IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2020 Doi Number

Upper Limb Rehabilitation Robot System Based on Internet of Things Remote Control

Xing Li [1, 2a] , Junpei Zhong [3,b*]
1School of Electrical Engineering & Intelligentization, Dongguan University of Technology, Dongguan, 523808, Guangdong, China
2State Key Laboratory of Synthetical Automation for Process Industries, Northeastern University, Shenyang 110819, Liaoning, China
3 S.M. Wu School of Intelligent Engineering, South China University of Technology, Guangzhou 511442, Guangdong, China
a lixing@mail.neu.edu.cn
*Corresponding author b joni.zhong@ieee.org
The authors acknowledge the National Natural Science Foundation of China (Grant: 61873054 and 61503070). Fundamental Research Funds for the Central Universities(N170804006).

ABSTRACT Modern technology has been improving, as is medical technology. Over the years, rehabilitation medicine is developing and growing. The use of rehabilitation robots to achieve the upper limb motor function of patients with hemiplegia has also become a popular research in academia. Under this background, this paper proposes an upper limb robot rehabilitation system based on Internet of Things remote control. The upper limb robotic rehabilitation system based on the Internet of Things in this paper is composed of upper computer and lower computer. Information is collected by pressure sensor. The transmission process is realized by STM32 controller, which is first transmitted to the upper computer, and then the information needs to be processed After processing, it sends control commands to the lower computer controller to control the motor drive of the rehabilitation robot, so as to realize the rehabilitation training of the patient. In order to verify the reliability of the system in this paper, this paper conducted a motion test and system dynamic performance test. The research results of this paper show that the passive motion accuracy of the system in this paper has reached more than 97%, and the active motion accuracy has reached more than 98%. In addition, the maximum speed response time of the upper limb rehabilitation robot system based on the remote control of the Internet of Things in this paper is 5.7ms. The amount of adjustment is 5.32%, and the dynamic performance is good. The research results of this paper show that the upper limb rehabilitation robot system based on the Internet of Things remote control in this paper has excellent performance, which can provide a certain reference value for the research of rehabilitation robot.

KEY WORDS: Internet of Things Remote Control, Upper Limb Rehabilitation Robot, Wireless Communication Technology, Dynamic Performance

I. IINTRODUCTION

Science and technology and people's living standards are gradually improving, whether it is China or other countries in the world, and these changes will bring about an aging population problem. In recent years, due to the impact of cardiovascular and cerebrovascular diseases, there have been some changes in middle-aged and elderly patients with hemiplegia. The number of patients has increased and the trend of becoming younger. At the same time, on the other hand, due to the rapid growth of the number of transportation vehicles, more and more The more people suffer from nervous system injuries or limb injuries due to traffic accidents [1]. Strictly speaking, according to medical theory and clinical medicine, in addition to early surgical treatment and necessary medical care, correct and scientific rehabilitation education is also very important for the recovery and improvement of limb motor ability, but these patients have exercise Obstacles, can't do rehabilitation training alone, and someone needs help, but in view of the fact that there are not enough medical staff in our country, these patients will be in an embarrassing situation. In this respect, the development of a remotely controlled upper limb rehabilitation robot is of great significance for solving the problem of unattended patients with hemiplegia.

Sanja Vukićević once designed a robust controller of a two-degree-of-freedom upper limb rehabilitation robot for the motion characteristics of rehabilitation training and the inherent properties of the robot, so that the robot can drive the precise trajectory of hemiplegic patients according to the given trajectory, ensuring Under the system dynamics model with zero error, the modeling error bounded error remains consistent and bounded, and the tracking error is zero. The simulation results of Sanja Vukićević show that the robust control strategy can make the system tracking error tend to under certain conditions Zero, has a good control effect, although Sanja Vukićević's method improves the robustness of rehabilitation training robots, but the reliability has decreased [2-3]. Dobkin BH used the hemiplegic rehabilitation theory and upper limb physiological structure as the basis, combined with biological science, mechanical engineering, automatic control and other disciplines to design the upper limb functional rehabilitation robot. The control system of impedance control, and Simulink software was used to establish the simulation model of the control system, and the influence of the control parameters based on position impedance on the upper limb function control of rehabilitation robot was analyzed. The results of Dobkin B H show that the rehabilitation robot's control effect on the upper limb function changes with the change of movement speed. The upper limb rehabilitation robot designed by Dobkin B H has good stability but its accuracy is lacking, and it needs to be improved [4-5]. Naranjo-Hernández David once proposed a new upper limb rehabilitation robot system based on virtual reality, which fully utilizes many advantages of robots participating in stroke upper limb rehabilitation. The system has the advantages of small size, light weight and rehabilitation interaction. Naranjo-Hernández David's system is mainly composed of a haptic device called Phantom Premium, Upper Extremity Exoskeleton Rehabilitation Device (ULERD) and virtual reality environment. It has been experimentally proved that Naranjo-Hernández David's method is accurate and convenient during the rehabilitation process However, the economy is not strong and needs to be strengthened [6-7].

This article adopts the Internet of Things remote control technology and designs the upper limb rehabilitation robot system. In this paper, the relevant theory of the remote control of the Internet of Things is first elaborated, then from the perspective of human kinematics, the motion model of the upper limb rehabilitation robot is constructed, and finally, the upper limb rehabilitation robot system based on the Internet of Things remote control is designed and set The corresponding experiment was carried out to test the system. The test results show that the system in this paper has good accuracy and dynamic performance.

II.INTERNET OF THINGS REMOTE CONTROL

The so-called remote control technology refers to the technology that the Internet controls and manages remote devices to control and manage signals based on signals. Its software usually includes client-side and server-side programs. As the Internet of Things becomes more and more popular, remote control technology is also popularized. It can achieve the effect of unconventional remote control through IoT media [8-9].

