A control method to prevent falling from a treadmill based on STM32 microcontroller and ultrasonic transducer

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Abstract: A treadmill is widely used at home or health entertainment centers, its safety is essential. If the body gait is not appropriate or the inclination degree of the body is too large, movement instability may be caused or even be fallen down from a treadmill. This paper presents an intelligent electronic control method based on STM32 microcontroller and ultrasonic transducer, which can real-time automatically control the treadmill velocity through detection of the upper body position or the tilt angle of human body. Control components are mainly STM32 microcontroller, signal detection unit and motor control unit. The STM32 microcontroller accepts ultrasonic signals of detection unit from input port and digitally processes these signals, and then drives the motor control unit to adjust the operating state and speed of motor through output port. The emitting and receiving of signals are realized by using the ultrasonic T/R module. The main control method is using multiple ultrasonic transducers to measure the interval time between the emitting signals and receiving signals to detect the distance between the subject's position and treadmill or the tilt angle of the body. These collected measurement data are digitally processed by some correlation calculation algorithm, in which some noise and interference signals can be excluded to avoid false judgments. The preliminary test results show that the upper limit of the distance error is less than 8 mm for a 43 kHz ultrasonic wave, and the tilt angular error of human body is approximately 1 to 5 degrees. Therefore the proposed control method and correlation calculation are effective and feasible.

Key Words: STM32 microcontroller, Ultrasonic transducer, Signal detection, Automatic control, Treadmill

1 INTRODUCTION

Treadmill has become the most popular indoor fitness equipment in the world. Also in our country, in order to make exercise is not affected by the outside weather and other external environment, it has become one of necessary sport equipments for many family.

Currently the adopted technology is relatively simple in running equipment used in fitness exercise, and very few has intelligent control device. If the body running action range is too large or gait is not correct, it will cause the body out of balance or even falling down from a treadmill, therefore some running people are injured because of using treadmill. Some sports equipment accidents frequently increased, people pay more attention to their own safety in the fitness process. Sometimes, once an accident occurs, the treadmill needs to be stopped immediately. It is necessary to design an intelligent control system to prevent falling down on a treadmill [1]. There are many treadmill velocity control methods reported in the references [2-5]. But treadmill motor driving is very simple, most of them are using the relay to control start and stop, fast real-time and continuous speed adjustment is difficult to achieve. In recent years, several new adaptation control methods have been proposed [6-10], however, the detection system of anti-fall is not perfect and the misjudgment may occur. On the moment of falling down, it is difficult to quickly find the emergency stop switch. In order to overcome the deficiencies of existing control method, this paper presents an intelligent real-time electronic control method based on the STM32F103 microcontroller and ultrasonic transducer. Multiple ultrasonic transceiver modules have been set on the treadmill for monitoring the distance between the upper body position and treadmill and the tilt angle of the human body. Based on these acquired detection data results, the treadmill velocity is automatically controlled through microcontroller in real time to prevent from falling down on a treadmill. If there is a serious instability, the treadmill would automatically stop. Therefore the control of treadmill will be more rapid and more intelligent

2 CONTROL SYSTEM

In view of the safety of the treadmill user to prevent falling down from it, ultrasonic detection and electronic automatic control is designed, the block diagram of the control system is shown in Figure 1. The system mainly concludes three modules: the signal detection unit, microcontroller and motor speed control unit. The signal detection unit consists of s distance detection and the tilt angle detection. In the microcontroller, many 32bits controllers could be selected. Here we use the STM32F103 microcontroller with strong performance. It has 72 MHz maximum frequency and the calculation speed of peak value reaches 1.25 DMIPS/MHz (Dhrystone2.1). And it's 12bits A/D module sampling rate is 1 MSPS. The STM32F103 microcontroller first accepts detection signals of detection unit from input port, and then drives control unit to control the motor operating state and adaptively adjust treadmill velocity through output port. The motor control unit is the motor electronic speed governor, which controls the treadmill velocity by the output pulse width modulation signal, voltage signal or current signal.

