# A Design of Dynamic Exoskeleton for Self-learning Human Movements

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**Abstract**

In order to make the athletes more flexible and simple in the movement training, this project designed a kind of intelligent exoskeleton for the athletes to learn and complete a set of fixed movements with a higher efficiency in the training. In order to optimize the user's sports experience and adapt to more sports scenes, the product is divided into three parts: embedded device, mobile phone client and background server. The smart exoskeleton can be mechanically worn only by connecting the leg bandage and hand bandage to the human body. A single person can be completed, more convenient. It is a multi-degree-of-freedom humanoid robot system that can follow the movement of human limbs in real time. The equipment sets a series of standard movements, which leads human to repeat exercises and slowly forms muscle memory. The main target of the design is the people who want to quickly and accurately achieve the purpose of action learning.

*Key words:* robot; Exoskeleton. Embedded device; Motor learning; Smart devices

## 1. Introduction

In today's world, people pay more and more attention to the importance of physical health, in addition to a healthy diet, physical exercise is also an important part of the achievement of physical health, but in the daily physical exercise people tend to ignore the standard of exercise movement. Incorrect movement posture, will cause joint injury, muscle strain, serious even cause muscle strain; At the same time, the effect of exercise is not very good. Professional coaching is too expensive for most people to afford, and they have to rely on their own insights[1].

Although smart exoskeleton technology has gradually matured, traditional exoskeletons are mostly used in medical rehabilitation and military fields[2], and few exoskeleton devices are used in daily life (such as delivery workers wearing exoskeletons). In the rehabilitation training exoskeleton, the exoskeleton enables the patient to recover through the operation of the motor and various flexible controls. The sports training exoskeleton invented in this project is different, for example: Basketball novice in shooting training blindly will cause harm to the body, after wearing our exoskeletons, can rely on exoskeleton muscles even reach muscle memory, in a very short time to reach the standard of shooting action, etc., in the same way, we can apply exoskeleton in a variety of sports training, such as badminton, tennis serve in training[3]. Therefore, this application can be widely used in athletes, technical workers and other people in need[4].

## 2. Research purpose and Content

The research purpose of this project is to design an exoskeleton to carry out sports training that drives the human body. It can input a perfect set of sports training movements, and the user can wear it and repeat the movements to form muscle memory and achieve the best effect in a short time. It can also be used in medical rehabilitation, fire and rescue activities and daily exercise.

The main content of this project is to write a complete and standard motion coordination program, input the exoskeleton through the mobile app, and execute this program after the human body wears the exoskeleton, so as to achieve the effect of muscle memory by driving the human body to repeat training for many times.

## 3. The Overall Design of Exoskeleton

### 3.1. *General function frame diagram of exoskeleton*

The overall functional system of the product includes embedded equipment, mobile phone client and background server, which integrates Bluetooth communication technology, network communication technology, asynchronous serial communication and other technologies. In the three components, the client can realize two-way data exchange through Bluetooth and embedded system, two-way data exchange between the client and the background can be realized through wireless data network, and the embedded device can send one-way information to the background through GPRS(General Packet Radio Service).

When users in preparation for connecting the exoskeleton, via mobile phone client scans the bar code on the exoskeleton, access to include information about the corresponding use of exoskeleton, and the exoskeletons of mobile client according to the corresponding bar code to send the corresponding information embedded devices, embedded devices according to receive the information on the corresponding storage unit. When the embedded device opens the storage unit, it will send feedback information to the mobile client in real time through Bluetooth communication, and the mobile client will judge whether the user correctly opens the required motion mode according to the feedback information. Then the mobile phone client sends information to the background server for the background server to judge the number of exercises and other relevant information of the current skeletal movement, and finally feedback to the mobile phone client, so that users can intuitively know their own action practice situation.

In addition to movement exercises, users can also use the mobile app to program the exoskeleton to lift and carry objects, for example. By wearing the exoskeleton and sending programs to the exoskeleton, users can easily lift and carry heavy objects.