2.1 INTERNET OF THINGS

The Internet of Things realizes the mutual exchange, mutual knowledge, and interactive information exchange between "machines and machines". It can also be understood that through a variety of communication technologies, the Internet of Things is a very complex and diverse system technology. . According to the principles of information generation, transmission, processing and application, the Internet of Things can be divided into four levels: perception recognition layer, network construction layer, management service layer and integrated application layer [10-11].

(1) Perception recognition layer.

What is the core technology of the Internet of Things? It is perception and recognition, so the perception recognition layer is very important for the Internet of Things. So let's take a look at what the perceptual recognition layer includes. The level of perceptual recognition includes radio frequency identification, wireless sensors and automatic information production equipment. Not only that, but also includes a variety of intelligent information used to artificially produce electronic products. It can be said that as an emerging technology, wireless sensor networks mainly use different types of sensors to obtain large-scale, long-term, real-time information on environmental status and behavior patterns [12].

(2) Network building layer.

The main function of this layer is to connect lower-level data (perceived recognition-level data) to higher levels such as the Internet for its use. The Internet and next-generation Internet (including IPv6 and other technologies) are the core networks of the Internet of Things. Various wireless networks on the edge can provide network access services anytime and anywhere. The existing WIMAX technology is included in the scope of the wireless metropolitan area network, and its role is to provide high-speed data transmission services in the metro area (about 100 km). On the other hand, the wireless local area network also includes the WIFI that almost every household is currently trying. The use of WIFI is very wide. The main function is to provide network access services for users in a certain area (family, campus, restaurant, airport, etc.). Not only that, the wireless personal area network also includes Bluetooth, ZigBee and other communication protocols. These several things have a common feature, that is, low power consumption, low transmission rate, short distance, generally used for personal electronic product interconnection, industrial equipment Control and other fields. The various types of wireless networks listed above are suitable for different environments and work together to provide convenient network access so that the Internet of Things can be achieved [13].

(3) Management service layer

By supporting high-performance computer technology and large-capacity storage, the management service level can efficiently and reliably organize large-scale data and provide an intelligent support platform for high-level industry applications. Storage is the first step in information processing. The database system and various mass storage technologies developed later, even including network storage (such as data centers), have now been widely used in information technology, finance, telecommunications, automation, etc. These industries. Faced with massive amounts of information, how to organize and search for effective data is a key issue. Therefore, the main feature of the management service layer is "wisdom". Through rich and detailed data, mechanical learning, data mining, expert systems and other means, it serves the management 's The function is increasingly powerful [14].

(4) Comprehensive application layer

What was the original role of the Internet? It is used to achieve computer-to-computer communication, and then developed into a connection between users and people as the main body, and the times are changing. Now, it is moving towards the goal of connecting things-things-people . Not only that, along with this process, network applications have also undergone tremendous changes, from the initial transmission of files and emails with basic functions of data services to user-centric applications. In addition, the layers of the Internet of Things are relatively independent but closely connected.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2020.3014378, IEEE Access

Below the integrated application layer, different technologies at the same layer are complementary and suitable for different environments, forming a complete set of response strategies for this level of technology, and at different levels, providing different technical compositions and combinations to Create a complete solution according to the requirements of the implementation [15].

The network topology diagrams of the mobile communication network and the wireless sensor network are shown in Figure 1 and Figure 2, respectively.

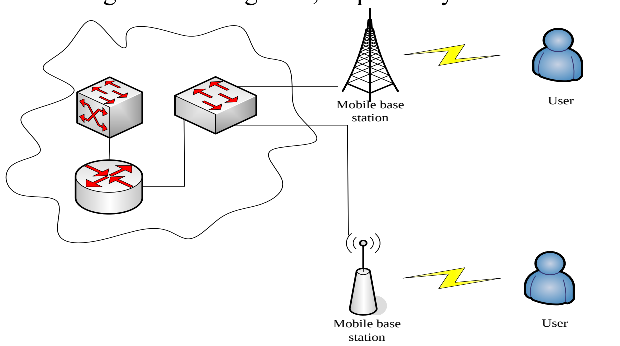

FIGURE 1. Mobile communication network topology

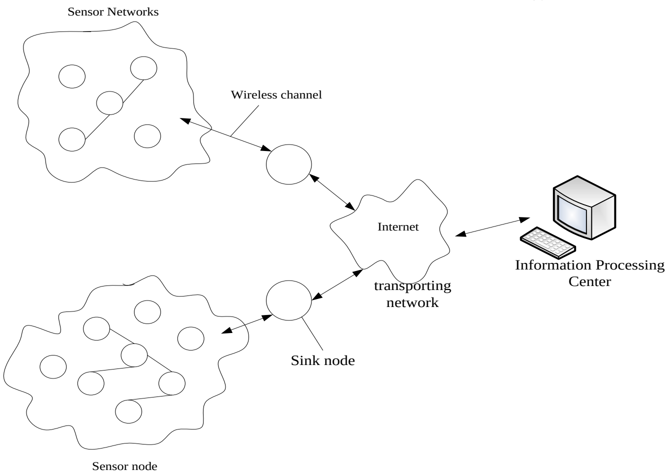

Figure 2. Wireless sensor network topology

From Figure 1 and Figure 2 we can see the network topology of the mobile communication network and wireless sensor network. The sensor is the first basic link to realize the automatic monitoring function of the system.It is generally composed of sensitive components, conversion originals, conversion circuits and auxiliary power sources.It can convert the sensed information into electrical signals or other output forms according to certain rules. So as to transmit and process information [16].

2.2 WIRELESS COMMUNICATION TECHNOLOGY

(1) Wi-Fi technology

Wi-Fi is a wireless technology that allows electronic devices to connect to local wireless networks. In the Wi-Fi hotspot area, users can use the access code and connect through authentication, so that they can use the network. The basic structure of Wi-Fi is relatively simple, its function is similar to Bluetooth, but it is more powerful than Bluetooth, and then from the main service unit to the extended service unit, the Wi-Fi access point adds a distribution system for more networks Members provide services, which is one of the important reasons why many people prefer to choose Wi-Fi [17].

