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Based on the force feedback vibration interaction design of the ultrasonic robot

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Abstract

This paper presents a force feedback vibration interaction design method applicable to the ultrasonic robot remote operation system. This design combines the interaction logic of the force feedback module and the pen-like operation hand system, allowing users to obtain better interaction effects and a sense of presence through the vibration module, and improving the user's operation experience in a more intuitive way. In the design of the mechanical structure, the hardware and software are integrated to achieve coordination between the vibration module, the force feedback module, and the ultrasonic robot. The vibration feedback has a significant effect in the scenario of remotely operating the ultrasonic robot. The human-computer interaction design based on vibration feedback provides a new feedback method for the development of multimodal interaction of ultrasonic robots.

Keywords

Ultrasound robot Remote operation; Vibration feedback; Interaction design.

1. Introduction

In recent years, the emergence of ultrasound robots has alleviated to some extent the problems of insufficient medical resources and the high work pressure of ultrasound doctors. This is of great benefit to improving medical efficiency and diagnostic accuracy. Currently, most of the research technologies for ultrasound robots adopt the method of streaming the on-site images to the screen end, and combine force feedback handles to assist in controlling the ultrasound robot. However, they lack more direct physical space touch sensation. Therefore, based on the existing pen-style handle operating system, this paper embeds a vibration haptic module in the handle and proposes a vibration feedback interaction design method in force feedback, and provides quantifiable necessary information, including the operator's perception intensity of the vibration feedback, the operator's familiarity with the vibration information, and the relevant data of the operator during the experiment, to provide a new way for ultrasound robots in human-computer interaction.

Currently, the remote ultrasound robot independently developed by Huada Technology Co., Ltd. and already in market application adopts a remote control system mode. This system allows doctors to remotely operate the robot using a pen-like handle. It outputs electrical signals through the plane and the hand-held posture to obtain the hand movements of the ultrasound doctor. Force feedback and audio-video are utilized to achieve human-computer interaction. The interaction mainly involves the photography method for patients. The images are transmitted via the network to the doctor's screen. The ultrasound doctor observes the contact state and position information between the robot and the patient through the computer screen. They cannot intuitively perceive whether the robot has touched the patient's body surface, and there is a lack of force interaction vibration feedback reminder from the doctor's end to the operator. Vibration feedback is a derivative of touch sensation, similar to visual and auditory perception, and can be used to achieve silent command. It can be regarded as an effective auxiliary sensory method. The operator manually operates the handle to sense the vibration feedback-induced vibration. The information transmitted by the vibration can improve the operator's perception sensitivity to the operating environment. When the generated vibration exceeds the human perception range, it may lead to the operator's operational errors. This paper designs different levels of vibration and conducts experiments to determine the differences in operators' thresholds under different vibration intensities.

2. Vibration feedback intensity grading design

2.1. System framework and hierarchical design

The hardware system studied in this article consists of an embedded computer, a force feedback module, and a vibration module. Among them, the embedded computer is the core component of the hardware system, responsible for processing data and instructions; the force feedback module is a part of the hardware system, mainly used to simulate force and motion, and realizes the perception and feedback of the user's force and motion through mechanical structures, motors, sensors and other technical means. The vibration module is the core component of the hardware system, mainly generating vibration and vibration effects through motor or vibrationers and other technical means, to achieve human-computer interaction. The vibration module is usually composed of a controller, power supply, motor or vibrationer, etc., where the controller is used to control the intensity, frequency and duration of the vibration and vibration effects of the motor or vibrationer, providing a more realistic sensory experience and enhancing the user's participation and immersion.

When an ultrasound doctor uses an ultrasound robot, they need to ensure safety by monitoring the pressure exerted by the end of the robotic arm on the human body. During the examination, if the end of the robotic arm is suspended, it indicates no danger. When the end of the robotic arm starts to press and come into contact with the human body, various states will occur, including the force of contact, duration, and position, which represent different levels of danger severity. To ensure safety, thresholds and constraints need to be set, pressure indicators need to be quantified to form a safety performance level and evaluation system, enabling control of the robot's movement state and ensuring the safety of the ultrasound examination.

