Fall prevention system based on airbag protection and mechanical exoskeleton support

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Abstract. The aging of population is a worldwide social problem that all countries will face in the 21st century. The health and quality of life of the elderly will have a significant impact on the country and society. In fact, falls are the leading cause of accidental injury or death in the elderly. Fortunately, using inflatable airbags as a buffer to reduce the injuries caused by falls is currently the most effective means of fall protection. This paper designs an indoor protection device for elderly patients in the rehabilitation stage. It not only includes an accurate and effective fall detection system, but also can use airbags and mechanical exoskeleton to perform head, waist and hip joints on patients who are about to fall. Through experiments, the designed airbag can be ejected within a specified time, and the designed algorithm can accurately distinguish the fall of the human body from the daily behaviour of human body.

1 Introduction

The "China Injury Prevention Report" issued by the Ministry of Health of China pointed out that falls are the main cause of accidental injuries to the elderly. According to statistics, about one-third of the elderly over the age of 65 experience a fall every year, and about 10% to 15% of them stay still for more than 20 minutes without taking rescue measures [2]. About 75% of those who fall are afraid of falling and moving again, which will further lead to a decline in the physical function of the elderly [2]. Among the injuries caused by falls, hip fractures are the most severe.

The design is very user-friendly, and the original algorithm is improved in terms of fall detection. For the first time, the quaternion representation and data fusion algorithm are used to calculate the human body posture data collected by the sensor, so that the detection of human fall behavior is more accurate and efficient. At the same time, the head, hip, and knee joints of the elderly are protected in many ways, which solves the defect that the equipment cannot take care of various parts of the body, making it the best choice for the

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elderly to prevent falls. At present, a complete set of equipment has been developed and equipment testing in the laboratory is underway.

2 Existing solutions have deficiencies

Scholars from various countries have done a lot of research on fall detection and have achieved many research results. Jin Heyu introduced the fall detection watch. The watch has two built-in three-axis acceleration sensors. Due to frequent wrist movements, this is the most difficult problem in detecting falls. When the table is tilted back and sideways, the accuracy of the watch is only 58% and 45%.

The above products are in the laboratory exploration stage, and no products have been released yet.

3. Design architecture

In this page, I will comprehensively introduce the system architecture of the design. The first is a functional overview, then the core modules that implement the solution, and finally the effect of the solution.

3.1 Project Overview

The entire system consists of hardware and software. The hardware includes head airbags, waist airbags, and mechanical leg exoskeleton. The software includes fall detection modules and alarm devices. The work flow design diagram of the equipment is as follows:
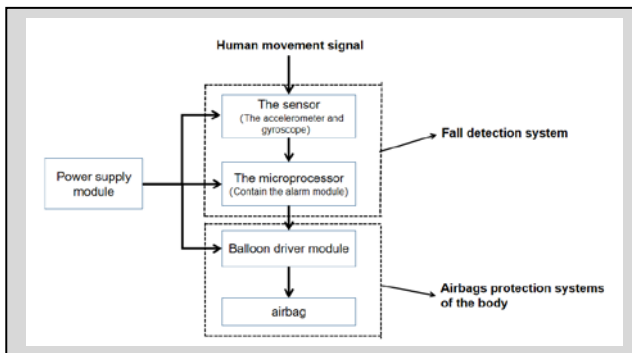

Fig. 1. Overall design drawing.

3.2 Fall detection module

The fall judgment system includes the following parts: microprocessor (MCU, low-power microcontroller STM32F103C8T6) for data processing and related control; MEMS inertial sensor (MPU9150) for collecting human motion signals, which can be used for gyroscope and acceleration [1]. Collected data is fused to obtain the attitude quaternion, and then the attitude angle is obtained through the attitude quaternion. Through specific fall experiments, analyze the reasonable fall attitude angle threshold and combined acceleration threshold, and design the threshold judgment algorithm for fall behavior detection based on the threshold obtained from the experiment;

3.2.1 The overall design of the hardware system

The main control chip of this design is a low-power single-chip STM32F103C8T6, and the inertial sensor chip is a nine-axis sensor MPU9150. MPU9150 sends the collected data to STM32 through IIC, and STM32 sends motion data to TF storage through SPI, and collects historical data for the study of fall judgment algorithms. At the same time, STM32103C8T6 uses a fall detection algorithm to determine whether a fall has occurred. The hardware functional block diagram is as follows:
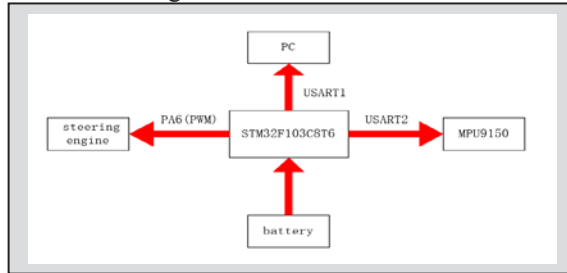

Fig. 2. Hardware design drawing.