Not only that, Wi-Fi technology has unparalleled compatibility, its TCP / IP compatible chip, smart nodes can be directly connected to the wireless switch, the number of connected nodes can be arbitrarily expanded, it can even complete the control of the nodes on the LAN through the mobile phone, But it is not without shortcomings. Compared with ZigBee, Wi-Fi has relatively high energy consumption and relatively high price. These problems have been gradually solved by improving chip technology [18].

(2) Wireless radio frequency technology

What is the concept of radio frequency technology? Refers to the general name of the technology that uses radio frequency modules to transmit or receive information, or uses electromagnetic waves for energy transmission. The application range of radio frequency technology is very wide, covering a lot of areas, ranging from radar, radio telescopes to magnetic cards or RFID transmitters for sensing applications. The reason why wireless radio frequency technology can be widely used is because of its fast data transmission speed. The transmission data has high reliability and low energy consumption.

Radio frequency technology mainly encodes and forms the information to be transmitted through the radio frequency unit, emits electromagnetic waves through the antenna, and the transmitter or receiver receives the information in different frequency bands through the antenna and responds to the received information. Take the next step through preliminary identification. Its operating frequency range is very wide, from the low frequency band level 100KHz to the high frequency band or even very high frequency band GHz. It has a wide range of applications. In addition to the traditional communication field, it also includes identification applications and industrial applications, as well as the use of high-energy radio frequency sources for medical applications and scientific research. [19]

III. INTERNET OF THINGS REMOTE CONTROL UPPER LIMB REHABILITATION ROBOT SYSTEM

3.1 Motion Model Description of Upper Limb Rehabilitation Robot

(1) Human kinematics

Human kinematics originated from the Greek "sports" and "research", the main research is the relationship between body position, speed, acceleration under the action of external forces. The form of body movement is translation and rotation. To understand the model of human physiological results, we must first understand the relevant terms such as human motion surface and human motion rotation axis in human anatomy [20-21].

1) Sports surface

What are the three main physical aspects? Generally speaking, it includes sagittal plane, coronal plane and horizontal plane. The meaning of the sagittal plane refers to the long plane that separates the human body from left to right; the meaning of the coronal plane refers to the long cut plane that divides the human body into two parts; the horizontal plane means the parallel to the ground, perpendicular to the sagittal plane and the coronal plane, The human body is divided into upper and lower parts of the horizontal plane.

2) Rotating axis

The rotation axis can be divided into three parts, namely the sagittal axis, the coronal axis and the vertical axis. The bone rotates around the joint on a horizontal plane perpendicular to the axis of rotation, and the axis position is on the curved surface of the joint. The sagittal axis refers to the axis parallel to the horizontal plane and perpendicular to the coronal plane. The coronal axis refers to the axis parallel to the horizontal plane and perpendicular to the sagittal plane, and the last vertical axis refers to the axis parallel to the longitudinal axis of the human body and perpendicular to the horizontal plane.

3) Description of joint kinematics

A joint is formed by connecting two or more bones or limb segments. Joint mobility can be described in two ways: first, the proximal segment can rotate around the distal fixed segment; second, the distal segment can rotate around the proximal fixed segment. Most of the upper extremity movement is from the distal segment to the proximal segment [22]. The proximal segment of the upper limb joint is usually stabilized by muscle, gravity or inertia, while the distal segment is less constrained and can rotate.

4) Dynamics

Kinetics is mainly the role of various elements in the subject. The force acting on the body is generally called a load, which can make the body move or keep stable, and can also deform and damage the tissue. Common loads in the skeletal muscle system include stretching, squeezing, bending, shearing, torsion, and mixed loads. Normal tissue has the ability to resist structural or morphological changes within a certain range, but if a certain tissue is ill due to disease, injury or long-term inactivity, the ability to resist load will be greatly reduced. The movement of various parts of the human body is carried out under the action of force, which is divided into internal force and external force according to the object of the force. The external force is the force caused by external factors, such as gravity, the traction force exerted by the object, etc., while the internal force is the force caused by the body, which is the interaction between the internal organs and structures.

5) The mechanical lever of the human body

The movements of muscles, bones and joints of the human body can be described by the principle of lever. The force points, fulcrums and resistance points in the lever correspond to the muscles, bones and joints of the human body. The force point is the attachment point of the muscle on the bone, the fulcrum is the center of the joint of movement, and the resistance point is the resistance on the bone lever, which is opposite to the direction of movement. The vertical distance from the fulcrum to the force point is the force arm, and the vertical distance from the fulcrum to the resistance point is the resistance arm.

(2) Description of sports posture

1) Location

In three-dimensional space, the position of each object is determined, generally expressed in coordinates, and if the coordinate system given by space is {A}, then the position of any space point P can be expressed as:

$$^{A}P = \left[p_x, p_y, p_z\right]^T \tag{1}$$

In the formula, px, py, and pz respectively represent the projected coordinates of point P in the three directions of coordinate system $\{A\}$.