To ensure the safety of the interaction process between the ultrasound robot and the patient, vibrations are used to represent different levels of danger severity as a reminder. The vibration levels are classified and graded. Six interaction states between the robot and the human body are determined, including the robot suspended, the robot contacting the patient, the robot contacting the patient without applying pressure, the robot applying heavy pressure, the robot reducing pressure, and the robot applying excessive pressure. Corresponding six different vibration feedback modes are designed. The vibration modes are pre-encoded and directly conveyed to the operator through tactile feedback, helping the operator master the robot's movement state and contact situation, and taking appropriate measures in time to avoid causing harm to the patient. As the pressure value is returned, vibration displacement occurs, forming an up-and-down fluctuation curve. It can be seen that in the non-contact stage, there is no vibration response. Then, in the initial contact stage, there will be small fluctuations in up-and-down direction, and when the contact pressure remains unchanged, the vibration amplitude remains the same. Later, as the pressure increases, the vibration amplitude increases accordingly, and conversely, the vibration amplitude decreases.

Based on the force conditions, and then observe the vibration intensity output of the linear motor. Specifically, during the experiment, the operator needs to apply hand pressure to the pressure feedback module, generating pressure, and record the initial pressure value and the numerical value of each pressure change by the data collector. And according to different pressure change situations, the system inputs the force between the robot and the patient as F, with the range of F being [0, Fm]. 0 represents no contact, and Fm is the maximum range that the force sensor can output. Fl is the boundary value of the pressure that the person can accept. When the F value is greater than or equal to Fl, it is considered excessive pressure. Conversely, when the F value is less than Fl, it is considered normal pressure. Additionally, it is a positive real number. The system output is the vibration intensity M of the linear motor, with the range being [0, m], where 0 represents no vibration, and m represents the maximum vibration intensity. It can be divided into:

No contact: When F = 0, the vibration intensity of the linear motor is 0.

Initial Contact: If F is not equal to 0 and F was equal to 0 before the time interval, it is determined that the robot has just touched the person. The linear motor will vibrate with an intensity of 1/2m once, and the vibration duration is Δt.

Contact has occurred and the pressure is basically unchanged: When F is not equal to 0 and the absolute value of the difference between the two F values in the Δt time interval: $|\Delta F| < \delta$, the vibration intensity M of the linear motor will gradually decrease according to Equation (1), where M is the latest vibration intensity and M' is the motor vibration intensity at the previous moment. The duration of each vibration is Δt, and the time interval is Δt_1.

$$M=M'\times(t+1)^{-1/3}$$

(4) Contacted, pressure gradually increases and is normal: When F is not equal to 0 and the difference between two F values (the current moment minus the previous moment) within the Δt time interval, the vibration intensity M of the linear motor will gradually decrease according to Equation (2), where M is the latest vibration intensity and M' is the motor vibration intensity of the previous moment. The duration of each vibration is Δt and the time interval is Δt_2.

$$M=M'\times(t+1)^{-1/2}$$

(5)Contacted, pressure gradually decreases and is normal: When F is not equal to 0 and the difference between two F values (the current moment minus the previous moment) ΔF in the Δt time interval is greater than δ, the vibration intensity M of the linear motor will gradually increase according to Equation (3), where M is the latest vibration intensity and M' is the vibration intensity of the motor in the previous moment. The duration of each vibration is Δt, and the time interval is Δt_3.

$$M=M'\times(t+1)^{1/2}$$

(6)Contacted and excessive pressure: When F is not equal to 0 and F > Fl, the vibration intensity M of the linear motor will continuously vibrate at the maximum vibration intensity m. The duration of each vibration is Δt, and the time interval is Δt_4.

2.2. Experiments and Results

The purpose of the experiment is to verify the feasibility and effectiveness of vibration feedback in remote operation. In the early stage of the experiment, the hardware was installed. Pressure sensors were attached to the end of the CR robotic arm from Rotosis Company, and the handle was connected to the robotic arm for communication. The experimenter felt the vibration range by operating the handle. Ten participants were required to participate in the experiment. During the experiment, different levels of vibration feedback intensity were used. Before starting, the experimenter was informed of the level of vibration intensity and completed the tasks of holding the handle, sliding and pressing different objects. The contact pressure at the end used a gradually increasing range from 0N to 10N, approaching 10N as a high-risk state, and the experiment needed to be stopped. Each experimenter operated 10 times in sequence. Through the vibration function experiment program, the vibration and pressure data of the

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experimenter, as well as the operation handle time and operation error times, were collected in 10 groups each.

