration (Figure 5) designates the target feature line that needs to be digitized. Filtering the digitalized 3D point cloud data is necessary before processing the refined data in the Taati (2005) adopted 3D point selection interface, which allows users to choose the desired 3D points and automatically output the coordinates of those points in Excel. The CAM data are then produced using the standard B-code generation algorithm using the coordinates. To assess the viability of the proposed programs, Hamid and Ito (2017) conducted some research of this type of instance.[11,12]

3.5. Method 3: 2D teeth image



Point	x	y
1	76.78917	232.0783
2	83.42627	187.6014
3	97.87609	148.5612
4	109.6851	113.1093
5	109.1254	69.37755
6	133.4873	46.74815
7	162.3662	34.59535
8	197.6486	36.17166
9	236.5887	51.60714
10	246.5895	80.92945
11	252.6603	116.7015
12	267.4636	149.4793
13	273.8037	189.157
14	286.7883	242.7393

No.	L	β	θ
Bend 1	44.97	0	11.82
Bend 2	41.63	0	1.89
Bend 3	37.37	0	19.16
Bend 4	43.74	0	47.84
Bend 5	33.25	0	20.07
Bend 6	31.33	0	25.38
Bend 7	35.32	0	19.06
Bend 8	41.89	0	49.541
Bend 9	30.98	0	9.20
Bend 10	36.28	0	14.67
Bend 11	35.97	0	15.236
Bend 12	40.18	0	4.54
	55.13		

Figure 6: a: Bend points planning; **b:** XY coordinate extraction; **c:** B-code generation; **d:** Actual intended application.

A 2D image is fed into Matlab's 2D polyline selection interface in the third method (Figure 6). This kind of input information could be used to plan the lingual archwire treatment. This method imports the 2D picture file from Ursell (2013) into the program, where the user can estimate the appropriate bend points for the patient's treatment plan, as shown in Figure 6a. As seen in Figure 6b, the program exports the XY Cartesian coordinates of all selected points to Excel, where the B-code creation program will use them to create the necessary CAM data.[10–13]

3.6. CNC wire bender[14]

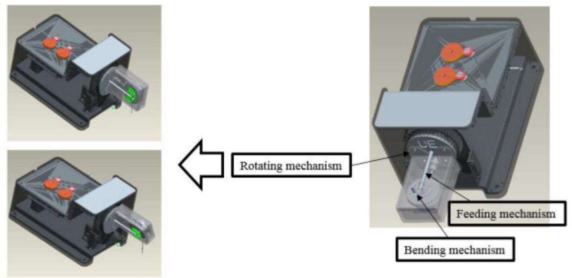


Figure 7: CNC dental wire bender consists of a feeding mechanism, a rotating mechanism, and a bending mechanism.

The feed length (L), rotation angle ((β), and bending angle (θ) are the three bending parameters that have been identified in this CNC wire bender (Figure 7) as being used to regulate the machine. The relationship between these characteristics and the wire bender is obvious given that the CNC wire bender is made up of three primary mechanisms: a rotating mechanism for feeding the wire, a bending mechanism, and a wire feeding mechanism.[15] The operation of this wire bender is simple; in relation to the B-code, L controls the feed of a straight length of wire in millimeters; in relation to the sign of (β), (θ) directs the rotating mechanism to make a significant rotation in either the clockwise or anticlockwise direction; and finally, (θ) establishes the corresponding bending angle for each bending operation. The rotation (β) of counterclockwise is considered as negative (-ve), while the clockwise rotation is alternatively represented as positive (+ve). The rotation angle (β) indicates a change of plane between the previous bend and the subsequent bend, and the rotating mechanism must adjust to this change in preparation for a successive bending operation.[16,17]

4. Drawbacks

The complexity of the oral cavity and the physical characteristics of the archwire give the robot a challenge to provide the necessary elements for the right orthodontic treatment. The key to progress is human and computer interaction, and future research must concentrate on a 3D virtual display of the orthodontic appliances, a virtual expectation of the therapy. Because the architecture of the oral cavity area has restrictions that make it difficult for the robots to understand working conditions, there may always be a need for the human component in the treatment. Robots are designed to be adaptable, precise, and trustworthy, but all those qualities are confined by the mouth cavity, which was created to limit the degree of freedom of the robots.[18] For the archwire bending robots, research must concentrate on the spring-back and bending algorithm. To improve the accuracy of the job done by the archwire bending robots, more study about the physical characteristics of orthodontic archwires is required.[19]

5. Conclusion

Due to the robot's advantages in standardization, industrialization, and intelligence, orthodontics can undergo a significant revolution from qualitative to quantitative, and this has been a key area for medical robot development.[19] The current state of robot application and research in orthodontics is discussed, along with its fundamental requirements and research challenges. Finally, future robot research in orthodontics is anticipated from three angles, including new structure, sensor and control technology, and human-computer interaction techniques. The results of orthodontic treatment using a robot or machine to twist the archwire used in fixed orthodontic appliances will be significantly better with a startlingly shorter course of treatment.[14,20]

6. Source of Funding

None.

7. Conflict of Interest

None.

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Cite this article: Mahajan S, Goyal M, Mittal S, Aggarwal I, Parween A. Robotic wire bending in orthodontics -A review. *J Dent Spec* 2024;12(1):7-11.