2) Bearing

The orientation mainly refers to the position and direction of any rigid body B in space relative to the other coordinate system $\{A\}$ in the fixed coordinate system $\{B\}$. Respectively rotate the fixed coordinate system $\{B\}$ in three directions, that is, rotate the three coordinate axes into the same direction as the three coordinate axes of the coordinate system $\{A\}$, we use a rotation matrix 3×3 to describe the rigid body B in coordinates Department of $\{A\}$. Let ABR be the rotation matrix, which represents the transformation matrix of the coordinate system $\{B\}$ relative to the coordinate system $\{A\}$ [23]. This is an orthogonal matrix, which satisfies the following formula:

$$^{A}R_B^{-1} = {}^{A}R_B^{T}, \left|{}^{A}R_B\right| = 1 \tag{2}$$

The rotation matrix is expressed as follows:

$$^{A}R_B = \left[{}^{A}x_B \quad {}^{A}y_B \quad {}^{A}z_B\right] = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \tag{3}$$

3) Posture

The position and posture of the object B in the reference frame {A} is $\left[{}^{A}R_B \quad {}^{A}p_{BO}\right]$, when only the relative position is shown, there is ${}^{A}R_B = 0$; when only the relative position is shown, there is ${}^{A}p_{BO} = 0$. As the homogeneous transformation matrix matures in the field of position description and calculation, it can also be used to describe the pose of the three-dimensional object B in the base coordinate system {A}, expressed as:

$$^{A}T_B = \begin{bmatrix} {}^{A}R_B & {}^{A}p_{BO} \\ 0 & 1 \end{bmatrix} \tag{4}$$

(3) Kinematics modeling

This paper uses the method of establishing D-H coordinate system to analyze the space kinematics of the robot [24]. The D-H method is used to express the relationship between translation and rotation between adjacent rods. The coordinate relationship of the rods at each joint relative to the previous rod is described by establishing a 4 * 4 homogeneous transformation matrix. The D-H coordinate system of each joint is shown in Figure 3.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2020.3014378, IEEE Access

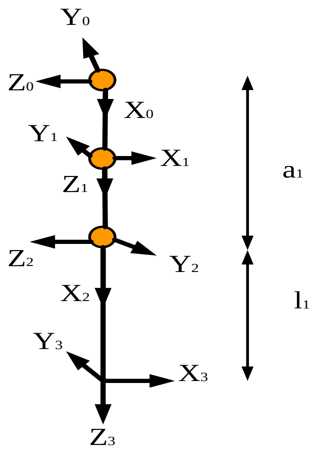

Figure 3. D-H coordinate of robot joint

As can be seen from Figure 3, the parameters between each joint and the connecting rod are: θ1 is the rotation angle around the Z1 axis from the X0 to X1 axis, and θ2 is the rotation angle around the Z2 axis from the X2 axis.

1) Positive kinematics

Then the positive solution expression of robot kinematics is:

$$T = \begin{bmatrix} c_x & d_x & e_x & f_x \\ c_y & d_y & e_y & f_y \\ c_z & d_z & e_z & f_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

Let $\theta_1 = 0^0$, the $\theta_1 = 0^0$, $\theta_1 = 0^0$, initial state of the robot be and bring the initial state into the transformation matrix, which is the initial coordinate matrix of the upper limb rehabilitation robot:

$$T = \begin{bmatrix} 0 & 0 & 1 & a_1 + l_2 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

2) Inverse kinematics

When the terminal posture of the upper limb rehabilitation robot has been determined, the motion parameters of the joints of the robot arm are also determined at this moment, then solving the problem of the size of each joint of the robot is called the inverse kinematics problem. In this paper, the algebraic solution method is used to solve the inverse kinematics of the upper limb rehabilitation robot. Find the inverse matrix:

$$T = \begin{bmatrix} c_x & d_x & e_x & f_x \\ c_y & d_y & e_y & f_y \\ c_z & d_z & e_z & f_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = {}_1^0T(\theta_1)\,{}_2^1T(\theta_2)\,{}_3^2T(\theta_3) \tag{7}$$

3.2 Upper Limb Rehabilitation Robot System Controlled by Internet of Things

(1) Software design

The control system software is divided into two upper and lower parts, namely upper computer software and lower computer software [26]. Among them, the main function of the upper computer software is to pass the motion parameters of the robot's kinematic joints through the chip of the serial port of the industrial computer. Through this method, it is sent to the lower computer of the system, and the engine stepper parameters are set through the visual interface The lower computer sends control commands and displays its feedback information. The lower computer and system status monitoring [23-25]. On the other hand, the operation of the lower computer software includes two aspects: on the one hand, it receives the control commands issued by the upper computer, and receives the connection code signal and the boundary switch to form a closed loop control [27-28].

The control system of the upper limb rehabilitation robot in this article is shown in Figure 4. This control system mainly includes upper and lower computer. In this article, the lower computer of this article adopts STM32 microcontroller based on ARM-M3 core. This controller has 12-bit analog-to-digital converter (ADC) and digital-to-analog converter (DAC). It has many advantages and has energy consumption. Low, real-time and cost-effective. Use the man-machine interface on the computer (upper computer position) to select different operation modes, and transmit the information to the STM32 controller (lower computer) through serial communication to control the motor to work, so as to drive the mechanical arm to move, and in the same At the time, the position information collected from the encoder and the torque information collected from the torque sensor are fed back to the computer through the STM32 controller [29], which can realize the evaluation, analysis and guidance of patient rehabilitation training [30-31].

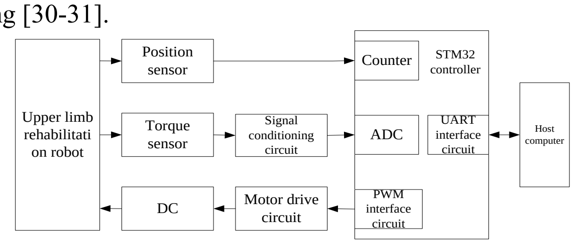

Figure 4. Control system of upper limb rehabilitation robot

As can be seen from Figure 4, the upper limb rehabilitation IoT is the application of parameter information collected by various sensors as parameter variables to the automatically controlled IoT, providing a scientific basis for upper limb rehabilitation robots for data information and video information transmission, and server-side remote control The purpose of client patients for rehabilitation training [32, 33].

