Research on Real-time Sensing Technology of Aerospace Interactive Behavior Based on Infrared Array Force Tactile

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Abstract. Aerospace robots can replace astronauts to complete dangerous work in the expanded space. How to efficiently and reliably interact with robots in complex and harsh space environment has become an urgent problem and technical challenge. Based on the infrared array force tactile technology, an infrared point force touch detection system is developed to realize the intention sensing of aerospace human-robot interaction. Based on multipoint positioning technology combined with image method and global combined optimal tracking method, the control software is designed, and the effective human-robot interaction in the process of cooperation is realized. Finally, the touch panel test effect of the system is given. This research can provide a theoretical basis for the practical application of aerospace human-robot interaction.

1. Introduction

In the space station, astronauts must work in a variety of facilities and carry out experiments in different disciplines in a complex environment. The working environment of astronauts is bad and their work is full of challenges. Nevertheless, robots can help them reduce work pressure and replace their work. At present, important progress has been made in natural human-robot interaction technology on sensory channels such as force and touch, and a number of general human-robot interaction equipment and tools have been formed. However, in the face of more extensive and complex mission requirements, there are still urgent problems and technical challenges in the natural interaction between robots and astronauts. For example, the expression of perception channel (mode) is single, and the understanding of user interaction intention is limited; In the process of interaction and cooperation between robot and human, the judgment of human error or even malicious interaction intention is insufficient, and it is difficult to make reasonable and safe action response [1-5].

In order to realize human-robot interaction with high reliability and robustness, the real-time perception technology of human-robot interaction behavior intention in aerospace environment based on infrared array force tactile technology is studied. Phase locked amplification technology is used to filter environmental interference; the multi-point positioning technology combined with image method based on the global optical path information is used to realize the sub-pixel recognition accuracy, and the global combined optimal tracking method can effectively solve the problem of trajectory crosstalk. Finally, the infrared point force touch detection system can realize accurate tactile feedback and can provide technical support for the effective interaction between robot and human in the process of cooperation.
2. General technical scheme

2.1. Hardware design
The infrared point firing touch control system is composed of analog signal processing module and digital signal processing module. The analog signal processing module is composed of infrared modulation transmitting module and infrared demodulation receiving module. The digital signal processing module is composed of digital to analog conversion module, digital signal processing module, data transmission module and control module. As shown in Figure 1.

Figure 1. Frame diagram of general system scheme

The unit circuit schematic diagram of infrared touch screen is shown in Figure 2. It is mainly composed of power supply circuit, infrared modulation transmitting circuit, photoelectric conversion circuit, signal conditioning module, phase-locked amplification circuit and low-pass filter circuit. The power supply circuit provides the voltage required for the operation of the whole unit circuit. The infrared modulation transmitting circuit emits an infrared light signal, which is received by the photoelectric converter and converted into an electrical signal. The conditioned signal and reference signal enter the phase-locked amplifier circuit, and the phase detector realizes the cross-correlation operation between the two signal, then, through the infinite integration, the noise can be filtered, and the output DC signal is the amplitude of the useful signal. Through the signal processing circuit, it can be displayed on the mainframe for further processing.

Figure 2. Unit circuit schematic diagram of infrared touch screen

2.1.1. Infrared optical coding and decoding technology
As the ambient light is the main interference source of the light of the infrared touch screen, the anti-interference ability of the infrared touch screen can be improved by greatly weakening the influence of the external ambient light. The infrared transmitter encodes the information through the infrared light
invisible to human eyes. Generally, the carrier with 38kHz 1/3 duty ratio is used for information modulation. As shown in Figure 3 below, when there is a carrier, it represents logic 1, and when there is no carrier, it represents logic 0. Then different infrared protocols are derived through different combinations of logic 0 and 1.

![Figure 3. Schematic diagram of the carrier wave](image)

There are two purposes of using carrier. The first advantage is to reduce external interference through carrier. After carrier modulation, the transmission will become relatively safe, because the infrared receiving part has a band-pass filter, which will only let the infrared signal with similar carrier frequency pass through, so the interference sources of other frequencies are filtered out. The second advantage is low power consumption. Compared with using 1/3 duty ratio carrier and not using carrier, those with carrier will save more power when working at the same time.

