

Smart wearable device with adaptive configuration function for neck rehabilitation

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ABSTRACT

Neck health problems are showing an increasingly severe trend in modern society, which is mainly manifested in the rising incidence of cervical spine diseases, the recovery of neck health problems, and the influence of the working environment on neck health. This paper proposes a wearable device with adaptive configuration for neck rehabilitation, which includes a clamping wheel massage mechanism and a pusher massage mechanism. The device has two massage modes, the adaptive, flexible massage part, and the pusher massage part, and uses the cam profile to plan its motion trajectory. It takes into account the structure of the human neck and the Chinese medicine neck acupuncture points and distinguishes it from the traditional fixed massage mode and the two massage modes can be switched to realize the configuration self-adaptation, and at the same time, ensure that the two massage modes are not interfering with each other. The device uses a wearable design; straps can be worn to the back, effectively achieving a wide range of neck massage coverage to achieve the desired massage effect.

Keywords: Smart wearable device; Neck Rehabilitation; Chinese medicine Massage; Cam Mechanism

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I. INTRODUCTION

With the development of modern society, the accelerated pace of people's lives, and the increase in work pressure, the incidence of cervical spondylosis is increasing year by year, and it occurs in all age groups. The onset of cervical spondylosis is also a slow accumulation process, which requires us to adhere to the principle of early intervention and early treatment. Clinical treatment of cervical spondylosis is based on conservative treatment, including medication, physical therapy, traction therapy, and so on. Since modern medicine lacks a comprehensive and systematic understanding of the pathogenesis of cervical spondylosis, and the treatment is only symptomatic, it is essential to conduct rehabilitation training for the neck. However, most of the current cervical rehabilitation training devices adopt mechanical structures, which are weak to realize complex movements. Therefore, this paper designs a wearable device with configuration adaptive, which has the advantages of simple structure and easy control.

The neck massage part of the device combines the massage theory of Chinese medicine so

that the massage organization targets specific acupoints. It relaxes the neck muscles, promotes blood circulation, and gradually restores the neck to its normal function, which remarkably affects some cervical spine diseases. Neck massage can promote the body's self-repair mechanism and improve the condition of the neck through the principle of TCM massage, which is beneficial to the health and comfort of the whole body^[1]. The combination with TCM is a new idea that has the potential to enhance the therapeutic effect on the neck, which is worth exploring.

This paper mainly focuses on the shortcomings of the existing neck rehabilitation training device, according to the principle of ergonomics, designing a wearable device with configuration adaptive.

Based on the physiological structure of the human neck and a constant velocity motion rule, the neck rehabilitation device is proposed and designed. It is consisted of two sets devices, including the adaptive, flexible massage parts and the push rod massage parts. Horizontal and longitudinal layout massage device is responsible for horizontal parts

and longitudinal parts of neck, respectively.

The overall frame is placed on the back of the human body using shoulder straps to ensure its stability and rely ability control. This device is designed with reasonable structure and perfect function, which can meet the needs of various rehabilitation training.

II. Human neck structure and Chinese medicine massage theory

The physiological structure of the human neck consists mainly of the cervical vertebrae. The cervical vertebrae are part of the human spine, located between the head and the chest, and play a role in connecting and protecting the spine. The structure of the cervical spine consists mainly of seven vertebrae, each of which is connected by an intervertebral disc, the presence of which allows the cervical spine to move in a back-and-forth bending motion. The neck is usually between 10 and 15 centimeters, the average length of the human neck. The width of the neck is usually proportional to the length of the neck, and variations in neck width largely depend on the skeletal structure and musculature of the individual^[2]. The physiology of the human neck is shown schematically in Fig.2.1. Referring to the physiological structure of the human neck in Fig.2.1, the movement and size of the mechanism are designed to fit the massage device to the neck with the direction of the shape structure of the neck combined with the Chinese medicine neck massage points.