### 3.2. *Overall design scheme of embedded end*

Considering cost and performance, we adopt industrial computer and STM32F1 chip equipped with ROS robot operating system as control module. In addition, bluetooth communication module, infrared detection module, motor drive module, GPRS module and relay for controlling storage unit switch are integrated outside the microcontroller. Among them, Bluetooth is used to communicate with the mobile phone client, infrared detection is used to detect the current storage state of the storage unit, and the sensor module is used to control the acquisition and preliminary processing of various external variables required in the algorithm.

### 3.3. *Overall design scheme of mobile client*

Mobile phone client integrates device binding and retrieval, self-check, device control, data display, Bluetooth communication, network communication and other functions. The Bluetooth function is used to communicate with embedded devices, and the network function is used to communicate with the server.

### 3.4. *Overall design scheme of background server*

The data processing part of the backend server takes Ali Cloud server as the carrier, and the data storage part takes Ali Cloud database as the carrier. The mobile client uploads the user's usage data to the database through network communication. The staff uses the background server to analyze and process the data received.

## 4. Exoskeleton Mechanical Structure Design

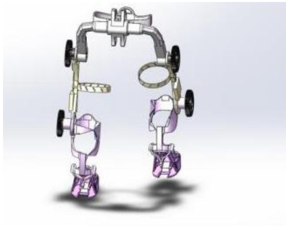
The exoskeleton robot has a total of 12 degrees of freedom, among which 10 degrees of freedom are motor-driven and 2 degrees of freedom are adaptive. The following is an overall view of the exoskeleton. The structure reduces human and motion errors.

Fig.1 Overall structure of exoskeleton

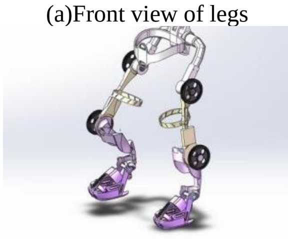
Each arm is provided with 3 degrees of freedom, and all are motor driven type, its extension is flexible, can be used for rehabilitation exoskeleton[5]. Suitable for operating under heavy load, as shown in Figure 2.

Fig.2 Structure of exoskeleton arm

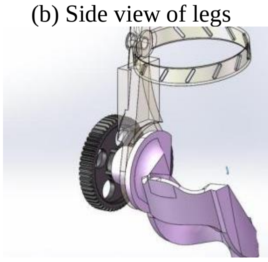
For the lower limbs, each leg is equipped with two degrees of freedom motor driveable type, and one degree of freedom is adaptive foot type, in which the two degrees of freedom motor can drive can meet the normal walking and running two states[6]. The adaptive degree of freedom of feet is to relieve the pressure and discomfort caused by mechanical devices on feet. The driving mode of the drivable degree of freedom mainly adopts the motor driving type, that is, the motor is fixed with a gear device, and the corresponding joint is driven by the transmission of the gear device. Here take the lower leg joint as an example. There are fixed gears on the lower leg joint. Assume that when the thigh joint is stationary, when the gear of the lower leg joint rotates the corresponding Angle, the lower leg joint also rotates the corresponding Angle, so the function of the lower leg joint is achieved[7]. The motor controlling the rotation of the lower leg joint is generally located on the thigh joint. The rotation of the lower leg joint is relative to the rotation of the thigh joint. Similarly, the gear controlling the rotation of the thigh joint is located in the crotch, and the rotation of the thigh joint is relative to the crotch joint, as shown in Figure 3.



