INVESTIGATION ON WIRE-ENABLED MECHANISM IN MEDICAL THERAPY FOR PROTOTYPING THE STYROFOAM MASK

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In poor nation, the existing problems in the healthcare service such as high fee or expensive treatment cost, could bring some troubles for patients. It is caused by luxurious devices or highly operating cost during the treatment process. Therefore, there are urgent demands to produce cheaper machine or inexpensive solution while the number of patients has increased rapidly. In this paper, a study of wire-enabled mechanism to yield the mask for medical usage is introduced. Firstly, the mechanical architecture and body frame which based on the working principle, are suggested. The 3D design of proposed mechanism is launched on personal computer before manufacturing. Then, the electrical design is demonstrated to clarify the internal schematic. Especially, the program control is built in the environment of open-source software which is popular and easy to implement. To verify the proposed design, the real-world hardware is established in order to experiment. From these results, the effectiveness and feasibility of this approach have been validated and confirmed. It could be employed in many applications such as radiotherapy or rapid prototyping.

Keywords: medical application, rapid prototyping, treatment supporting, motion control, medical machine

1. Introduction

With the rapid development of technology, the molding process has been gained significantly. The popular methods such as 3D printing, manufacturing techniques using milling machine, cutting process by metal tools or forming via heater, remain some barriers. Nowadays, the 3D printer becomes one of the most important factors in the fourth industrial revolution. It appears everywhere from construction, manufacturing, art, military defense and education. In [1, 2], authors introduced a new printing capability enable complex hydraulically actuated robots

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and robotic components. Many outputs of linear printing procedure are actuators, gear pump and soft gripper. However, the printing products are just made after a long-time processing. Because of low speed, the printer reveals many disadvantages in rapid prototyping. In this sense, using milling machine should be considered to replace printing method. In [3, 4], researchers described the milling machine that has been integrated with a robot both mechanically and on the controller level. To allow for robot and milling spindle to machine on the same workspace at the same time, the control concept is extended and a concept for a path planning method is developed. However, it is suitable for industrial manufacturing due to working conditions and environment. The cutter speed is enhanced and the tool path for CNC cutting machine is optimized in [5, 6]. The work requires the system parameters should be considered during operation. The metal cutter tool produces more dusts and noise while it harms to operators. Besides, the shaping object could be implemented through forming process. A forming simulation was proposed in [7, 8] using linear spring element to build more accurate numerical model of process conditions such as blank-holding force, draw-bead resistance. In reality, the forming machine has large physical dimension and it is hard to keep high precision owing to heating actuator.

The above methods may not be proper to apply in medical cornerstone. There are various severe constraints such as compact unit, less noise, fast prototyping, safety and data security. For cancer disease, it becomes one of serious challenges for the reason that the ratio of death increases gradually as well as the number of new patients is not in decreasing trend. Generally speaking, there are many types of cancer treatment. The types of treatment that our patients have will depend on the type of cancer they have and how advanced it is [9]. Our approach is to develop the mechanism to support the radiotherapy of cancer treatment [10]. Radical radiotherapy is usually delivered in multiple treatments on a daily basis over 3-7 weeks. It often uses a mask which made by Styrofoam material, in order to cover patient's body. Otherwise, the non-cancer cell could be destroyed by beam radiotherapy. Traditionally, people must pay much for radiation therapy because of high cost for Styrofoam masks. Especially, in the context of global pandemic, these masks must be produced as soon as possible owing to the increasing number of patients [11, 12]. Thus, a reasonable solution to assist the cancer treatment should be considered.

2. Problem Statement

The principle of radiation therapy is to focus a high (reasonable) dose at the tumor (target), and at the same time to reduce the harmful dose to the involved healthy tissue [13]. Radiation therapy can provide long-term control of local or locoregional cancer without removal of large volumes of tissue and with preservation of function of surrounding normal tissues. Radiation therapy is used for cancers that have extended near or around critical structures such as spinal cord, nerves, or large vessels. Normal tissue response limits the total radiation dose that can be used. The objective of radiation therapy is to provide the highest probability for local tumor control with a probability for serious complications such as bone or soft-tissue necrosis of less than 5% [14]. In the radiation therapy, one of the problems which many researchers still try to discover, is to protect the normal tissues with reasonable cost. It might be feasible for patient and effective for nursing care.