(2) Hardware design

1) CAN bus

This article selects the CAN bus for real-time communication. A field bus widely used in controller area networks. Compared with other communications, the CAN bus has the following characteristics: it can complete the framing of communication data; it uses communication data blocks for encoding; it uses a multi-master competitive bus structure, which can achieve free communication at any node and any time [34]; the structure is simple; There is no distinction between master and slave in data communication, which can initiate communication at the same time and communicate according to priority.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2020.3014378, IEEE Access

The CAN core completes the tasks of data transmission and reception filtering [35]. The message RAM is used for CAN to receive and send up to 32 message objects. The functions of the CAN register and the message processor are to provide a data transfer and status notification interface between the CAN controller and the CIP-51 [36].

2) Pressure sensor

When the patient begins to exercise, because there is no exercise for a long time, spasm may occur, and then the motor will follow the command to cause greater harm to the patient. In order to prevent this from happening, a pressure sensor is installed on the robot. Here, a piezoresistive sensor (FSR) is used, which is a thin-film sensor [37]. As the surface pressure increases, the impedance at both ends of the pin decreases accordingly. The linear characteristic of the sensor is an extremely critical index. If the linear characteristic is good, the simple linear relationship can be used to convert the collected electrical signal into the magnitude of force, which is of great significance to both the control and the processor. On the contrary, if its linearity is not good, it is relatively complicated to complete the conversion from electrical signal to force through two methods of nonlinear curve fitting and table look-up. The relationship between the impedance of the sensor and the load force: when the load force is less than 20g, the slope of the resistance change is larger, and after the load force is greater than 20g, the slope of the entire curve is relatively stable. In application, the force of general motion will be greater than 20g, so the applied interval is basically in the interval after 20g, then the curve can be considered to have good linear characteristics.

IV. Experimental Equipment and Design

4.1 Experimental Equipment

(1) Sensor

This paper selects WDD35D-4 type conductive plastic angle sensor, resistance value 5K, resistance tolerance ± 15%, independent linearity 0.1%, electrical rotation angle 345 ° ± 2 °, mechanical rotation angle 360°, rated power consumption: 2W (@ 70 °C), Temperature coefficient: 400ppm / °C, insulation resistance: ≥1000MΩ (500V.DC), insulation withstand voltage: 1000V (AC.RMS) 1min, smoothness: ± 0.10%. The angle sensor can realize the closed-loop control of the joint angle, and is installed at each joint connection to directly measure the joint angle. In order to be able to directly collect the direct force of the affected limb and the robotic arm, a force sensor is installed at the position where the patient is in contact with the robotic arm. Install four strain gauge pressure sensors between the wrist and the support ring.

(2) Motor

This article uses the 36SYK42, 36SYK-2 series of hollow cup permanent magnet DC servo motors in the DC servo motor. This series of motors has: rotor without iron core, small rotational inertia, no cogging effect, fast angular acceleration, and high conversion Efficiency; advantages such as small torque fluctuations, smooth operation at low speeds, and low system noise. The basic performance parameters are shown in Table 1.

TABLE 1.36SYK42、36SYK-2 BASIC PERFORMANCE PARAMETERS OF MOTOR

Model	Rated power(KW)	Rated voltage(V)	Rated current(A)	Rated torque(Nm)	Peak torque(Nm)	Rated speed(r/min)
36SYK42	0.06	48	4	0.2	0.9	3000
36SYK-2	0.04	24	2.5	0.13	0.39	3000

It can be seen from Table 1 that if the electronic speed is changed too fast, the PL60 reducer is used to form the deceleration mechanism, and its specific parameters are shown in Table 2.

TABLE 2. BASIC PERFORMANCE PARAMETERS OF PL60 REDUCER

Model	Rated input torque(r/min)	Rated input torque(Nm)	Deceleration ratio(i)
PL60	3000	20	160

4.2 Experimental Design

(1) Exercise test

Adjust the horizontal size of the shoulder joint and the lengths of the upper and lower arms to align the joints of the robot with the joints of the patient. Fix the upper limb of the patient on the robot with straps to complete the wearing work.

1) Passive movement test

In passive motion, the parameter settings are made through the touch screen. Taking the elbow joint as an example, the joint angular velocity is set to 12.0 ° / s, and the duration of each motion is 60s. Repeat this motion 10 times.

2) Active exercise test

This article conducted an active motion test. During the active motion, the sensor collects information and the robot arm follows the patient's motion. Through observation, when the non-compulsory training starts, the change signal of two consecutive samples is less than the threshold. This time indicates a meaning that the joint of the affected limb has no intention to move. At this time, the joint speed is 0 and the robot arm does not move. Then, when the torque change signal is greater than the threshold, the robot arm begins to move after moving the affected edge. In this article, in order to evaluate the effect of active exercise, the elbow joint was selected as an example. The elbow joint of the subject was slowly moved upward from the horizontal position. The angle of rotation of the robot arm during the process was recorded at 20 °, and the movement was repeated 10 times and repeated 10 times. It is to avoid accidental.

(2) System dynamic performance test

The dynamic performance index is the main index to verify the practicability of the system [38]. For this reason, the speed response characteristic test and the positioning accuracy characteristic test are carried out in this paper to verify the speed and accuracy of the system respectively.

This article takes the elbow joint as an example. The time required to increase the steady state value from 10% to 90% to 90% of the steady state value is evaluated. The response speed of the system is evaluated. The movement range of the elbow joint flexion is set to 0-60 °. Experiments were conducted at different speeds of ± 3 rpm and ± 7 rpm to verify the position accuracy of the system in this paper.

V. Analysis and Discussion of Test Results

5.1 Analysis of Test Results of Upper Limb Rehabilitation Robot System Based on Internet of Things Remote Control

(1) Passive movement test

Taking the elbow joint as an example, a passive motion test is performed on the upper limb rehabilitation robot system based on the remote control of the Internet of Things [39]. The test results are shown in Table 3 and Figure 5.