(a)Front view of legs

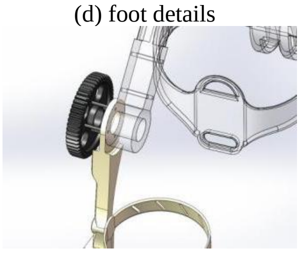


(b) Side view of legs

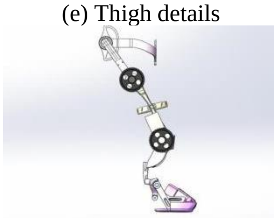


(c) Calf details

(d) foot details



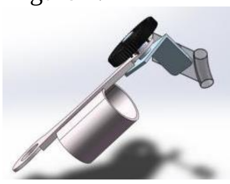
(e) Thigh details



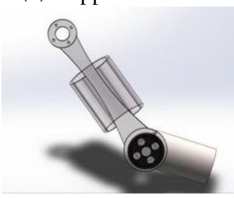
(f) Profile of a single leg

Fig.3 Exoskeleton leg structure

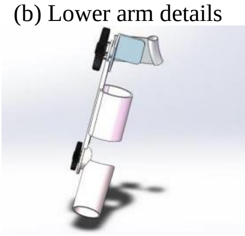
In the upper limb, the rotation of each joint is the same, and the rotation of the joint is relative to the upper joint. Therefore, by controlling the rotation Angle of each joint, the flexible operation of each joint can be achieved, that is, to achieve the rehabilitation and power effect of the exoskeleton. See Figure 4.



（a） Upper arm details

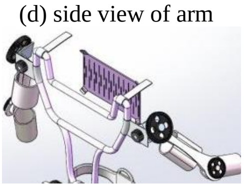


(b) Lower arm details

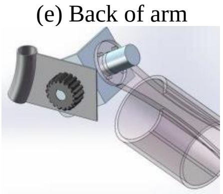


(c)Front view of arm

(d) side view of arm



(e) Back of arm



(f) Details of arm extension on both sides

Fig.4 Upper limb structure of exoskeleton

## 5. Exoskeleton Hardware Design Scheme

### 5.1. *Power management*

The exoskeleton's power core is powered by a series of lithium batteries[8]. In the process of using the battery charge, discharge constraint protection, so the design can meet the requirements of charge and discharge protection power management module. Power supply voltage is 36V. In the process of charging and discharging, the voltage of each battery is equalized by the internal self-balance and external balance of BQ76930 chip to prolong the battery life and increase the protection of battery pack overheating. In order to save MCU resources and facilitate wiring, BQ76930 is controlled by STM32 MCU.

### 5.2. *Control module*

The control core of the exoskeleton processes all kinds of data sampled by the exoskeleton through single chip microcomputer, and provides appropriate control strategies to guide the movement of the exoskeleton after calculation.

SCM control brushless DC motor joint to follow the human movement, considering the hardware in the process of signal acquisition, processing, control, as well as in the expansion, so choose the ARM core chip. We choose STM32 F1 series chips from the balance of cost, performance and range of use.

From the consideration of product cost and maintainability, the number of PCB boards is less. The control of each part of the joint also needs to be independently considered in the coordination from the perspective of cost saving. A main control board integrates a motor drive module and the sensor port required by this part of the joint. In the power supply part, in order to reduce the volume of the voltage regulator module, the Jin Sheng Yang voltage module is used to supply 36V to the drive module, and then to 24V, and then to 5V, and to supply the control board. In the board, there is a CAN bus module. The STM32 chip on the control board CAN interact with the chips on other control boards through the CAN bus. Achieve coordination and synchronization.

### 5.3. *Drive motor*

At the power core of the mechanical exoskeleton, each joint has a robotic joint motor, which transmits torque through cable traction to control the movement of each joint. The motor drive module needs to meet the motor position, speed and torque output requirements in the control process. In the selection of power, we choose the drive module has the advantages of light, small and stable product commercialization.

Choose electric drive mode. Since joint motion needs to be controlled and the motor needs to be blocked and frequently reversed, the robot joint motor is selected as the driving mode. The rotation position of the motor is detected by hall components, and the motor speed is accurately measured by a three-phase encoder.

### 5.4. *Sensor module*

The part of the exoskeleton interacting with human body undertakes the acquisition and preliminary processing of various external variables needed in the control algorithm, including EMG EMG signal acquisition sensor, angular speedometer, angular accelerometer, inertial navigation sensor and pressure sensor.

When the nerve controls the muscle movement, there is a potential difference along the nerve direction, and the EMG electromyography sensor determines whether there is a nerve signal controlling the muscle movement by detecting the pressure difference. According to the sensor line is relatively close, the amplifier needs to have a good common-mode rejection ratio, the AD8221 is used for signal processing, in the AD8221 front, there is TL084 operational amplifier for the first step of signal amplification.

