Proceedings of the Sixth International Conference on Research in Intelligent and Computing pp. 33–37
DOI: 10.15439/2021R01
ISSN 2300-5963 ACSIS, Vol. 27

Ankle joint rehabilitation system—the preliminary results

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***Abstract*—Ankle joint injury is often caused due to sport activities or accidents. This makes it difficult for the daily life. Therefore, the rehabilitation of ankle joint plays an essential role, which helps patients to enhance their life qualities. Practicing physical therapy is an effective approach to aid the patients recover from injury. Currently, not only are the conventional physiotherapy methods used, but the application of hi-tech advancements, especially robots in physiotherapy, is increasingly ubiquitous and creates possible and optimistic results. This paper concentrates on the building of a supportive system for the low-cost physiotherapy and manipulating other devices by physical buttons. A mobile application programmed for smartphone displays the pieces of system information, which brings convenience to users. On the other hand, application is also connected to Bluetooth as showing the angle of device and controlling it with an intentional angle. The preliminary results of system consist of a model and a mobile smartphone application presented in this article. The proposed system operates exactly as design, this is promising for application with clinical trials on patients in the following studies.**

***Index Terms*—Ankle-joint, rehabilitation, mobile-app, physical training.**

I. Introduction

ANKLES are the important component in human movements, they act as the essential part in daily-living activities such as walking, standing, and running. Due to joint osteoarthritis, sports activities or accidents, the damage in ankle joint occurred frequently. For instance, a survey was carried out with 70 different sports from 38 countries and 201,600 patients in total. The final statistics has indicated that ankle has been the most injured site. It accounts for 34.3% that is equivalent to 24 sports and 32,509 ankle injuries [1]. When the ankle is injured, it will cause difficulties in daily life activities such as falling, limping and this depends on the severity of the injury.

It is considered to be two common treatments that would be applied for the ankle joint treatment. The first one is the total ankle replacement (TAR) surgery. This is an invasive solution which is appropriate to older patients low demands, and multiple joint osteoarthritis or inflammatory arthropathy [2]. For the minor traumas, surgery is not the most optimal and effective solution. At this moment, physiotherapy will be an alternative plan. It is mentioned to be a non-invasive treatment and safe for both the young and the old, even patients are in recovering period after TAR surgery. With the ongoing progression of the modern medical field, there are also combinations of medical devices, in addition to traditional exercises. Some traditional physical exercise methods such as flexion-extension feet movement. This treatment uses an elastic band to create resistance around the soles of the feet and pull hands to hold the ends. In opposite the backs of legs, there is a band restores resistance around the ankles and instep of the foot with both ends of the strip securely attached to the floor or wall. In addition, the training could be stepping on a platform, stepping, heel walking, ankle swivel, folding and stretching of the foot [3, 4].

Nowadays, the application of robotics or supportive systems in physiotherapy offers several advantages. There are two types of robots used in ankle therapy are Plat-form based ankle rehabilitation robots and Wearable ankle rehabilitation robots [5]. Platform based ankle rehabilitation devices have a fixed platform and thus cannot be used during gait training [6]. Parallel mechanisms are typically used for multiple degrees of freedom (DOF) systems to diminish the size of robots. Wearable robots known as exoskeleton robots or as powered orthoses are being developed in contrast to Platform based rehabilitation robots [7, 8], robots mainly referred to wearable anklebot and AFOs. The AFO (Ankle-Foot Orthosis) is a single-joint orthosis designed to assist and support movements of the ankle joint. It plays an important role during human walking [5]. The application of robots in treatment helps patients to monitor their health, propose a specific exercise plan. Moreover, exercising along with robots also contributes to control the correct movements of the patient, which minimizes the subjective errors and improves the quality of recovery treatment.