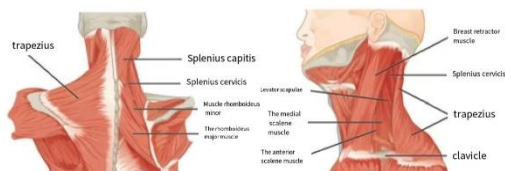


Fig.2.1 Schematic diagram of the physiological structure of the human neck

Chinese medicine neck massage is a traditional treatment method, mainly through stimulating the neck points to relieve neck symptoms, generally used to treat cervical spondylosis and other diseases. The techniques of Chinese neck massage mainly include holding and kneading the neck and shoulders and percussion, which can effectively open the veins and collaterals, promote the local blood circulation, eliminate the local inflammatory pathogenic factors, enhance the local supply of oxygen and nutrients, to remove the harmful metabolite products.

Combined with the idea of traditional Chinese medicine and considered that the device should be multifunctional in order to realize the

active training of human neck muscles at the same time, it should also have the function of massaging the neck in order to achieve a better neck rehabilitation effect and prevent neck muscle atrophy. Massage Fengchi point, Fengfu point, Tianzhu point, and other points have a good effect on the relaxation of neck muscles; these points are commonly used in Chinese medicine neck massage position, its distribution in the neck as shown in Fig.2.2; massage of these points can help to soothe neck discomfort, improve blood circulation, soothe tendons and activate collaterals, etc.^[3]. In addition, some cervical spine problems caused by other diseases, such as lumbar disc herniation, headache, and dizziness, have significant effects.

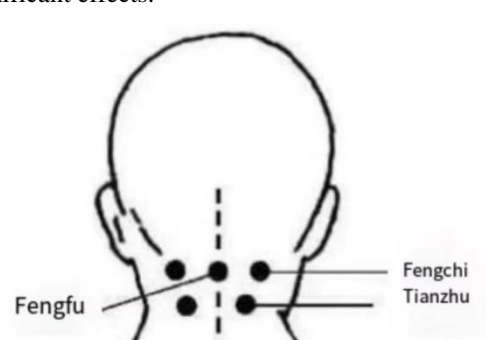


Fig.2.2 Diagram of the primary acupoints on the back of the neck of the human body

Considering that Chinese medicine emphasizes the principle of treatment that varies from person to person, rehabilitation devices can provide personalized adjustment functions to meet the rehabilitation needs of different individuals. Considering the Chinese medicine concepts of qi, blood, meridians and tendon relaxation, a neck rehabilitation device can be designed that aligns with Chinese medicine ideas to provide more comprehensive and targeted assistance for neck rehabilitation.

III. Chinese medicine Massage device design

The selection of the follower motion law will directly affect the quality of the mechanism in the design process to get a cam mechanism with better motion characteristics of the follower motion law; the realization of this hope, firstly, through the exploration of new laws of motion to complete, and secondly, through the clever combination of a variety of laws of motion to complete^[4]. Since the object of the device is the neck, we need to design the trajectory of the follower through the structure of the neck to determine the mechanism's motion.

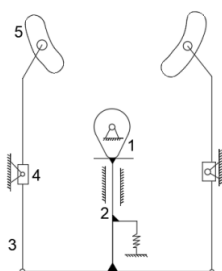
Combined with the neck structure, we designed the massage device mainly consisting of an adaptive, flexible massage part, a pusher massage part, and a wearable part. The design process needs

to control each part's size and installation position to ensure that the massage mechanisms do not interfere with each other during the movement process^[5].

3.1 Adaptive, flexible massage section

In the design of the two sides of the neck massage, in order to ensure that the two sides of the massage strength and massage frequency are moderate, we drew on the clamping mechanism; the design of the clamping mechanism needs to ensure that the object to be measured is clamped stably, with little disturbance, high positioning accuracy of the rotary and mobile, and flexible measurement^[6]. Taking into account the structure of the human neck, we optimize the transmission mode of each part on this basis to ensure that the follower's law of motion and the human neck fit to design a clamp wheel massage mechanism to achieve the massage of the two sides of the neck, Fig. 3.1 for the mechanism of the sketch.