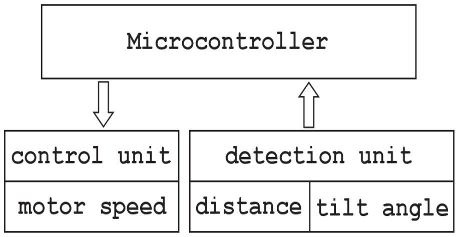

Fig 1. The block diagram of the control system

The emitting and receiving signal of the system utilizes the ultrasonic T/R module commonly used components in the electronic market, as shown in Figure 2. In order to achieve the precise distance or tilt angle detection, it is better that the system consists of multiple ultrasonic T/R modules. Each ultrasonic T/R module emits different frequency square pulse. Figure 3 is the schematic diagram of ultrasonic detecting. To distinguish the different channels signal processing work procedures, different frequencies are transmitted at the same time, so that detection speed would be quicker. If the standard of requirements is not high enough, the same frequency can be emitted at different times to detect the distance respectively.

Fig 2. The photo of ultrasonic T/R module

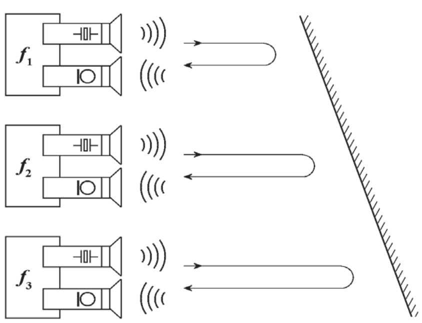

Fig 3. The schematic of ultrasonic detecting

3 CONTROL PRINCIPLE AND DETECTION METHOD

3.1 The control principle

Figure 4 is the principle schematic of the control system. STM32F103 microcontroller has a strong function with quick speed 72M clock, its own accessory timer can generate 8-cycle square wave, and the timing accuracy is relatively high. Through the transducer (i.e.speaker), an ultrasonic wave is emitted to a certain direction. After the emitted signal is reflected by the human body, ultrasonic echo signal will be received by the microphone of ultrasonic module. And then through the signal amplification and 20 kHz-50 kHz active band-pass filter (BPF), the ultrasonic signal can be targeted to amplify to reduce the noise interference such as voice signal and so on. After the analog signal filtering, AD function of the microcontroller would automatically collect ultrasonic echo signal through 12-bit 1M / s sampling rate. Digital filtering and correlation calculation are performed on the collected ultrasonic echo signals, and the precise time of the ultrasonic echo signal can be obtained, thus the distance can be calculated through sound velocity, therefore the distance detection is achieved.

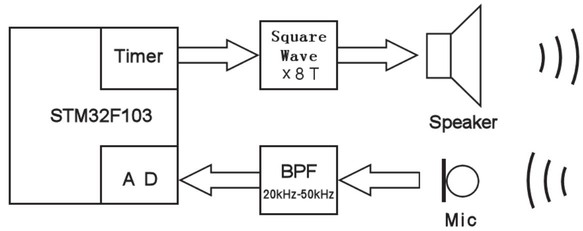

Fig 4. The schematic of the control principle

The control scheme of the system has two kinds of ways. The first one is through distance detection to control the treadmill velocity. The second one is through the tilt angle detection of human body to control the treadmill velocity. Specific methods are as follows:

3.2 The distance detection

The measurement of distance can be performed using a single ultrasonic echo T/R module, and then through the micro-controller to control automatically treadmill motor speed. According to the set square-wave frequency, the micro-controller performs a single frequency digital filtering and correlated calculations to the collected ultrasonic echo signal, and then could derive the precise time of the ultrasonic echo signal. That is corresponding to the center position time of 8 square wave periods. The time interval $\triangle t$ from the center position of the emitted 8-cycle square wave to the center position of the received ultrasonic echo signal can be obtained by the microcontroller, And then using the propagation velocity(V=340 m/s) of sound waves in the air to calculate the round trip distance L of the ultrasonic wave, thus the distance between the ultrasonic transducer(speaker) and the human body is as follow equation:

$$L = \frac{\Delta t \times V}{2} \tag{1}$$

If the human body is closer from the ultrasonic transducer, the microcontroller would control the motor increase peed to make body be far away a certain distance through the PWM and other functions. If the human body is relatively far away from the ultrasonic transducer, it indicates that running speed is slower or motor velocity is slightly faster, the microcontroller would control the motor slow down to ensure that the treadmill velocity is coordinated with the pace of people. Consequently, an adaptive automatic control system would be realized by using STM32 microcontroller and the ultrasonic transducer. Once the human body is detected in the treadmill tail, the motor can automatically stop.

3.3 The tilt angle detection

The multiple ultrasonic T/R modules can be used to detect the different distances from the ultrasonic transducer to the upper parts of the human body, as shown in Figure 5.