For the low-income country like in Vietnam, these systems are not affordable since the investigate cost is still high. Owning an individual device becomes hard to be possible. Moreover, going to training officials takes much time and is inflexible. The need of a low-cost supportive system for ankle rehabilitation is high. The research of a team in Pham Van Dong University has proposed a device for rehabilitating ankle joints using a linear actuator [9]. However, the model did not included the software or a mobile-app to make it easy for user.

From these cornerstones have been mentioned above, our team has studied, de-signed and built an application on smartphone what is intended to the ankle joint physiotherapy equipment. With this topic, the proposed system could be used to assist the injured people to have a flexible and easily controlled training device. The system was designed with the mobile application, which can reduce the existence of therapist to control the device.

This paper comprises of the following section: the brief information on ankle joint is described in the Section 2; Section 3 presents the design of the system; the preliminary results of the system operation are shown in the Section 4.

II. Method

A. Ankle joint structure

The anatomy of ankle joint is a fair complication due to its connection among bones, muscles, ligaments, tendons, nerves, blood vessels and with foot, limb. Fundamentally, It is a complex of the tibia, the fibula and the Talus at the tibiotalar joint [10, 11]. There are about 20 muscles in the foot and they are classified as intrinsic or extrinsic. The gastrocnemius or calf muscle is the largest one in all of them and aids with movement of the foot [10, 11]. Ligaments are the soft tissues that attach bones to bones. Ligaments are very similar to tendons. The difference is that tendons attach muscles to bones [10, 11]. There are also several nerves such as the superficial and deep peroneal, sural, saphenous, tibial, medial and lateral plantar, me-dial and inferior calcaneal, common digital, and medial proper plantar digital nerves [12]. They stretch and intertwine with bones, muscles, tendons, and ligaments.

Generally, the ankle joint allows the foot to move in six different ways: dorsiflex-ion (DF), plantarflexion (FP), inversion, eversion, and medial and lateral rotation [10]. Within the research scope of this topic merely focuses on two movements that are dorsiflexion and plantarflexion. Two motions are greatly common when people walk or run.

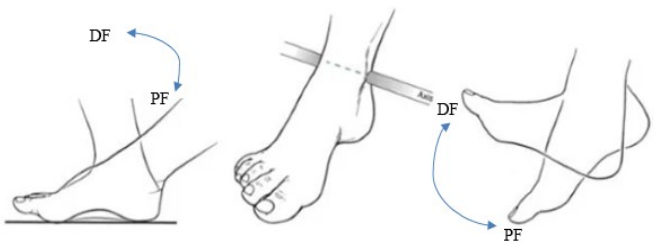


Fig. 1. Dorsiflexion (DF) and Plantarflexion (FP).

B. The ankle joint range of motion

The ankle range of motion is proved to be diverse dramatically amid individuals. Some reasons are considered like geographical region, cultural activities of daily living, or even ancestral origins. Motion of the ankle is primarily examined in the sagittal plane, with plantarflexion and dorsiflexion at the tibiotalar joint [13]. The overall ROM in the ankle joint can be shown in the Table I. Normally, dorsiflexion and plantarflexion are examined at the sagittal plane. Inversion and eversion are at frontal plane.

TABLE I. The Typical Range Of Ankle Joint Motion

	Range of ankle joint motion	
	Sagittal plane	***Frontal plane***
Dorsiflexion	0 to 30°	None
Plantarflexion	0 to 55°	None
Iversion	None	0 to 23°
Eversion	None	0 to 12°

III. System Description

A. The block diagram

The block diagram of system is illustrated throughout the Fig. 2.

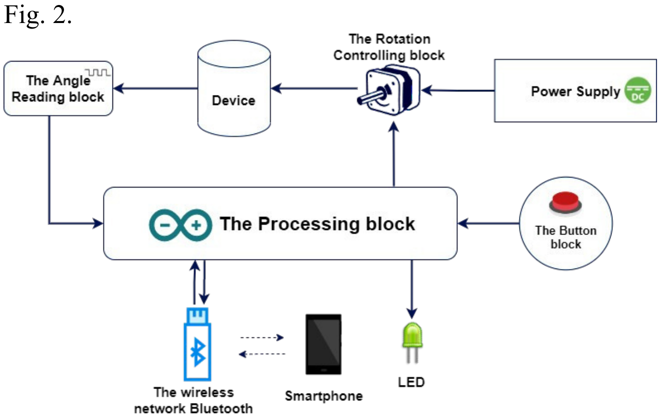


Fig. 2. The block diagram of the system.