The adaptive, flexible massage part consists of a clamp wheel massage mechanism; massage is the sides of the neck, through the active member of the cam swing drive the prismatic pair for forward and backward reciprocating motion, the middle of the pull rod is connected to the frame, the two sides were connected to the massage wheel and the prismatic pair, in the back and forth movement of the prismatic pair, the pull rod for a certain angle of the swing to achieve the effect of clamping, such as shown in Fig.3.1 sketch, Fig.3.2 is the actual picture.



1.Cam 2.Prismatic pair 3. Pull rod
 4. Pull rod 5.Massage wheel

Fig.3.1 Sketch of the pinch wheel massage mechanism.

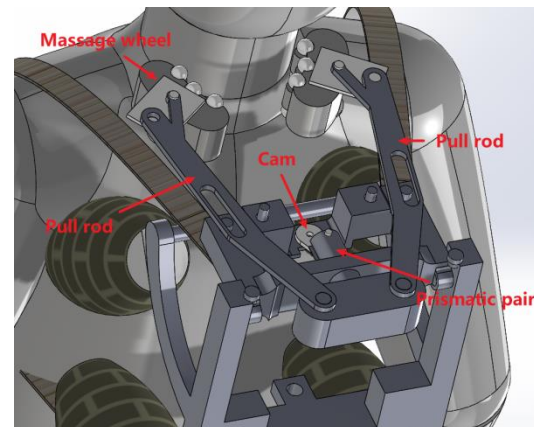


Fig.3.2 Model of the clamping wheel massage mechanism

Calculation of the degree of freedom of the clamp wheel massage mechanism: as shown in Fig.3.2, the number of active members is 4, the higher pair is $P_h = 1$, the lower pair is $P_l = 5$, then the degree of freedom of the mechanism cam massage mechanism is:

$$F = 3n - 2P_l - P_h = 3 \times 4 - 2 \times 5 - 1 = 1$$

The massage wheel's shape is designed with a waist shape plus rollers to keep its curve in line with the trajectory of the human neck. This shape better adapts to the curve of the human neck, providing a more precise and comfortable massage experience.

When the roller is close to the neck of the body, the clamping jaws are connected to it. The clamping jaws automatically adjust to the shape of the cam to hold the roller in position on the neck of the body. Adjusting the tightening of the clamping jaws allows a clamping massage effect, providing targeted massage intensity.

The function of the adaptive, flexible massage part is to massage the muscles and acupoints on both sides of the neck, and the cam swing of the active member drives the rollers and clamping jaws. Fig.2.2 and Fig.3.2 show that the adaptive, flexible massage portion mainly massages the Fengchi and Tianzhu acupoints. The Fengchi point is located under the occipital bone at the back of the neck, outside the depression of the large tendons on both sides of the hairline. Massaging Fengchi point can relieve neck pain, promote the meridian qi and blood flow, accelerate blood circulation, and restore the tense and stiff cervical vertebrae to normal. Fengfu point is under the back of the head, under the occipital protruding area; Tianzhu point is along the horizontal line of the hairline at the edge of the large tendons. With the passage of qi and blood, Shu tendons and collaterals replenish the essence and fill the marrow, clear heat and bright eyes, dredge the

wind and clear the head through the meridians and activate the role, is the first choice for the treatment of the head, neck, spine, and neurological diseases within the preferred acupuncture points, often massage Tianzhu point, can improve blood circulation in the brain, smooth qi and blood, and harmonize the efficacy of all the veins^[7].

3.2 Pusher message section

In order to prevent the problem of neck massage discomfort caused by the interaction between the two parts of the massage mechanism, the design of the push rod massage part is independent of the adaptive, flexible massage part to ensure that the two movements do not interfere with each other. Considering that it is difficult for the push wheel to keep in line with the neck structure when massaging. we designed massage parts of push rod end As shown in Fig.3.3, where the massage part presents a certain angle and the massage part can still keep in line with the neck structure when the whole part moves to different positions.