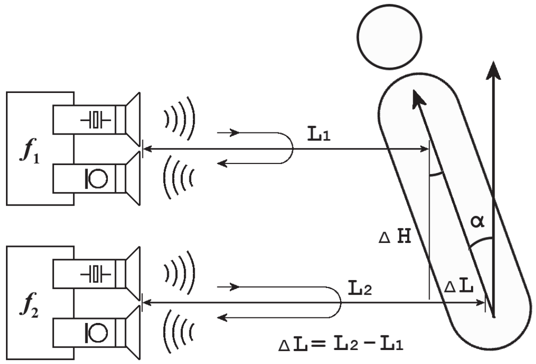

Fig 5. The schematic of the tilt angle detection

It can be seen that the position of each ultrasonic transducer is fixed and known. The inclination angle α of the upper part of the human body can be calculated by using the distance difference ΔL between L_2 and L_1 measured by the two ultrasonic waves and the vertical distance ΔH of the two ultrasonic transducers. The calculation formula is as follows

$$\alpha = arctg\frac{\Delta L}{\Delta H} \tag{2}$$

So the tilt degree of human body can be detected through more than two ultrasound modules. If the inclination angle exceeds the set safety threshold, it can be determined the human body is in the unstable state, that is, the motor needs to be stopped immediately to achieve emergency stop function. In generally, on the moment of falling down on a treadmill, it is difficult to quickly find the emergency stop switch. Here, the designed intelligent security protection system can realize an automatic emergency stop to prevent falling down on treadmills due to accidents. For more than two ultrasonic echo signals, the upper body tilt angle can be also obtained by taking the difference average method in order to reach accurate control of treadmill speed.

Multiple sets of ultrasonic measurement data can be compared with each other, the abnormal calculation results are excluded. In addition, through the digital correlation calculation, noise and false action signal can also be identified to exclude most of the random interference signal. For example, the swing arm movements during running, protruding arms or certain wearing items may produce an echo signal similar to that of the moving upper body. There will be relatively weak correlation calculation results, these signals should be neglected. Among the multi-group ultrasonic echo measurement results, if the individual echo signal is too strong or the result of individual correlation is too strong, If the individual echo signal is too strong or the result of individual correlation is too strong, it may be because the arm and other small area reflector is close to the ultrasonic transducer(speaker), these detection signals should be also excluded.

4 TESTING RESULTS AND ANALYSIS

We perform a preliminary test by adopting the designed 8-cycle ultrasonic square wave signal, some detection effects are obtained and the experimental results are relatively satisfied. Figure 6 is a 41 kHz, 8T square wave oscillation signal generated by a timer of STM32 microcontroller. The ultrasonic wave is emitted through the transducer and the reflected echo signal is received as shown in Figure 7. We can see that the received ultrasonic echo signal is weak, which needs to pass through active band-pass filter (BPF) amplification in order to get a strong received signal.

Fig 6. The emitted signal of the 8-cycle square wave

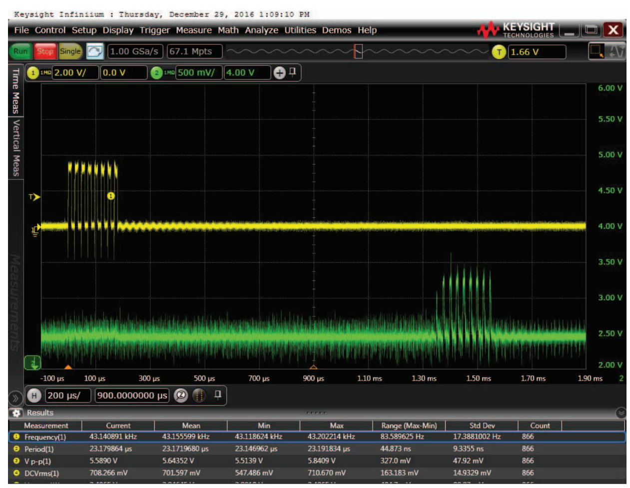

Fig 7. The emitted and received signal of ultrasonic detecting

Under stable conditions, a complete 8-cycle signal can be received as shown in Figure 8. We can see that the front and rear end of the waveform is slightly weaker and distorted. For the acquired receiving waveform data, using the emitted square wave signal as another input function to carry fast numerical correlation operation, the result is that a approximate triangular wave can be obtained, in which, the front edge is the starting point of the received wave packet, and then compared with the front edge of the transmitted signal wave packet, the time interval of echoes can be calculated. In the Fig.7, using 43 kHz ultrasonic signal, the echo time is about 1.35 ms. the calculated distance is 23cm.