As shown in the figure, the dash line stands for the wireless connections and the solid line represent the wired connections. Diagram includes as the following blocks and their functions respectively:

- The Processing block: KIT Arduino Mega 2560 is used to program and control all of actions in system. Arduino receives signals from the Button block, the Angle Reading block and module Bluetooth. After processing these signals, microcontroller outputs signals for controlling action of the Rotation Control-ling block and lightening LED. Furthermore, Arduino also supplies power to the Angle Reading block and module Bluetooth HC-05.
- Power Supply: A power source has 24V/5A output supplying energy for the Rotation Controlling block.
- The Rotation Controlling block: the main part of block is a 2-phase stepper motor whose rate is 57/11 (~5/1). This motor is wired directly with Micro-step driver TB6600 to run the rotational direction as well as speed of device. TB6600 is powered by the Power Supply.
- The Button block and LED: There are two pushbuttons. One is used to activate ON or OFF state of stepper motor. Each state is alarmed by LED. The other button drives device rotate as Sine wave.
- The Angle Reading block: A Rotary Encoder with 600 pulse per revolution comprises two outputs A and B producing pulses. Output signals are passed to the Processing block to calculate the angle of device.

- The wireless network Bluetooth: Module BLE HC-05 sends data from the Processing block to smartphone and vice versa. Module interacts with the Processing block via UART protocol.
- A mobile app that is programmed by MIT app inventor will be paired with module HC-05 by its address before showing data on screen.

B. Control diagram

Devices and peripherals interact with Arduino are shown in the Fig. 3.

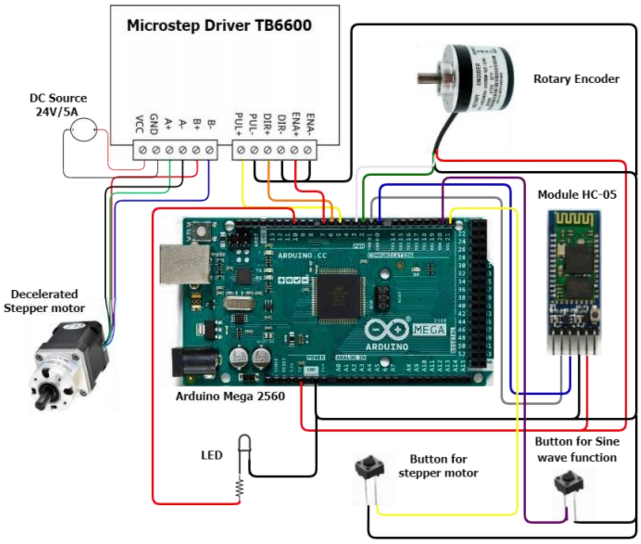


Fig. 3. The hardware connection diagram beween KITArduino Mega 2560 and other devices, peripherals.

Arduino charges 5V power to module HC-05 and Rotary Encoder. TX and RX pin of module are wired respectively with RX pin (pin 0 on Arduino) and TX pin (pin 1). Pin 2 on MCU is connected to phase A while pin 3 is linked with phase B of Encoder. Port VCC of TB6600 receives energy source 24V/5A. Four other ports A +, A-, B + and B- will be connected to the stepper motor pins respectively. PUL-, DIR- and ENA- are generally grounded to the Arduino. Pin 5, 6, 7 are connected to PUL +, DIR +, ENA + of the TB6600 driver respectively. The signal LED is connected to pin 10 through a 300Ohm resistor. The two buttons respectively control are connected to pin 20 and 21 of Arduino.