High-energy radiation is delivered to tumors by means of a linear accelerator. A beam of electrons is generated and accelerated through a waveguide that increases their energy to the keV to MeV range. Once the collimators from machine have been opened to the desired field size that encompasses the tumor, the physician may decide to block out some normal tissue that remains in the treatment field. This is accomplished by placing blocks (or alloy), constructed of a combination of bismuth, tin, cadmium, and lead, in the path of the beam. In this way, normal tissues are shielded, and the dose can be delivered to the tumor at a higher level than if the normal structures were in the field. These individually constructed blocks are used in both x-ray and electron treatments [15].

Tumors usually have a natural shape, and current external radiotherapy devices usually only produce projection fields with straight edges and right angles. In terms of anatomical location, cancerous tumor(s) are often adjacent to protected healthy tissues. Commonly, the block that built by lead alloy, is often utilized since the production is not much difficult and local engineer could handle this work. Therefore, it is necessary to make a lead mold that covers the projection field according to the shape of the tumor.

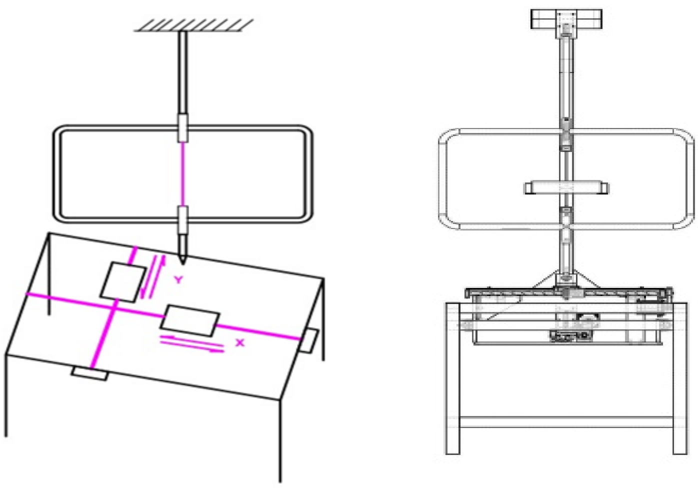
To support many technicians in producing the lead mold, a wire-based cutter machine is currently deployed to perform different shapes for any patient. The drawbacks of this machine are too hard to find the replaceable equipment in domestic market, and its price is higher than local products. Thus, our motivation is to launch a new mechanism which could perform various shapes for lead mold, and it is easy to maintenance and reasonable cost.

In this paper, a novel design of mechanical approach is proposed to treat cancer disease in Vietnam. The idea to enhance the wire-enabled mechanism for prototyping the Styrofoam material which is essential for cancer treatment, is carried out. Since the driving actuators together with heating wire follow the reference trajectory on 2D plane, both the computational mechanics and electrical design are manipulated to ensure the stable movement while tracking. The software programming that allows technician to implement easily, is analyzed under G code format. The rest of this work is organized as following. In Section

III, a structure of device is illustrated in detail. Some mechanical computations are mentioned to systematize the design process. Section IV describes the control topology such as operating routine, software control and electrical connection. To prove the effectiveness and feasibility of design, a prototyping mold cutter machine is developed to concrete the experimental results in Section V. Finally, several conclusions in Section VI are carried out to apply this machine in reality.

3. Design of mechanical architecture

The criterion of mechanical architecture should be compact unit, simple to handle, low cost and lightweight. There are two options to design the machine: horizontal and vertical direction. In the horizontal style, its height is low and the control method is decentralized scheme which is more complex. Hence, the vertical mold cutter machine as Fig. 1a is chosen to develop in this paper.



(a) (b)

Fig. 1. Diagram of vertical mold cutter machine (a) and front view of proposed design (b).

The hard-set frame which carry heating wire is hang vertically. The heating wire is made of Ni-Cr material that is capable of anticorrosion and oxidization at high temperature. This wire reaches a temperature of several hundred degrees Celsius in seconds. The Ni-Cr wire is located inside frame that works at an angle of 90^o to x-y plane. It is ensured that the wire is strained to enhance the high precision of product during operating process.

In Fig. 1b, front view of proposed machine is shown. In this model, it is essential to design a component below heating wire attaching electrical adapter. Moreover, above heating wire, a spring is used to establish stressing force to guarantee that wire is always in stressing status. For driving mechanism, many actuators are considered to connect between motors and moving parts. The belt solution is not good to avoid sliding phenomena and high maintenance fee. In remaining case, ball screw gives the impression of accuracy, stability and reliability. The step motor is selected as low cost, easy to control and small dimension.