The pressure sensor is used to detect the pressure between the skin and the outer fabric of the exoskeleton, and is used as a feedback signal to guide the drive of the motor. The optimal goal is zero pressure between the human body and the exoskeleton in all directions. The pressure sensor is a thin film piezoresistive sensor. The pressure is measured by the change of the pressure generated by the change of the resistance value of the compression resistance in the resistance bridge.

Angular speedometer and angular accelerometer are bound to each limb of the human body, without relative movement, and the angular change of the limb relative to the vertical plane is determined. Among them, MPU-3050 is a three-axis gyroscope, which measures the Angle. MMA8421 is a triaxial accelerometer that measures acceleration. The data they measure are the raw data of the generalized variables in the Lagrange equation. In hardware design, the angular velocity and angular accelerometer integrated in a 0.5 cm x 1 cm of small PCB, its with and to measure the body through the bind fixed, PCB by needle are connected to the main control board, the signal back to the single chip microcomputer, using inertial navigation position sensor, the relative position of the body and ensure the accuracy of the motion.

## 6. Conclusion

The project in all respects have carried on the thorough research and exploration, including mechanical structure, hardware, software, etc., this one in sports training exoskeleton is a new type of intelligent training system based on AI control technology, through the use of humanoid robot technology combined with the content of the movement technology subject, provide short-term effective mass sports training methods, It can help people to exercise correctly, so that people can reduce the time of ineffective exercise while avoiding injury, quickly achieve the desired effect, and then carry out the follow-up training, and can be connected to the mobile phone client. Correct movement mistakes in time, convenient and correct wearing, intelligent, lightweight and powerful.

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## References

1. Wan SL, Yang MX, Xi RR, et al. Design and control strategy of humanoid lower limb exoskeleton driven by pneumatic artificial muscles. Proceedings of 2016 23rd International Conference Mechanic Machine Vision Practice. 2016
2. Han Yali, Wang Xingsong. Dynamics analysis and simulation of lower limb assisted exoskeleton [J]. Journal of system simulation,2013,25(01):61-67+73.
3. Li Longfei, Zhu Lingyun, GOU Xiangfeng. Design of human-machine closed chain lower limb rehabilitation exoskeleton for Human Movement requirements [J]. Machinery Design,2021, V. 38; No. 382 (8) : 53-60, DOI: 10.13841 / j.carol carroll nki JXSJ. 2021.08.008
4. Alan T. Asbeck, Stefano M.M. De Rossi, Kenneth G. Holt,Conor J. Walsh. A biologically inspired soft exosuit for walking assistance[J]. The International Journal of Robotics Research . 2015 (6)

5. Gao Jianshe, Zuo Weilong, Yu Qianyuan. An upper limb rehabilitation robot motion simulation and experimental research [J]. Journal of mechanical design and manufacturing, 2020, No. 349 (3) : 155-158. The DOI: 10.19356 / j.carol carroll nki. 1001-3997.2020.
6. Shi Xiaohua, Wang Hongbo, Sun Li, Gao Feng, Xu Zhen. Structural design and dynamics analysis of exoskeleton-type lower limb rehabilitation robot [J]. Journal of mechanical engineering,2014,50(03):41-48.
7. Xiang Zhongxia, Zhao Ming, Gao Fei, Jin Teng, Hu Zhigang, Zhang Jian. Simulation of training Effect of exoskeleton Rehabilitation Robot [J]. Journal of Tianjin University (Natural Science and Engineering Technology),2016, V. 49; No.302(07):695-701.
8. Fan Boqian. Research on Key Technologies of Hydraulically Driven Lower Limb Exoskeleton Robot [D]. Zhejiang University,2017.
9. Variable impedance actuators: A review[J]. B. Vanderborght,A. Albu-Schaeffer,A. Bicchi,E. Burdet,D.G. Caldwell,R. Carloni,M. Catalano,O. Eiberger,W. Friedl,G. Ganesh,M. Garabini,M. Grebenstein,G. Grioli,S. Haddadin,H. Hoppner,A. Jafari,M. Laffranchi,D. Le

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