TABLE 3. PASSIVE MOTION TEST RESULTS

Number of tests	Set value(°/s)	Measured value(°/s)	Relative error(%)
1	12.0	11.8	-2
2	12.0	11.7	-3
3	12.0	12.1	1
4	12.0	11.9	-1
5	12.0	12.3	3
6	12.0	11.9	-1
7	12.0	11.8	-2
8	12.0	12.2	2
9	12.0	12.1	1
10	12.0	11.8	-2

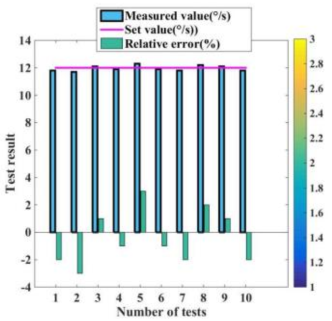

Figure 5. Analysis of elbow passive movement test results

It can be seen from Table 3 and Figure 5 that the relative error when the elbow joint movement speed is 12.0 ° / s is between -3 and 3, that is, the accuracy of the robot arm movement speed is more than 97%. This research result shows that the mechanical arm of the controlled upper extremity rehabilitation robot system can move smoothly according to the instructions within the range of safe motion angle, which meets the design requirements. Similarly, the extension / flexion and internal rotation / external rotation of the shoulder joint can be obtained. When the movement speed is 12.0 ° / s, the accuracy of the movement speed of the robot arm is also more than 97%, which meets the design requirements [40].

(2) Active exercise test

Taking the elbow joint as an example, the upper limb rehabilitation robot system based on the Internet of Things remote control is used for active motion testing.

TABLE 4. ACTIVE MOTION TEST RESULTS

Number of tests	Set value(°)	Measured value(°)	Relative error(%)
1	20	19.8	-1
2	20	19.6	-2
3	20	19.8	-1
4	20	20.4	2
5	20	20.3	1.5
6	20	20.1	0.5
7	20	19.7	-1.5
8	20	19.8	-1
9	20	20.4	2
10	20	20.2	1

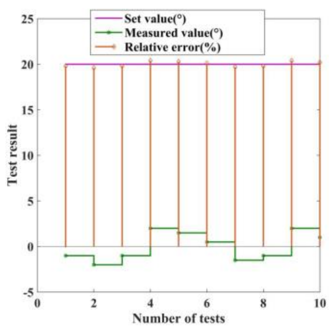

Figure 6. Analysis of elbow joint active movement test results

As can be seen from Table 4 and Figure 6, the accuracy of the robot arm of the upper limb rehabilitation robot system based on the Internet of Things to follow the movement of the affected limb is more than 98% [41]. This experimental result shows that the robot arm can not only follow the movement of the affected limb well. Moreover, it can basically keep consistent with the movement trajectory of the affected limb, which can effectively help the patient to achieve the extension and flexion movements. Through this result, the same extension and flexion test can be done on the shoulder joint, and the data obtained in the experiment also indicate that the accuracy of the robot arm following the movement of the affected limb has reached more than 98%.

From the above research results, we can see that the overall system test results of the upper limb rehabilitation robot system based on the Internet of Things remote control show that the robotic arm can fully meet the training requirements of patients and meet the design requirements.

5.2 Analysis of Dynamic Performance Test Results of Upper Limb Rehabilitation Robot System Based on Internet of Things Remote Control

In this paper, the speed response is tested under the step response, and the two important time domain indicators, rise time and overshoot, are analyzed. Among them, tr is the time required for the response curve to rise from 10% of the steady state value of 90% to the steady state value of 90%, and the response speed of the system is evaluated; σ% evaluates the degree of damping of the system, and its calculation formula is:

$$\sigma\% = \frac{Y_{\max} - Y_{\mathrm{Re}\,f}}{Y_{\mathrm{Re}\,f}} \times 100\% \tag{8}$$

In the formula, $Y_{\max}$ it represents the maximum speed value of ; $Y_{\mathrm{Re}\,f}$ represents the speed target reference value. Then select the rising edge of each speed response curve to do polynomial fitting to get the rising edge equation. The result is shown in Figure 7.

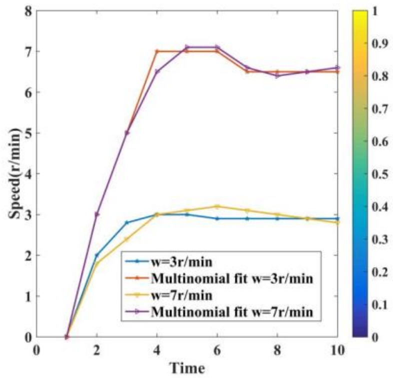

Figure 7. Analysis of speed change results of elbow joint transmission mechanism

It can be seen from Figure 7 that at 3r / min, the time for the speed to rise from 0.3r / min to 2.1r / min is the speed response time, and the response time is 4.1ms after calculation; at 7r / min, the speed is from 0.7 The time when r / min rises to .3r / min is the speed response time. After calculation, the response time is 5.15ms. Substituting these two results into the formula for calculation, the maximum speed response time of the upper limb rehabilitation robot system based on the Internet of Things remote control in this paper is 5.7ms, and the maximum overshoot is 5.32%.

When the arm is in a straight line and the position is horizontal, when the elbow joint is flexed, due to the downward gravity of the mechanical arm, the motion mechanism is moving under the maximum load; when the motion is reverse, the motion mechanism bears the minimum load. At this time, the motion range of elbow joint flexion is set to 0-60 °, and experiments are carried out at different speeds of ± 3rpm and ± 7rpm respectively. The root mean square equation formula of position accuracy is as follows:

$$\Delta = \frac{\sum_{0}^{n} \sqrt{Y_i^2 - Y_{\mathrm{Re}\,f}^2}}{n} \tag{9}$$

In the formula, $Y_{\mathrm{Re}\,f}$ represents the positioning target reference speed, and Y_i represents the actual speed after reaching the positioning target. The system requires a position accuracy error value of 0.50mm, and the experimental results are shown in Figure 8.