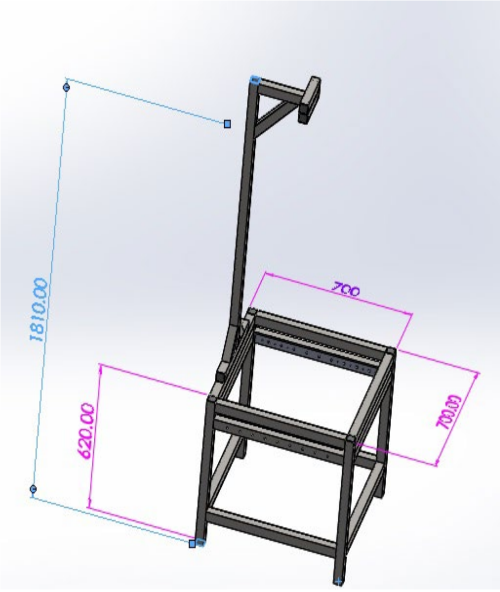


Fig. 2. Physical dimension of proposed design

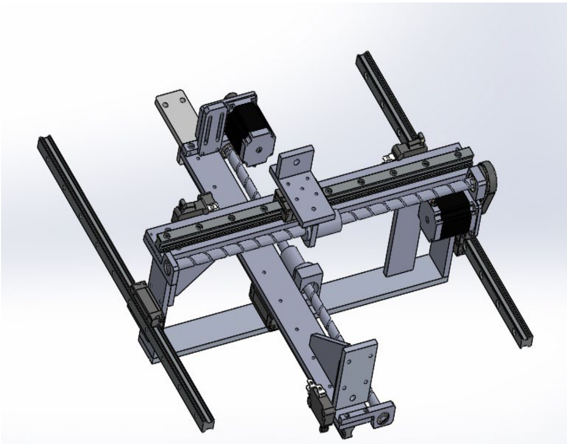
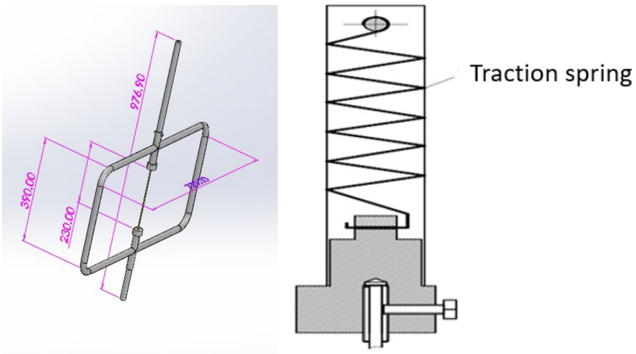


Fig. 3. Mechanical connection between x axis and y axis.



(a) (b)

Fig. 4. Wire tensioning mechanism, (a) wire frame, (b) tensioning actuator.

The specifications of dimension parameters are explained in Fig. 2. The platform of machine is assembled from many shaped square steels (40mm x 40mm), thickness 2mm. The joint between two square steels is soldered together. The evaluation of whole frame of mold cutter machine confirms that the welding is durable and work well while the frame is stiff enough and feasible.

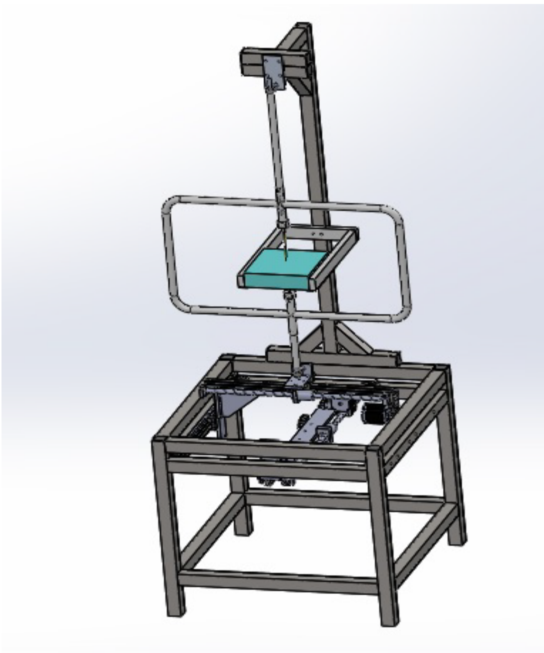


Fig. 5. 3D view of overall design.