2.1.2. Phase locked amplification technology

After the ambient light signal is received by the infrared receiving module, the photocurrent after photoelectric conversion is a DC signal. Therefore, it can be thought that if the DC signal generated by the ambient light can be reduced, the anti-interference ability of the infrared touch screen can be improved. However, if only DC signal is considered, it will weaken not only the optical signal converted by external light, but also the useful infrared optical signal. Therefore, the infrared transmitting module is driven by pulse mode, that is, the infrared transmitting module will transmit a regular frequency infrared light signal, and the infrared receiving circuit will only respond to this regular frequency signal.

In this paper, the resonant circuit is used for frequency selection. Because the resonant circuit has a certain bandwidth and the quality factor Q value is not very large, even the signal generated by frequency selection still contains the noise converted by factors such as ambient light. The lock-in amplifier shows excellent performance in weak signal detection. It has the characteristics that the useful signal is related to the reference signal, but the noise is not related to the reference signal. After multiplying with the infinite integral, the correlation signal comes out as a DC signal, and the uncorrelated signal is zero after positive and negative superposition. After photoelectric conversion, the frequency of the signal is selected through the resonant circuit. At this time, the signal is very weak, and then it is amplified and band-pass filtered to filter out the high-frequency and low-frequency interference. Then the signal is amplified by phase-locked amplification and infinite integration to realize the narrowband filtering of high Q value.

2.2. Software design

The main functions of the control software are to control the working process of ADC, communicate with computer through serial port and generate square wave signal to drive LED. ADC data acquisition adopts circular query mode. Each time ADC is started, query its interrupt flag bit to determine whether new data is available. When new data is collected, the data is processed and sent to the computer through the serial port. The square wave signal is realized by timer interrupt. Every time the timer generates an interrupt, it reverses the output level of the output I/O, so as to generate the square wave signal. The flow chart of the control software is shown in Figure 4.
2.2.1. Multipoint positioning technology combined with image method

Multipoint positioning technology combined with image method is a multipoint positioning technology based on global optical path information combined with image processing method. In the process of image processing, refer to the image processing function in the open source computer vision library (hereinafter referred to as OpenCV) supported by Willow Garage [6]. The algorithm flow of image multipoint positioning technology adopts the following modules:

1. Image generation: when a touch occurs on the touch screen, the lower computer collects the scanned optical path data within a scanning cycle, and then uploads it to the upper computer for processing to generate a candidate touch point image. Due to the discreteness of infrared optical path, the interference of ambient light source and the hardware problems of the system itself, at this time, there are many small white connected areas, namely noise, in the image, and those large white connected areas are candidate touch points.

2. Smooth denoising: in the previously obtained candidate touch point images, the presence of noise will have a great impact on the subsequent touch point recognition, which must be removed. In the process of denoising, the edge of candidate touch points and useful information will be lost. In order to restore the edge of the candidate touch point, the image must be smoothed.

3. Image segmentation: the main purpose of image segmentation is to segment candidate touch points from useless information such as background, so as to analyze and calculate each candidate touch point. The method of image segmentation is to extract the outline of each candidate touch point. Compared with extracting the whole candidate touch point, the amount of data processed is greatly reduced.

4. Remove ghost points: the candidate touch points are not necessarily real touch points, and there may be "ghost points". The existence of ghost points will cause false recognition of the touch screen, so they must be removed first. The area of the touch point is mainly obtained by calculating the area surrounded by the outline.

As shown in Figure 5, black points are real touch points and white points are ghost points. Moreover, with the increase of touch points, there are more and more ghost points. The real point is a touch point that can block the light path passing through it in any direction. The ghost point is only the shadow of the real point, and it cannot block any light path. Based on the global optical path information, the system forms an optical network with interwoven optical paths, and uses the "network
breaking effect" to locate the touch points, so as to achieve the effect of no ghost points or few ghost points.