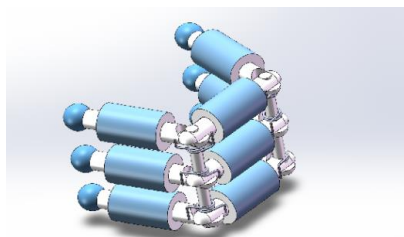


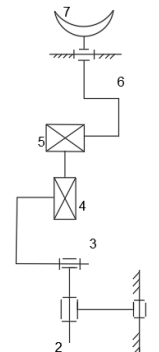
Fig.3.3 Massage parts of push rod end

The pusher message mechanism massages the middle of the neck; the active part is designed to do circular movement of the cam, powered by the motor; the cam is connected to the connecting rod, the connecting rod is designed with a certain length of the slide chute, in the movement of the connecting rod through the slide groove with the frame support rod to limit the cam's circular movement to a specific range, so that the overall movement of the mechanism and the structure of the neck to maintain consistency. The massage part is installed with a rotatable roller, which rotates by friction to achieve the effect of massaging the neck when contacting the neck.

Fig.3.4 shows the push rod massage mechanism; Fig.3.5 is a real mechanism diagram. Calculation of the degree of freedom of the push rod massage mechanism: as shown in Fig.3.4, the number of active components for 3, the higher pair $P_h = 2$, the

lower pair $P_l = 3$, then the agency cam massage mechanism degree of freedom for:

$$F = 3n - 2P_l - P_h = 3 \times 3 - 2 \times 3 - 2 = 1$$



- 1.Actuator 2.Vertical revolute joint
- 3.Horizontal revolute joint 4.Longitudinal revolute joint
- 5.Transverse revolute joint 6.Fixed revolute joint
- 7.Massager

Fig.3.4 Push rod massage mechanism sketch

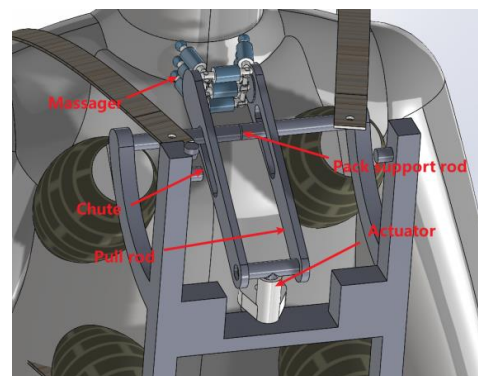


Fig.3.5 Push rod massage mechanism actual drawing

The design not only considers the matching with the trajectory of the human neck but also focuses on the effect of massage. The push rod massage mechanism can be matched with the structure of the human neck to massage the area in the middle of the human neck, and when the active part rotates, it will transfer power to the push rod part, which will cause the push wheel to produce a movement arc. During this movement, the push wheel is in contact with the neck of the human body and moves by a predetermined arc trajectory, applying a suitable massage strength for specific acupoints. Fig.2.2 and Fig.3.5 show that the pusher message portion mainly massages the Fengfu acupoint. The Fengfu acupoint is a key acupoint for treating stroke and aphasia and has the effect of dissipating heat and removing dampness, which helps relieve pain in the back of the head, and also relieves fatigue and regulates bodily functions, improves neck discomfort and enhances a sense of health in the body.

3.3 Wearable design

Considering comfort and portability, the overall wearing design adopts a wearable design. As shown in Fig.3.6 and Fig.3.7, the top and bottom of the rack are connected by a strap and four soft bags are added in the middle to isolate the back of the human body from the rack. The overall size is controlled within a certain range, which makes it more portable and comfortable than the head-worn design.

As shown in Fig.3.6 and Fig.3.7, the distance from the center of the massage mechanism to the bottom of the device is $L_1 = 223mm$, the distance from the upper portion of the shoulder strap to the bottom of the device is $L_2 = 214mm$, the length of the rack bar is $L_3 = 240mm$, and the distance from the shoulder of the mannequin to the bottom of the device is $L_4 = 184mm$.