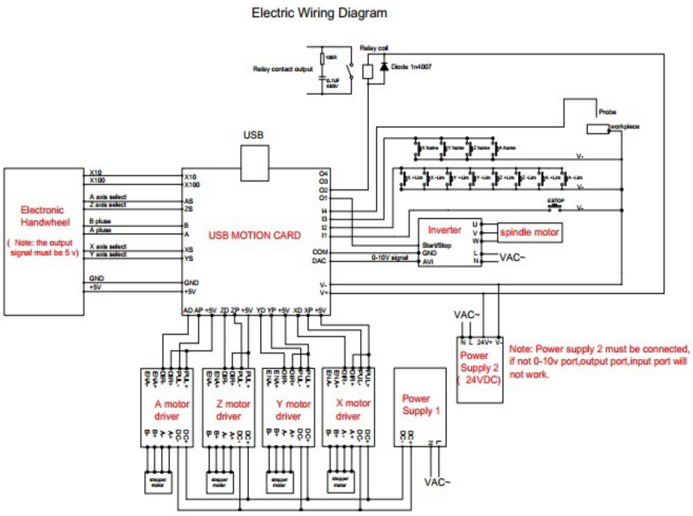


Fig. 6. Connection schematic of interface module.

In the design of driving mechanism, two axes could be operated independently or dependently. In case of independent design, the control method is complex and separated. Hence, it is recommended to create a mechanical relationship between x axis and y axis. In this way, the movement of x axis would affect on y axis movement as Fig. 3. Both of them are integrated together to form an unified body. Conversely, the design should be optimized in light weight. Its weight ranges from average level of working table. The medical staff could handle it easier. One of the key factors touching the system precision is wire tensioning frame as Fig. 4. The cutting error becomes larger if wire is not stretched. Simultaneously, the current would run via heating wire. The insulation part should be noticed to implement. In Fig. 5, the overall machine model is demonstrated. In virtual environment, the operation of machine is simulated to estimate system performance. After completing review, the detail design is manufactured in mechanical workshop. The size of each component is strictly consolidated. In assembling job, the loose coupling ought to execute.

4. Control topology

A. Design of electrical components

To break out the cost, popular accessories and devices in market are used in our system. The universal usb card motion control plays a role as interface module in Fig. 6. The isolation schematic among inputs and outputs is main part. This diagram protects centralized computer not to be damaged from driving actuators. Concurrently, the understanding connection could help to prevent technical problems.

In Fig. 7, all electrical components are listed. To drive step motor, TB6600 driver is needed to implement. The role of driver is to transform digital control pulse and directional pulse into two phases control signal of step motor. The rated input current and output current are 5A and 4A respectively. The consumed power is approximately 160W. The power supply with AC input and 24 VDC 20A output provide stable energy for entire system. In central computer, the control program is selected as Mach 3 software. This tool is opened source, therefore, easy to download. Furthermore, the graphical interface is oriented to user. The operator could execute or handle immediately without training.

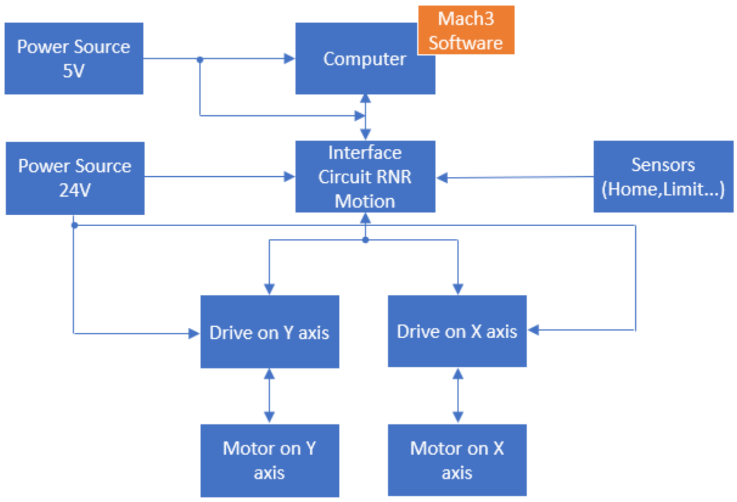


Fig. 7. Electrical components scheme.

