Design of the Control System for an Rehabilitative Robot

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1. Introduction

Rehabilitative robot is the combination of industrial robot and medical robot. The initial stage of research of the rehabilitation robot started at 20th century while United States, Britain and Canada were taking the lead in the world [1]. 1990 years ago, there were 56 research centers distributed within five industrial zones including North America, Commonwealth, Canada, Continental Europe, Scandinavia and Japan [2]. After 1990, the research of rehabilitation robot bumped into a comprehensive development period. At present, the research is mainly concentrated on rehabilitation manipulator, surgical robot, intelligent wheelchair, prosthetics and rehabilitation robot.

2. Framework of Control System

In this paper a control system framework including the hardware and software is developed for the rehabilitation robot. The total structure of this rehabilitative robot is shown in Figure 1, the basic function is focus on helping patients who was trying to recover from leg injuries or people who needed to exercise walking. The bottom of the robot has two conveyor belts while a cushion and an annular bracket is fixed on a column in the middle of the robot. Users need to sit on the seat cushion with each foot trampled on a conveyor belt where the annular bracket is just enable to set at the waist.

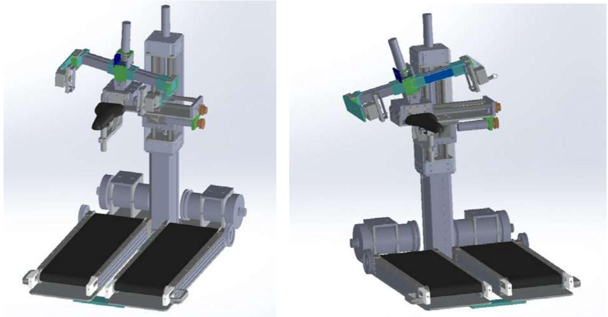

Fig. 1. The total structure of this rehabilitative robot

As shown in Figure 2, three motors is installed on the upper part of the robot that can realize the movement in the vertical direction, horizontal direction and rotation around vertical axis respectively. When a user is sitting on the cushion, the motor which controls the movement in the vertical direction will hold up (s)he so that the user can stand firmly on a conveyor belt even if (s)he has no strength to stand. There are two electric motors equipped at the bottom of the robot to control the conveyor belt respectively. When a user is try to walk, s(he) needs to set the speed of the conveyor belt firstly and then the conveyor belt will accelerate to that speed slowly to assist the user in walking training.

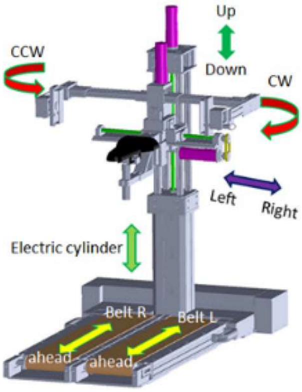

Fig. 2. Rehabilitative robot's DOF

An array of pressure sensors was mounted at the bottom of the conveyor belt which are able to read the positions and gestures of the user's feet. When the user is about to fall in the process of walking, the horizontal moving joint and vertical rotary joint of the robot can achieve a mutual cooperation while the bottom of the conveyor belt will also speed up or slow down correspondingly to make a calculation of the body's center of gravity and the total feet position in the real-time.

3. Hardware

As shown in Figure 3, the STM32F407 model of ARM chip and EP4CE10F17C8N FPGA chip are the heart of the hardware structure of the system. STM32F407 uses SPI interface as well as the network communication protocol chip W5500 to realize the network communication and interaction with external server or cloud. It also realizes data exchange from FPGA's registers using the FMSC interface [3]. What's more, it can also drive up to three motors through CAN interface. Three joints information of the upper part on the robot can be collected using analog to digital converter.

The FPGA system mainly realizes signal acquisition from complex sensors as well as large data processing and complex algorithm operation in the real-time. Through the realization of soft module of SPI, the FPGA can collect the pressure data from 4*84*84 grid sensors. The pose of the human's feet on the conveyor belt is recorded by the grid pressure sensors. After data processing, the user's information and current status including the center of gravity, the pose of feet and contacting force between human and robot's joints can be obtained. The three joints of the robot is equipped with a force sensor, which can detect the collision moment with the waist of the human body after the analog to digital conversion.

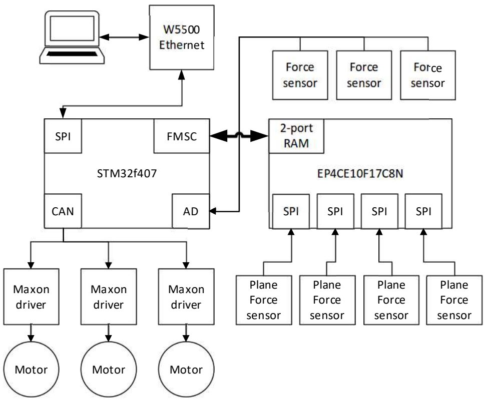

Fig. 3. Hardware of the controller for the robot

4. Software Framework

In this system, software architecture of ARM is shown in Figure 4 which is running the μc/OS II real-time system.

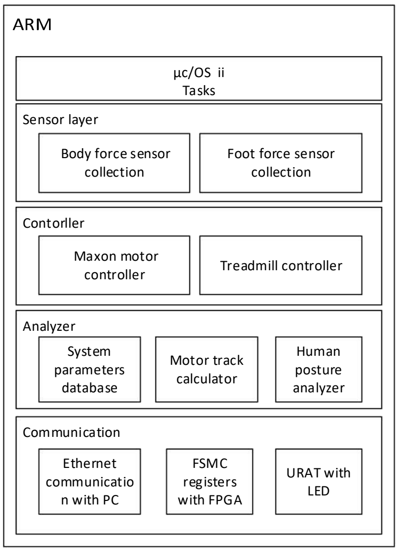

Fig. 4. Software architecture of ARM

The sensor layer has a body force sensor collector to form an analog to digital conversion interface in order to acquire joint sensing information as well as the array of sensing information through FMSC interface on a shared memory between FPGA and STM32.

The controller layer runs MAXON motor controller and Treadmill controller to control the speed, position of the joint and conveyor's speed.

Analysis layer runs totally three sub tasks, one of which is the system parameters database held responsible for saving the user specified data. Motor track calculator is used to generate the S-shape speed curve trajectory by acquiring the current position of the motor and control motor speed through CAN in real-time. Human posture analyzer combines user's feet information each joint angles and force sensing information to analyze periodic state in whole human's walking period.

The communication layer is used to make high speed communications to host computer through Ethernet communication sub-task to acquire the body's pose and each module's status in the real-time. FSMC registers sub-task builds a shared memory buffer to establish communication between STM32 and FPGA through a strict fault-tolerant mechanisms.

Software architecture of FPGA is shown in Figure 5 including three main modules: communication module, sensor module and algorithm module.

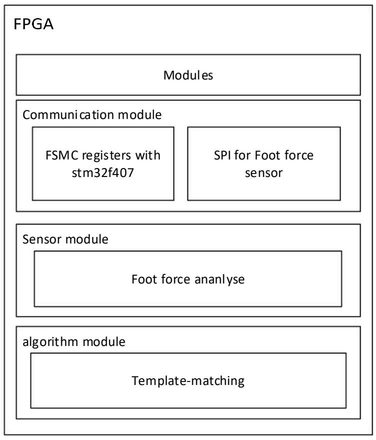

Fig. 5. Software architecture of FPGA

SPI for Foot force sensor gets the user's feet info through the SPI interface which is then processed by Kalman filter after into the Sensor module layer.

5. Acknowledgement

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6. References

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