The average adult neck length is between 10 and 18 cm. At the same time, the Fengchi acupoint is located under the occipital bone at the back of the neck, at the outer depression of the large tendons on both sides of the hairline; the Fengfu acupoint is under the back of the head, under the occipital protrusion area; the Tianzhu acupoint is along the horizontal line of the hairline, at the edge of the large tendons, and the body massage mechanism is set higher than the shoulders $\Delta L_1 = L_1 - L_4 = 39mm$ place so that the massage portion can be aligned with the acupoints shown in Fig.2.2.

In order to prevent the feeling of tightness and extrusion when wearing, the position of the shoulder belt is set higher than the shoulder $\Delta L_2 = L_2 - L_4 = 30mm$. In order to prevent tightness and squeeze feeling when wearing, the position of the shoulder strap is set higher than the shoulder so that it retains a certain distance. The shoulder width of an average adult is about 35cm. The distance of the fixed position of the endpoint of the shoulder strap is $L_5 = 16.5cm$ so that the shoulder strap maintains a certain angle of the pressure on the human body, which not only reduces the discomfort brought by the shoulder strap to the human body but also ensures the comfort and stability when using.

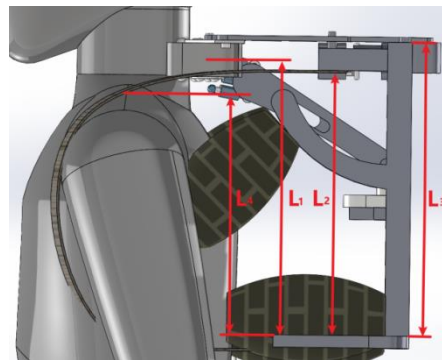


Fig.3.6 Side view of wearable design

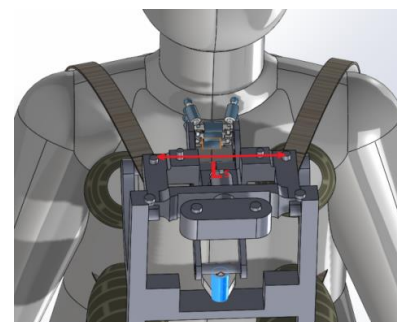


Fig.3.7 Front view of wearable design

The wearable neck massage design allows it to rest freely on the neck, allowing the user to perform other activities, such as working, reading, or watching TV. This design provides greater freedom and is more convenient compared to handheld massagers. It suits various scenarios, including home, office, and long-distance traveling. Users can enjoy a comfortable massage whenever they need it.

Wearable massagers are often designed to cover a large area of the neck to provide a full range of massage, which can help reduce tension and fatigue in various areas of the neck and improve symptoms of stiffness or nerve pain.

The wearable design allows the massager to hang around the neck, allowing the user's hands to move freely without holding the massager. This allows the user to perform other activities while enabling the massage chair, improving its convenience. This makes the massage more convenient and comprehensive and improves the user's comfort experience.

IV. Mechanism design and motion analysis

In designing the pinch wheel massage mechanism, we need to analyze the law of motion of the push rod and the cam profile curve of the clamping wheel massage mechanism, its motion is shown in Fig.4.1.

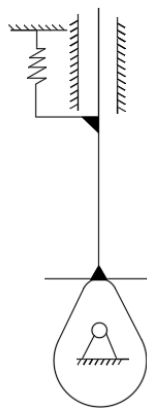


Fig.4.1 Cam of the clamping wheel massage mechanism

The law of motion of the push rod refers to the displacement s , velocity v , and acceleration a of the push rod changing with the cam angle $\delta^{[8]}$, Since the

cam rotates at an equal angular velocity ω rotation,

we can study the motion of the actuator by the primary polynomial law of motion. According to the design of the mechanism, the displacement s ranges from 0 to 10 mm, i.e., the stroke $h = 10\text{mm}$. The

cam angle δ ranges from -60° to 60° , i.e., the

angle of motion of the cams $\delta_0 = 60^\circ$.