The system resolution is also concerned on machine performance. It represents the minimum resolvable size of machining system.

$$\mathrm{Re} = \frac{L}{P} = \frac{L}{\dfrac{360^o}{m \times n}} \tag{1}$$

Re: system resolution

L: pitch of ball screw

P: number of pulses in one rotation

m: resolution of step motor

n: operating mode of step driver

It could be estimated that the motor which provides 200 full steps per revolution, use 1.8 degree for one step in full-step mode (n=2). And if the pitch of ball screw is 5 mm, then the system resolution is approximately $\mathrm{Re} = 0.05$.

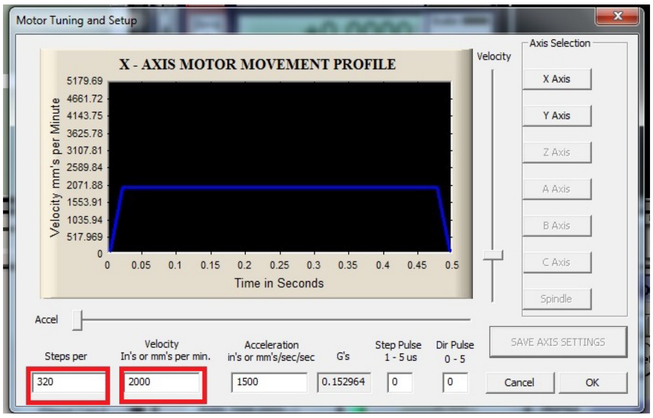


Fig. 8. Parameters of step specification and speed in motor tuning.

B. Control Software

The inputs of Mach 3 software are under G-code format as Fig. 8. Most of G-code compiler do not have switching function among operational mode. Whenever hardware platform is built, some notifications of pulse frequency ought to be noticed. Besides, the usage of G-code library is extracted into running program. Some basic functions are recorded such as G90 for absolute coordinate, G91 for relative coordinate, G00 for rapid process. If the geometrical contour is simple, technical operator could program in Mach 3 instantly. Otherwise, the third-party software should be judged to generate G-code. Technicians suggest geometrical shape for patient in radiation therapy. They send shaped profile to the third-party software and receive contour under G-code format. Then, G-code is input to Mach 3 to drive motors.

C. Example Program

To demonstrate the execution of machine, an example of simple profile is plotted in Fig. 9. The sample product has size of 100mm x 100mm. In the coordination of x-y, perimeter of shape is determined and directional cutting process is drawn. The machine always starts at home position. In step I, heating wire moves along x axis until center of shape. From initial point on x axis, it moves along y axis perpendicularly. Step III gives the changes in x location. Then, the cutting line moves vertically in y axis. In step V, from start point to end point on x axis, the cutting wire run continuously. Similarly, it moves along whole dimension on y axis. Orderly, the cutting actuator closes the rectangular shape when it backs to center point on x axis. The G-code program to generate this profile is designated in following.

```
N5 G90
N10 G01    X12  Y0      (Step I)
N15 G01    X12  Y11.5   (Step II)
N20 G01    X17  Y11.5   (Step III)
N25 G01    X17  Y21.5   (Step IV)
N30 G01    X7   Y21.5   (Step V)
N35 G01    X7   Y11.5   (Step VI)
N40 G01    X12  Y 11.5  (Step VII)
N45 G01    X0   Y0      (Step VIII)
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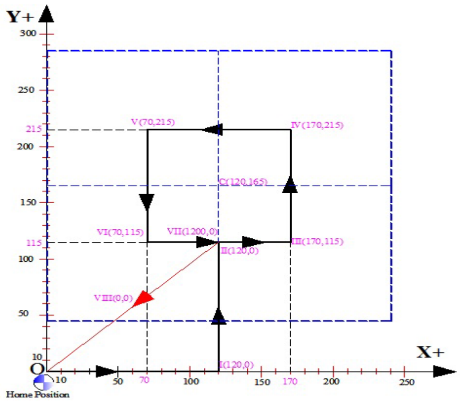

Fig. 9. Example A: rectangular profile processing.

In the other example, the geometrical contour is closed circle as Fig. 10. To do this work, the collaboration between two axes is a must. The entire circle is divided into four sub areas. In each area, the role of two axes is different. The axis with longer distance becomes master axis whilst the axis with shorter movement is slave axis. At each sampling time, master axis run firstly. Later, master axis would drive slave axis depending on coordinating constraints among them. In below code, an example program for circular shape is shown.