3.2.2 Human body posture calculation algorithm

The attitude solution of the MPU9150 is one of the cores of this design, and the core of the attitude solution algorithm is rotation. As far as combined rotation is concerned, the quaternion represents the most effective. This article uses quaternion notation.

Because the MPU9150 used in this article has a built-in DMP (digital motion processor), it can fuse accelerometer and gyroscope data into a quaternion. The downward heading angle will always drift in one direction, which has a greater impact on the accurate output of the attitude angle. Therefore, this paper uses the Kalman filter algorithm to first merge the attitude quaternion fused by DMP with the quaternion output by the magnetometer [3].

Threshold judgment algorithm Threshold detection algorithm is used to judge whether a fall event has occurred, and then issue execution instructions to each module, which can realize the system's comprehensive detection of various emergencies and real-time alarm instructions. At the moment of a fall, the human body's gravity, acceleration, displacement, and posture will change accordingly. At this time, the human body's acceleration SMV is compared with the general daily behavioral activities ADL (activities of daily living) such as walking and standing. big change. Because we cannot know the direction of the fall in advance, the three-axis acceleration changes differently for different falling directions, which increases the complexity of the algorithm implementation. In order to facilitate the algorithm implementation, here only the vector sum of ax, ay, az is calculated, and SMV (Signal Magnitude Vector, acceleration intensity vector) is introduced, which is defined as follows:

$$SMV = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

(1)

It can be seen from the formula that no matter which direction the human body falls, the SMV will change significantly. Using SMV as the basis for judgment of falls can not only simplify the algorithm complexity, but also effectively judge the behavior of falls. If you set a reasonable total acceleration threshold TH1 to ensure that TH1 is lower than the acceleration value caused by the fall and higher than the ADL acceleration value for the ease of movement, we can distinguish the ADL with low acceleration such as walking, standing, and sitting from the fall behaviour [4].

Through experiments, we found that an obvious difference between jumping and other activities and falling is that the tilt angle of the human torso will be larger after a fall. And through the quaternion settlement algorithm, you can output the tilt angle of a human torso, which we call the pitch angle. When the suspected fall action ends, by detecting the size of the pitch angle at the moment, set an appropriate pitch angle threshold TH2. Since the human body fall process lasts between 1 to 3 seconds, when the acceleration SMV of the suspected fall action exceeds TH1, the system detects the change in pitch angle within 1 second before and after the action. Suppose the inclination angle before the suspected fall is 1 and the inclination angle after the suspected fall is 2, then set TH3=|1- 2|. Set an appropriate pitch angle change threshold TH3 according to the experimental statistics. Using the relationship with TH3, you can effectively distinguish between falling actions and push-ups and other actions that have relatively large SMV and pitch angles. In summary, by comparing the detected SMV with the corresponding thresholds TH1, TH2, and TH3, it can effectively distinguish between falls and ADL [4].

3.3 Airbag realization part

3.3.1 The gas generator

The gas generator includes steering gear, cams, springs, airbags, gas cylinders, needles, etc. When the steering gear receives the MCU's falling signal, it drives the cam to rotate, and the rotation of the cam makes the needle move forward and pierce the cylinder to release carbon dioxide gas Fill the air bag [5]. It is worth mentioning that this device is designed with a sharp and grooved needle, and a spring is added to the tail of the needle. After the puncture needle punctures the gas cylinder, the gas in the groove of the puncture needle head can quickly pass through, and the spring pulls the puncture needle back from the inside of the gas cylinder, increasing the0 gas release area of the gas cylinder, thereby achieving more efficient gas release [5].
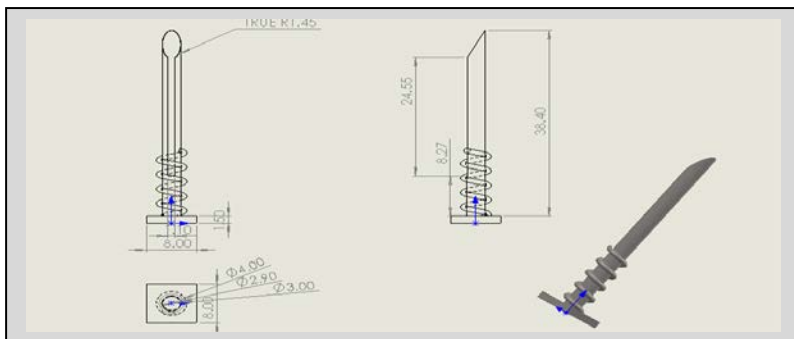

Fig. 4. Needle process drawing.

At the same time, the most important thing of the airbag protection device is to protect the airbag from inflation before the elderly fall. According to the fall detection algorithm, between 300 to 400 ms after the start of the fall, the fall detection rate is determined to be 96%. The fall time is about 830ms, and the maximum inflation time is 500 ms.

