Computers and Electrical Engineering 000 (2016) 1–12

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

The design and implementation of a motor drive for foot rehabilitation

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ARTICLE INFO

Article history:
Received 11 July 2016
Revised 30 July 2016
Accepted 30 July 2016
Available online xxx

Keywords:
Microcontroller
Brushless dc motor
PID control
User interface

ABSTRACT

The aim of this paper is to present the design and implementation of an electric foot rehabilitation machine that uses an advanced RISC (reduced instruction set computer) machine (ARM) microcontroller based brushless dc (BLDC) motor drive. The function of the electric foot rehabilitation machine is to help patients who need physical therapy for a foot. The goal is for patients to have increased muscle strength after rehabilitation. The system hardware and software are designed and programmed. The proportion, integration and derivation (PID) control algorithm is employed to the motor drive for the speed and torque control. A user interface is also developed and implemented to provide a user-friendly experience. Finally, a prototype of the foot rehabilitation machine is built and tested. The experimental results demonstrate the feasibility and integrity of the complete system.
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1. Introduction

World demographics have changed dramatically over the past few decades. There are around 600 million people aged 60 years and over. This will double by 2025 and will reach about two billion by 2050 [1]. Population aging has major consequences for all facets of human life and has an especially profound impact on health and health-care [1]. Elderly people are more likely to experience strokes. This usually causes neurological impairment and results in hemiparesis or partial paralysis of the body. This then affects the patient's ability to perform activities in their daily lives such as walking and eating. Physical therapy with rehabilitation equipment can help improve the damaged functions [2].

Stroke is the leading cause of permanent disability in the USA and Europe [3]. Thus, rehabilitation therapy after a stroke is of great importance. Intensive therapy with rehabilitation equipment can help motor-impaired patients recover motor function and mobility. For example, intensive therapy using a gait trainer and floor walking exercises effectively improves the locomotion of lower limb patients in [4]. Using robotic stationary systems can help patients improve their strength and endurance [5]. In order to provide paraplegics with locomotion, a device, such as a four-wheeled cycling vehicle that incorporates an electric motor to assist or retard the cycling motion and to provide speed and direction controls, is used to exercise the subjects [6]. An exercise tricycle, which has a power-assisted motor in the front of wheel to help paraplegics exercise their leg muscles, is addressed in [7]. Many cycling devices for paraplegics are assisted by electric motors in case the muscle force of the patient is not sufficient [6–9].

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http://dx.doi.org/10.1016/j.compeleceng.2016.07.017
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Please cite this article as: T.-Y. Ho et al., The design and implementation of a motor drive for foot rehabilitation, Computers and Electrical Engineering (2016), http://dx.doi.org/10.1016/j.compeleceng.2016.07.017

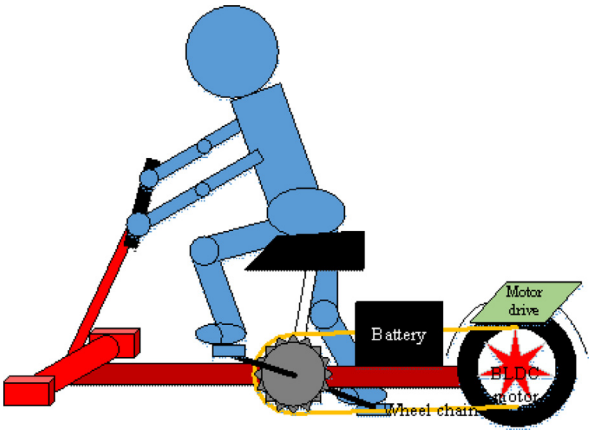

Fig. 1. Mechanical structure of the foot rehabilitation system.

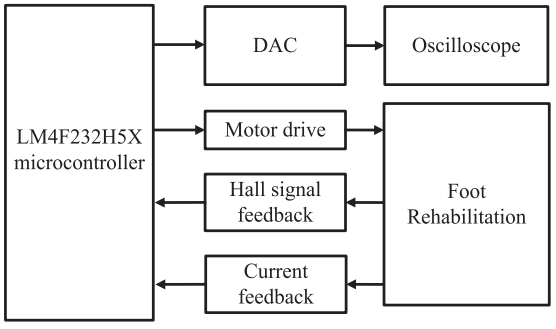

Fig. 2. Hardware structure of the foot rehabilitation system.

Rehabilitation therapies aided by rehabilitation equipment can not only speed up the rehabilitation therapy process but also reduce related healthcare costs. Most rehabilitation equipment requires the electric motor to provide accurate relative motion. Consequently, the design and implementation of motor drive becomes a very important issue in the fabrication of rehabilitation equipment. This paper focuses on the design of a motor drive for a foot rehabilitation device. Using the contribution of this paper, the researcher and engineers can improve the research and development and reduce the development time of motor-assisted rehabilitation devices.

This paper is organized as follows. The importance of rehabilitation equipment is introduced in Section 1. In Section 2, the system hardware structure of the foot rehabilitation is described. The software of rehabilitation equipment is presented in Section 3. In Section 4, the experimental results are illustrated and discussed. Finally, the conclusion is presented in Section 5.

2. System structure description

2.1. System hardware description

The mechanical structure of the foot rehabilitation equipment designed in this paper is very similar to that of an electric motorcycle, as illustrated in Fig. 1. The patient sits on the saddle and puts their feet on both pedals. The pedal straps are used to keep the feet from slipping out while the pedals rotate. A wheel chain connects the pedal and the BLDC motor so that power can be transferred and controlled by the motor drive. Therefore, proper control of the motor drive can make the feet move forward or backward, thereby achieving the effects of rehabilitation therapy. The hardware structure of the foot rehabilitation system designed and implemented in this paper includes an ARM microcontroller, a motor drive, a BLDC motor, Hall position sensors, current sensors, and an analog-to-digital converter, as shown in Fig. 2. The ARM microcontroller sends three-phase pulse width modulation (PWM) signals to the motor drive to control the BLDC motor; this causes the foot to step forward or backward [10]. The ARM LM4F232H5X microcontroller [11] manufactured by Texas Instruments is the core controller of the foot rehabilitation system. It has a 32-bit Cortex-M4 CPU with digital signal processing capability. Moreover, it includes many powerful modules such as a built-in PWM module, an addressable encoder interface module, and an input capture module. These modules make the design process friendly and thus shorten the development schedule. The three-phase bridge inverter comprises six power MOSFETs for switching. The motor currents are sensed through the

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