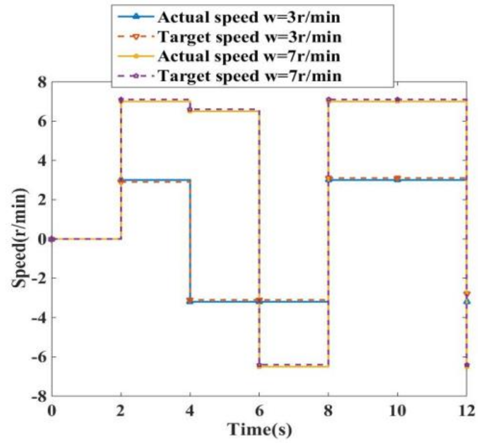

Figure 8. Analysis of the speed change of elbow joint transmission mechanism

It can be seen from Figure 8 that comparing the position accuracy at each rotation speed is within the set precision error value range, verifying that the upper limb rehabilitation robot meets the position accuracy requirements in single joint motion, that is, the upper limb rehabilitation based on the Internet of Things remote control the robot system has good dynamic performance.

VI. Conclusions

The development of technology has improved the robot technology. The development of robot technology and its combination with clinical rehabilitation medicine provide a good opportunity for the research of rehabilitation robots. This opportunity has prompted the emergence of rehabilitation robots. Rehabilitation robots can be said It is a new type of robot. It is technologically superior. It introduces advanced robot technology into rehabilitation engineering, which reflects the perfect combination of rehabilitation medicine and robot technology. It can be said that modern science and technology meet the needs of human rehabilitation The product of the combination, unfortunately, the research on the upper limb rehabilitation robot is still relatively unsatisfactory. Therefore, this paper proposes a research on the upper limb rehabilitation robot system based on the remote control of the Internet of Things.

In this paper, the upper limb rehabilitation robot system based on the Internet of Things remote control adopts the upper and lower two stations for information transmission, and realizes the control of the rehabilitation robot through the Internet of Things wireless communication technology and sensors. In order to verify the reliability of the system in this article, this article carried out a motion test and a system dynamic performance test on the system in this article.

The test results in this paper show that the passive motion accuracy of the system in this paper has reached more than 97% and the active motion accuracy has reached more than 98%. In addition, the dynamic performance test results in this paper show that the system in this paper has good motion performance. The research results of this paper show that the design of the upper limb rehabilitation robot system in this paper is feasible and effective, which will provide a certain paradigm for the study of upper limb rehabilitation robot.