Figure 5. Schematic diagram of real point and ghost point

5. Touch point positioning: locate the touch point after removing the ghost point. The positioning of the touch point is mainly realized by calculating the central coordinates of the touch point. The central coordinates of the touch point are mainly obtained by calculating the average of the coordinates of all outline points on the outline of the touch point.

2.2.2. Global combined optimal tracking technique

This scheme adopts the global combined optimal tracking technique, which can effectively solve the problem of trajectory crosstalk, and the amount of calculation is small. The main working modes are:

(1) All the touch points in the front and back frames are matched according to the combination mode, and the sum of the touch point distances in the front and back frames under each pairing mode is calculated respectively. The pairing mode with the minimum distance sum is taken as the track tracking mode. The specific steps are as follows: record all touch points and the number of touch points at frame \( k \) and frame \( k+1 \) respectively. The touch points in the front and back frames are combined and arranged, as shown in Figure 6:

Figure 6. Schematic diagram of touch point combination

There are three touch points in frame \( k \) and frame \( k+1 \). At this time, there are six combinations of touch points in these two frames. For any combination method, calculate the distance between each pair of touch points and sum the distances. Among all these combinations, the minimum combination of distance sum is taken.

(2) After the touch point matching of the first and second frames is completed, the final touch output trajectory cannot be determined. It may be that a touch point is lifted, a touch point just falls into or touched by mistake. At this time, the two touch points should not be directly associated, but should be disconnected, otherwise the wrong track will be output.

In the paper, the velocity and acceleration of touch point motion are introduced to predict the position of touch point in the next frame. The trajectory tracking scheme is based on the global information. It is judged by calculating the distance sum of all combination modes. It has nothing to
do with the order in which the touch points participate in the calculation, and the amount of calculation is small, which can significantly improve the problem of trajectory crosstalk.

3. Test result of infrared touch panel
The scheme adopts 9 groups of high-precision infrared LED force touch sensors to form the sensitive unit of the infrared touch panel. More than 15 different combinations can be built, one by one corresponding to the 15 basic instructions for astronaut-robot interaction. The sensor distribution adopts Jiugong grid mode, as shown in Figure 7.

In the test process of infrared touch panel, it is necessary to set the threshold of each point in the sensor matrix. Conduct 100 times of standardized key pressing for each point in the photoelectric sensor matrix on the test board, record the corresponding sensor value, and the collected threshold is shown in Figure 8.

Based on the image multi-point positioning method, the noise is removed and calculated according to the minimum value, and the key reading threshold is set. The acquired threshold is shown in Figure 9.

The setting of 9 key threshold is shown in Table 1.
Table 1. Setting of the 9 key threshold.

| Key number | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|------------|----|----|----|----|----|----|----|----|----|
| threshold  | 2938 | 3469 | 2845 | 2875 | 3620 | 2860 | 2930 | 2830 | 3313 |

As can be seen from Figure 9, after denoising, the threshold distribution of each point is clearer, which improves the reliability and accuracy of touch recognition. Touch the infrared touch panel in the order of "6-5-4" points, corresponding to the "stop walking" command, as shown in Figure 10. The software shows that the detection system matches the correct command.

![Diagram of software display interface ("stop walking" command)](image)

4. Conclusions
Based on the infrared array force tactile technology, the real-time perception technology of aerospace human-robot interaction is studied, and an infrared point force touch detection system is developed. The system has the following advantages: 1. In view of the influence of other ambient light on the system, the phase-locked amplification technology is designed to filter the light wave of other light and realize the narrow-band filtering of infinite Q value. 2. For the infrared touch screen with low point accuracy, low point recognition accuracy and many ghost points, the multi-point positioning technology of global optical path information combined with image processing method is designed to improve the accuracy and recognition accuracy and reduce the ghost point rate. 3. Aiming at the problem of trajectory crosstalk, the combination of global minimum distance sum is designed for trajectory tracking, and the concepts of velocity and acceleration are introduced for trajectory prediction. The test results show that the system can effectively recognize force tactile touch commands, which is expected to provide a theoretical basis for aerospace human-robot interaction.

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