The boundary conditions are:

$$\text{starting point } \delta = 0, s = 0$$

$$\text{at the finish line } \delta = \delta_0, s = h$$

The equation of work travel is:

$$\begin{cases} s = \frac{0.03\delta}{\pi} \\ v = \frac{0.03\delta}{\pi} \\ a = 0 \end{cases}$$

And the equation of return travel is:

$$\begin{cases} s = 0.01\left(1 - \frac{3\delta}{\pi}\right) \\ v = -\frac{0.03\delta}{\pi} \\ a = 0 \end{cases}$$

This gives the design law of motion of the actuator, as shown in Fig.4.2.

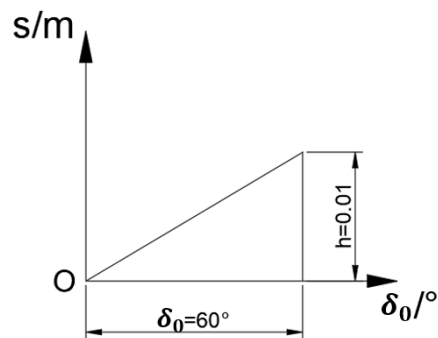


Fig.4.2 Constant velocity motion s - δ curve

After selecting the actuator motion law, the analytical method is used to design the cam profile, as shown in Fig.4.3.

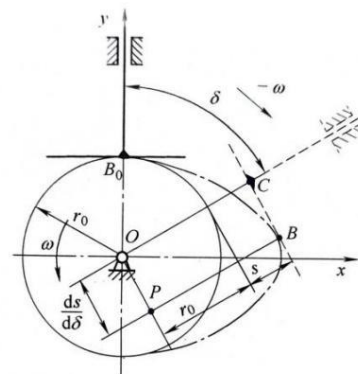


Fig.4.3 Parameters of cam profile with flat-faced follower

When the cam angle is δ , the displacement of the actuator is s , and the radius $r_0 = 8\text{mm}$ by the instantaneous center method to know the relative instantaneous center of the cam and the actuator is at the point P. At this time, the velocity of the actuator is:

$$v = v_p = \overline{OP}\omega$$

$$\text{or } \overline{OP} = v/\omega = ds/d\delta$$

The equation for $s-\delta$ is obtained earlier:

$$s = \frac{0.03\delta}{\pi}$$

So there is:

$$\overline{OP} = ds/d\delta = 0.03/\pi$$

The coordinates of point B are obtained from Fig.4.3:

$$\begin{cases} x = (0.008 + s) \sin \delta + \frac{0.03}{\pi} \cos \delta \\ y = (0.008 + s) \cos \delta - \frac{0.03}{\pi} \sin \delta \end{cases}$$

This is the equation for the cam profile.

V. Conclusion

(1) In connection with the structure of the human neck, a wearable massage device with configuration adaptable is designed. The device has an adaptive, flexible massage part and a pusher massage part, and the size and position of the two parts are reasonably controlled so that they do not interfere with each other. The massage part combines the traditional Chinese medicine neck massage, targeting the user's Fengchi point, Fengfu point, Tianzhu point, and other acupoints, which can effectively dredge the veins and collaterals, alleviate the neck pain, promote local blood circulation in order to achieve a better neck rehabilitation effect and prevent the neck muscle atrophy.

(2) Combined with a Chinese neck massage, it does not appear to modify the subject's different methods; different methods are utilized to design the trajectory of the mechanism movement to select the movement law that fits with the desired trajectory to achieve the effect of massaging the target position.

(3) The overall construction utilizes a wearable design to improve user comfort and portability. This means that it does not cause any obstruction to the user's vision, and the user's head can still move freely. The wearable design provides the user with a greater degree of freedom to perform other activities while performing the neck massage, improving the convenience of use.

(4) Based on the physiological structure of the human neck, the driving part of the neck rehabilitation mechanism is analyzed, abstracted as a cam push rod mechanism, and motion planning is carried out

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