References

[1] Sanja Vukićević, Zoran Stamenković, Murugesan S , et al. A New Telerehabilitation System Based on Internet of Things[J]. Facta Universitatis, 2016, 29(3):395-405.
[2] Zhang Y P , Xu X P . Design of a wearable human-computer interaction system based on bioelectrical signal recognition technology[J]. Journal of Interdisciplinary Mathematics, 2018, 21(5):1049-1054.
[3] Dobkin B H . A Rehabilitation-Internet-of-Things in the Home to Augment Motor Skills and Exercise Training[J]. Neurorehabilitation and neural repair, 2016, 31(3):217-227.
[4] Meng Q , Zhang H , Yu H . The Internet of Things-based Rehabilitation Equipment Monitoring System[J]. IOP Conference Series Materials Science and Engineering, 2018, 435(1):012015.
[5] Naranjo-Hernández David, Alejandro T B , Javier R T , et al. Smart Vest for Respiratory Rate Monitoring of COPD Patients Based on Non-Contact Capacitive Sensing[J]. Sensors, 2018, 18(7):2144-.
[6] Yao L , Sheng Q Z , Benatallah B , et al. WITS: an IoT-endowed computational framework for activity recognition in personalized smart homes[J]. Computing, 2018, 100(4):369-385.
[7] Balampanis S , Sotiriadis S , Petrakis E G M . Internet of Things Architecture for Enhanced Living Environments[J]. Cloud Computing IEEE, 2016, 3(6):28-34.
[8] Saini R , Kumar P , Kaur B , et al. Kinect sensor-based interaction monitoring system using the BLSTM neural network in healthcare[J]. International journal of machine learning and cybernetics, 2019, 10(9):2529-2540.
[9] Ipock B T . Limited patient choice within the Military Health System[J]. narrative inquiry in bioethics, 2018, 8(1):92-95.
[10] TAO Yuan-yuan, SUN Rong, SONG Lu-ping. Progress of assessment and rehabilitation therapy of cognitive impairment[J]. Chinese Journal of Contemporary Neurology & Neurosurgery, 2017, 17(5):320-327.
[11]]Lee K , Yi Y , Yu Y . Remote Control of T Cell Activation Using Magnetic Janus Particles[J]. Angewandte Chemie International Edition, 2016, 55(26):7384-7387.
[12] Achouri K , Lavigne G , Salem M A , et al. Metasurface Spatial Processor for Electromagnetic Remote Control[J]. IEEE Transactions on Antennas and Propagation, 2016, 64(5):1759-1767.
[13] Shih-Yao J , Jih-Gau J . Remote Control of a Mobile Robot for Indoor Patrol[J]. Applied Sciences, 2016, 6(3):82-.
[14] Kumar T A , Lorenzo P , Renato T , et al. Remote control of liquid crystal elastomer random laser using external stimuli[J]. Applied Physics Letters, 2018, 113(1):013701-.
[15] Zaiotti R , Martin D . Externalizing Migration Management: Europe, North America and the Spread of \"Remote Control\" Practices (Routledge Research in Place, Space and Politics)[J]. Sociological Research Online, 2016, 21(4):1-2.
[16] Kojima T , Koyama O , Maruyama H , et al. REMOTE CONTROL OF OPTICAL SWITCHES FOR WAVELENGTH PATH RELOCATION IN AWG-STAR NETWORKS[J]. International Journal of Innovative Computing Information and Control, 2017, 13(3):783-795.
[17] Patrick Sü. Remote Control: Impacts of Peripheral Tumor Necrosis Factor-Alpha on Alzheimer Disease-Related Pathology[J]. The Journal of Neuroence, 2017, 37(34):8045-8047.
[18] Cheng-Yi C , Chien-Yuan L , Chiu-Chan K , et al. Web-Based Remote Control of a Building's Electrical Power, Green Power Generation and Environmental System Using a Distributive Microcontroller[J]. Micromachines, 2017, 8(8):241-.
[19] Zhang X , Dai J , Li X , et al. sEMG-based shoulder-elbow composite motion pattern recognition and control methods for upper limb rehabilitation robot[J]. Assembly Automation, 2019, 39(3):394-400.
[20] Du Y , Li R , Li D , et al. An ankle rehabilitation robot based on 3-RRS spherical parallel mechanism[J]. Advances in Mechanical Engineering, 2017, 9(8):168781401771811.
[21] Mancisidor A , Zubizarreta A , Cabanes I , et al. Kinematical and dynamical modeling of a multipurpose upper limbs rehabilitation robot[J]. Robotics & Computer Integrated Manufacturing, 2018, 49(feb.):374-387.
[22] Shirui Pan, Ruiqi Hu, Sai-Fu Fung, Guodong Long, Jing Jiang, Chengqi Zhang (2019). Learning Graph Embedding with Adversarial Training Methods. IEEE Transactions on Cybernetics.
[23] Hong-Bing, Z., Xiao-Gui, L., Wei, W. (2019）"A Generalized Free-Matrix-Based Integral Inequality for Stability Analysis of Time-Varying Delay Systems" , *Applied Mathematics and Computation*,354, pp.1-8.
[24] S Wan, Z Gu, Q Ni. Cognitive computing and wireless communications on the edge for healthcare service robots, Computer Communications.
[25] Wang C , Wang L , Wang T , et al. Research on an Ankle Joint Auxiliary Rehabilitation Robot with a Rigid-Flexible Hybrid Drive Based on a 2-S′PS′ Mechanism[J]. Applied Bionics and Biomechanics, 2019, 2019(4):1-20.
[26] Wang B.; Liu Y.Z.; Zhang, X.H.(2019). A New Memristive Chaotic System and the Generated Random Sequence, IEICE Transactions on Fundamentals of Electronics Communications and Computer Sciences, E102A, 665-667.
[27] Nam H S , Hong N , Cho M , et al. Vision-Assisted Interactive Human-in-the-Loop Distal Upper Limb Rehabilitation Robot and its Clinical Usability Test[J]. Applied ences, 2019, 9(15):3106.
[28] Wang C , Xia J , Wei J , et al. Multi-Arm lower-limb rehabilitation robot for motor coordination training after stroke[J]. Journal of Engineering, 2019, 2019(14):478-484.
[29] Xiao, F. (2019) "Multi-Sensor Data Fusion Based on The Belief Divergence Measure of Evidences and the Belief Entropy", *Information Fusion*, 46, pp. 23-32.
[30] Zhang L , Li J , Dong M , et al. Design and Workspace Analysis of a Parallel Ankle Rehabilitation Robot (PARR)[J]. Journal of Healthcare Engineering, 2019, 2019(4):1-10.
[31] Yang T , Gao X , Gao R , et al. A Novel Activity Recognition System for Alternative Control Strategies of a Lower Limb Rehabilitation Robot[J]. Applied ences, 2019, 9(19):3986.
[32] Zou Y , Wang N , Liu K , et al. Design and analysis of movable cable-driven lower limb rehabilitation robot[J]. Huazhong Keji Daxue Xuebao, 2019, 47(1):22-26 and 38.
[33] Lv, Zhihan, Liang Qiao, and Houbing Song. "Analysis of the Security of Internet of Multimedia Things." ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)(2020).
[34] Ashit Kumar Dutta, Mohamed Elhoseny, Vandna Dahiya, K. Shankar, An efficient hierarchical clustering protocol for multihop Internet of vehicles communication, Transactions on Emerging Telecommunications Technologies, First Online 29 July 2019.
[35] Mohamed Elhoseny, K. Shankar, Optimal Bilateral Filter and Convolutional Neural Network based Denoising Method of Medical Image Measurements, Measurement, Volume 143, September 2019, pp. 125-135.
[36] K. Shankar, Mohamed Elhoseny, Trust Based Cluster Head Election of Secure Message Transmission in MANET Using Multi Secure Protocol with TDES, Journal of Universal Computer Science, 25(10) (2019), 1221-1239
[37] Lv Z, Kumar N. Software defined solutions for sensors in 6G/IoE. Comp uter Communications. 2020 Mar 1;153:42-47.
[38] Wang B.; Chen L.L.(2019). New Results on the Control for a Kind of Uncertain Chaotic Systems Based on Fuzzy Logic, Complexity, 2019, ID: 8789438.
[39] Lv, Zhihan, and Amit Kumar Singh. "Big Data Analysis of Internet of Things System." *ACM Transactions on Internet Technology (TOIT)(*2020).
[40] Lv Z, Qiao L. Deep belief network and linear perceptron based cognitive computing for collaborative robots. *Applied Soft Computing*. 2020 Apr 20:106300.
[41] Moamed Elhoseny, Abdulaziz Shehab and Xiaohui Yuan, Optimizing Robot Path in Dynamic Environments Using Genetic Algorithm and Bezier Curve, Journal of Intelligent & Fuzzy Systems, vol. 33, no. 4, pp. 2305-2316, 2017, IOS-Press