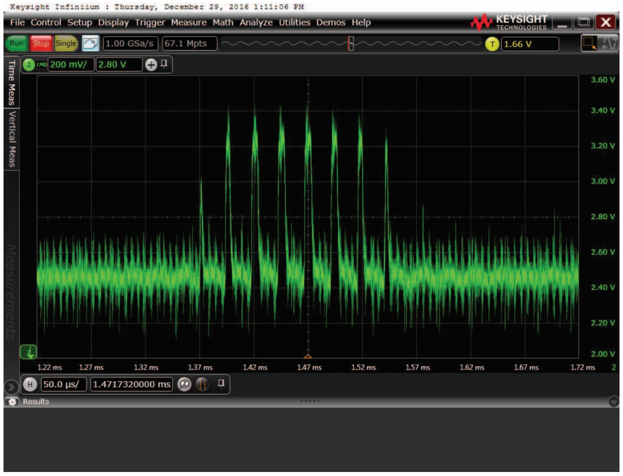

Fig 8. The received signal of the reflected echo wave

In the actual process of running movement, there will be a variety of interference factors, more complex interfered signal of reflected echo may occur. After the received signal is amplified by the BPF, the reflected signal may become a complicated multiple cycle (13 cycles in the Figure 9), a group of 4-cycle of the movement arm first appeared, it is not the upper body reflection signal (see the left waveform below). In the numerical correlation calculation, the result of the small wave packet reflected signal is obviously weaker than that of the normal 8-cycle reflection signal. The result of the correlation calculation of the multiple cycles wave packet is stronger than that of the reflection signal of 8-cycle. In this case, you need not judge the strength of the relevant calculation results, only extracting the front edge time of packet. The corresponding maximum distance calculation error is a periodic signal.

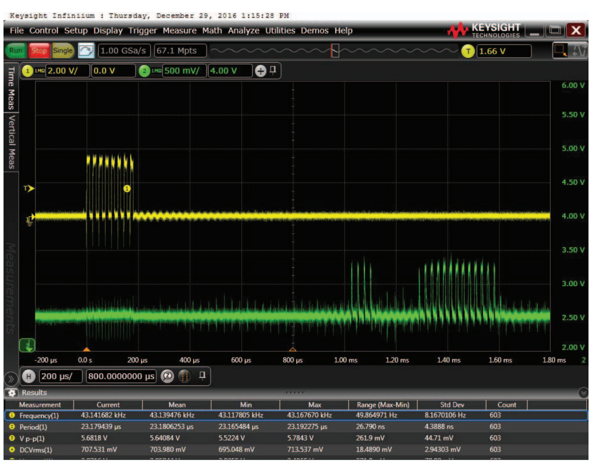

Fig 9. The interfered signal of reflected echo

The results show that the upper limit of the distance error is less than 8 mm for 43 kHz ultrasonic wave.

From the correlation calculation, for an effective upper body length of about 400 mm, a distance measurement error of 8 mm results in an angular error of approximately 1 to 5 degrees. The distance measurement accuracy can be further improved by performing the phase time interval calculation and other anti-interference processes. Through the multi-channel detection and comprehensive analysis, the upper body tilt angle can be more accurately obtained. When the inclination degree changes from a normal ±10°~20° to an abnormal ±50°~70°, it can be determined to have a serious instability, the motor system immediately stops, that is, the emergency stop function is activated to avoid serious injury.

5 CONCLUSION

This paper proposes an intelligent real-time electronic control method to prevent falling from a treadmill based on the STM32F103 microcontroller and ultrasonic transducer. It can automatically control the treadmill velocity through monitoring the upper body position or the inclination degree of human body. A preliminary testing is performed by using the 8-cycle ultrasonic square wave generated by the timer of STM32 microcontroller. The experimental results show that for an effective upper body length of approximately 400 mm, the distance measurement error is about 8 mm, and it would result in an angular error of 1-5 degrees. The error of the detection is relatively smaller. Therefore the proposed control method and correlation calculation algorithm are effective and feasible. The next step work is to implement such a safety protection system having a simple structure, accurate and quick detecting and real-time control the treadmill velocity. This would be of great significance to the treadmill user.

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