During the experiment, we found that the gas in the cylinder does not need to be completely released when falling onto the airbag. Only 80% of the airbag volume needs to be released to ensure safety. According to the amount of shielding gas released, the integration time t1 is about 370 ms, which meets the experimental requirements.

Fig. 5. Airbag design drawings and schematics.

3.4 Mechanical exoskeleton design

We have designed a new exoskeleton, which has the advantages of light weight, easy to wear, stable and reliable, and it can be fixed at a specific angle at the joints to achieve a chair-like function. Users can regain their physical strength anytime and anywhere, and perform stand-sit rehabilitation training. At the same time, when the user's legs are soft, the support function is provided in time to prevent the occurrence of falling behavior to a certain extent.

The exoskeleton angle designed by this system simulates the most comfortable fixed angle of the sitting posture, and the shape design of the exoskeleton can well satisfy the corresponding fixation and unlocking operations. In addition, at the knee joint of the exoskeleton, the system imitates the design of the human knee joint, and is improved so that the knee joint can be buckled and rotated by 180°. At the joints of the exoskeleton, a stronger metal material is used in this design to ensure the stability of the entire exoskeleton system.
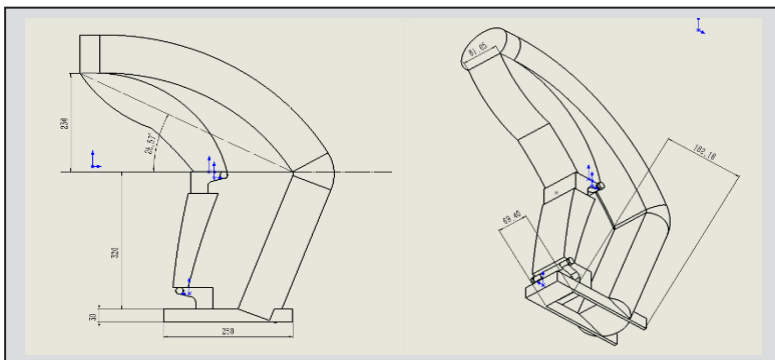

Fig. 6. Mechanical exoskeleton design.

In the existing design ideas and data of mechanical exoskeleton, if a person wears a mechanical exoskeleton, the human body is basically in a very relaxed state in an upright state. When the swinging leg and the supporting leg swing, the hip joint of the exoskeleton is bound to the waist of the person by an elastic band to ensure that the leg is not pinched. When the human body falls backward, the hip pad can also protect the hips from injury.

3.4.1 Data collection and experiment of mechanical exoskeleton

First, we collected data on the movement angles of the joints under various motions of the human legs, and designed the mechanical exoskeleton according to the angle data of the joints, so that the wearer can get a better experience.

Through experiments, we have obtained the following data for each joint motion angle

Table 1. Data of each joint motion angle of the human body.

Human leg parts	Leg movement	Action angle
hip joint	Bending/stretching	-120°~65°
	Adduction/Outreach	-35°~60°
Knee joint	Bending/stretching	-120°~(-160°)
ankle	Dorsiflexion/plantar flexion	-20°~(40°~50°)
	Inversion/Eversion	-30°~(-15°~20°)
	Screw in/out	-15°~(30°~50°)

The overall frame of the mechanical exoskeleton is similar to the frame of the mechanical leg prosthesis, but compared with the mechanical leg, the joints of the mechanical exoskeleton need to be more flexible and reliable. The updated mechanical exoskeleton can be fixed at a specific angle at the joints, so that the mechanical exoskeleton can be bent to a certain angle and then fixed, and then people can sit on it and rest.

We have conducted theoretical and practical analysis on the pressure of the human body when sitting on a stool. We found that if a person sits on an ordinary stool, the legs of the stool will fully bear the gravity, because the stool usually has four legs, so its load-bearing effect is better, but once it is replaced with two mechanical legs for support, we will Have to consider the load-bearing factor.

5 Further ideas

In the current solution, the sensor data has not been fully applied after the collection. According to the existing cloud platform analysis technology, the data of the sensor mobile phone can be uploaded to the cloud platform for data analysis and mining, generating personalized body posture records, and analyzing the possibility of falls. This is very positive for using the system for physical exercise. In addition, in the next step, the program can introduce a "voice recognition function" that allows users to communicate with the system, making the system more interesting. At the same time, the program can add more peripherals, such as "adaptive lighting adjustment" task reminder, "weather calendar" and other intimate small functions, making the program more complete. I hope that more people can use the program and provide more suggestions for this procedure.

6 Conclusions

The project is very user-friendly and improved the original algorithm in fall detection. For the first time, quaternion notation and data fusion algorithm are used for calculation, which makes the detection more accurate and efficient. At the same time, the head, hip, and knee joints of the elderly are protected in many ways, which solves the defect that the equipment cannot take care of various parts of the body, and has become the best choice for the elderly to prevent falls. At present, a complete set of equipment has been developed, and the laboratory is still undergoing technical testing. The technical details have been submitted to the conference, which will provide reference for more scholars.

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