The vibration function test program was designed based on force feedback and vibration feedback. Suppose the robot performs vibration control when it comes into contact with the human body. For this purpose, the following functions were designed:

get_force(): to obtain force feedback data;

control_vibration(): to control vibration;

calc_vibration_0(): to calculate the vibration intensity of no contact as zero;

calc_vibration_1(): to calculate the vibration intensity at the initial contact;

calc_vibration_2(): to calculate the vibration intensity when the pressure is basically unchanged;

calc_vibration_3(): to calculate the vibration intensity when the pressure gradually increases;

calc_vibration_4(): to calculate the vibration intensity when the pressure gradually decreases;

calc_vibration_5(): to calculate the vibration intensity when the pressure is too large;

slide_object(): task of sliding different objects;

press_object(): task of pressing different objects;

In the control_vibration() function, the vibration intensity is calculated using the calc_vibration_0() to _5() functions, and based on the current pressure value and the previous pressure value, the vibration duration and the PWM signal duty cycle are determined. The vibration intensity, vibration duration, and PWM signal duty cycle are output.

In this experiment, the vibration program was tested to measure the vibration. Different vibration intensities and pressure changes were applied to simulate the operation scenarios in the real world. Using serial communication technology, the experimental data was recorded and analyzed by the embedded computer.

With vibration feedback, a group of operations were conducted under operating conditions. The operation time was shorter in the presence of vibration feedback compared to the absence of it. Through repeated familiarization with the operation, the operation time was further reduced in the presence of the vibration feedback mechanism. By comparing the number of operation errors with and without vibration feedback, it can be seen that the number of errors was significantly reduced in the presence of vibration feedback, indicating that the vibration feedback technology can provide a visual tactile feedback, helping users better understand and perceive the process and results of the operation. When there is vibration feedback, users can judge the operation result more quickly, thereby avoiding operation errors and mistakes.

Based on the above experimental results, it is shown that the combined use of force feedback and vibration feedback in the operation can improve work efficiency, accuracy, and control ability in remote operation tasks. However, it may not have obvious effects in other unfamiliar scenarios. Therefore, the design of vibration feedback should be adjusted according to specific scenarios and task goals to achieve the best effect.

The experimental results of operation time and operation frequency objectively prove the feasibility of vibration feedback. All participants in the simulation experiment received relevant questionnaires. The survey was conducted from three aspects: the effectiveness of vibration feedback classification, the participants' feelings towards vibration feedback, and the cognition of the entire learning process. 74.54% of the participants believed that a stronger vibration would be more conducive to the learning of vibration feedback, and they also felt that the learning process of vibration feedback was simple. 81.81% of the participants recognized the effectiveness of vibration feedback. All participants had a positive emotion towards the learning process of vibration feedback, and 66.72% of the participants believed that they could master vibration feedback after training. This study proves the feasibility and effectiveness of vibration feedback in the interaction process between the ultrasonic robot and the operator. Through objective experimental results and subjective questionnaire surveys, it can be seen that vibration feedback can help experimenters better master the movement state and contact situation of the robot, improving operation efficiency and accuracy. This vibration-based interaction method can not only improve the safety and operational efficiency of the ultrasonic robot, but also provide a reference and inspiration for the interaction design of other robots.

3. Conclusion

This paper mainly addresses the issue that the existing pen-style operation hand systems lack sufficient reminders from the doctor's end. Therefore, an interactive system with vibration feedback reminders has been developed. The measurement results in the article are only applicable to the vibration motors used in the experiment. If different sizes and models of vibration motors are used for experiments, the resulting measurement results will also vary accordingly. Based on the experimental results, the vibration feedback interactive design process can be regarded as a method that can be applied to the design of the handle end of the ultrasonic robot pen-style operation hand system.

Researchers can refer to this method to obtain the required user data and design corresponding feedback experiments. For users who are not familiar with vibration feedback, it should be promptly informed that the vibration will vary due to differences in the human body. Therefore, the familiarity of the body with the feedback information is very crucial. For vibration feedback, our brain needs to establish a new nervous system to receive new information. Regardless of any form of mode substitution for feedback, the vibration does not provide the human body with its original perception. The operator still needs to undergo system training to allow the brain to learn. When new forms of stimulating signals are fed back with appropriate parameters and are mastered proficiently, they can be used as tools by the operator and truly become a part of their senses. Based on the above research results, the human-computer interaction design based on vibration feedback proposed in this paper can improve the user experience and provide a new feedback method for the development of multimodal interaction of ultrasonic robots.

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