```
N5  G90
N10 G01    X12    Y0      (Step I)
N15 G01    X12    Y8      (Step II)
N20 G03    X20.5 Y16.5  I0  J 8.5 (Step III)
N25 G03    X12    Y25  I- 8.5  J0 (Step IV)
N30 G03    X 3.5  Y16.5  I0   J-8.5 (Step V)
N35 G03    X 12   Y8  I8.5 J0     (Step VI)
N40 G01    X 0    Y 0             (Step VII)
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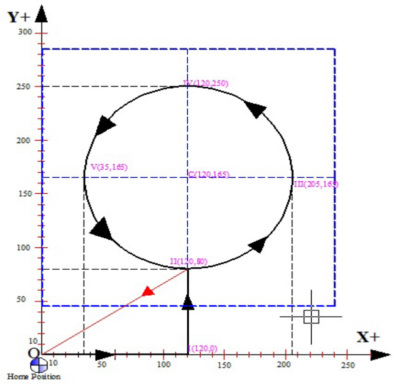


Fig. 10. Example B: circular profile processing.

5. Experimental results

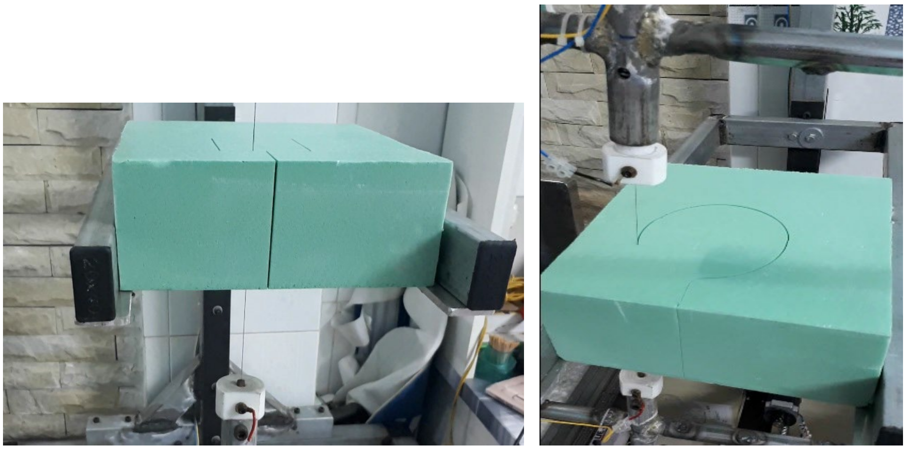
To validate the proposed design in this paper, the hardware platform of machine is built up. All control parameters and system specification are compliance with design as Table 1. The components could be found easily in market. Consequently, the manufacturing cost of machine is low and consuming time is short. The personal computer with i7 core six generation is used to be main

CPU. The operating environment is win 10 Home OS. The opened-source Mach 3 is free and easy to download. After finishing the assembled steps, hardware system is connected to computer. Most of coefficients are set in Mach 3. Lastly, several experimental tests are carried out to prove the proposed effectiveness and feasibility of design.

Table 1

Technical specifications of proposed hardware

Item	Description
Mask maximum dimension	350 mm x 300 mm
Thickness mask	100 – 150 mm
Mask material	Styrofoam
Wire diameter	1 – 2 mm
Tensile strength	~ 532 MPa
Stroke	500 mm
Weight	22 kg



(a) (b)

Fig. 11. Experimental results such (a) example A and (b) example B.

Fig. 11a and Fig. 11b exemplify linear and circular example correspondingly. From experimental results, it can be seen that the proposed approach is effective, reasonable and applicable. The mold cutter machine is able to work in practical scenarios.

6. Conclusions

In this paper, a prototyping styrofoam mold machine is designed to support the treatment by radiotherapy. There is a emergent need to carry out the aids since the cancer disease grows rapidly. A wire-enabled mechanism to yield the styrofoam mold was introduced. An opened-software was implemented to control overall system. To verify the feasibility and effectiveness of proposed approach, the mechanical platform was established. From various tests, the experimental performance of proposed system guarantees stable execution, high accuracy and easy to control. This machine could be applied in cancer treatment procedure with low-cost.

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