C. Algorithm flowchart

Main program of the proposed system is presented as in an algorithm flowchart in Fig. 4. On condition that Arduino detects data are send from module Bluetooth, it will process them and then go back to check data. On the other hand, Arduino does not detect any data from module Bluetooth, it will be in the following order: calculating angle, controlling motor direction, controlling motor rotation, controlling automatic motor rotation, checking motor button state and checking sine wave button state. After all of these steps, Arduino will go back to check data.

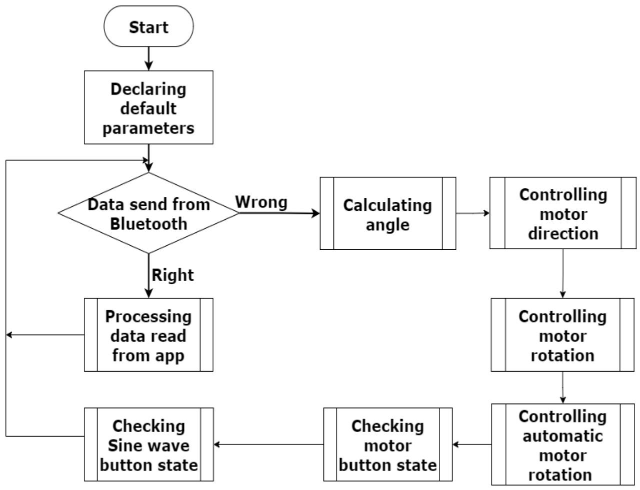


Fig. 4. Algorithm flowchart of the main programme.

D. System working principle

Two main activities of this device are lifting and lowering movement as in Fig. 6a and Fig. 6b. These movements could be caused from foot or the stepper motor.

At beginning, keep device at an equal position (Fig. 5c). Phase A and B produce no pulses so the default angle is 0 degree. There are two solutions to control this sys-tem.

The first solution is the mechanical impact from foot. At any time device is lifted or lowered, axis of Encoder will rotate and produce pulses at phase A and B output. They are transmitted to Arduino for figuring the current angle of device. Because revolution of Encoder is 600 BM, this means that there are 600 pulses created after Encoder axis has completed a 360 degree rotation.

The second solution is the interaction between stepper motor and device. First of all, it is necessary to push button (physical button or mobile app button). Arduino gets signals, activates the "ON" state of motor and makes LED bright. Signals will be transmitted to MCU by TX pin of module on condition that button is pressed on app.

Next, it is compulsory to fill any angle and press "ENTER" button on the application. This data is sent to the microcontroller via Bluetooth network. Arduino will control the device to rotate with the deliberate angle via the stepper motor.

Rotating automatically as Sine wave is an additional function. Modifying device at the balancing position is requisite. Arduino will control device to rotate automatically after button has pressed (physical button or mobile app button).

Concurrently, Encoder detects the modifications of angle while device rotates. Phase A and B transmit pulses at the output to Arduino for conducting the calculation. Final result which is the current angle is updated on mobile app. During the rotating process, if the button (mechanical button or button on the app is pressed), signal is sent back to Arduino to stop the stepper motor immediately.

IV. Results

A. *Hardware*

Below pictures illustrate for the completed model. It is made up and laser cut from iron materials. Rotary Encoder and Stepper motor are attached as in Fig. 5. Pedal is located at the top center position for up and down moving. The weight of the system is about 5 kilograms.

Detail expenditures of components in the system are listed in the TABLE II. In general, the total estimated cost of the system is about 130 USD.

TABLE II. ESTIMATED COST OF THE SYSTEM COMPONENTS

Component	**Quantity**	**Price (USD)**
Rotary Encoder	1	11
Stepper motor	1	34
Microstep Driver	1	5
Module Bluetooth HC-05	1	5
Arduino Mega	1	10
Laser cutting		65
Total price		**130**

a) Device on the side b) Device from above

c) Device at balancing position

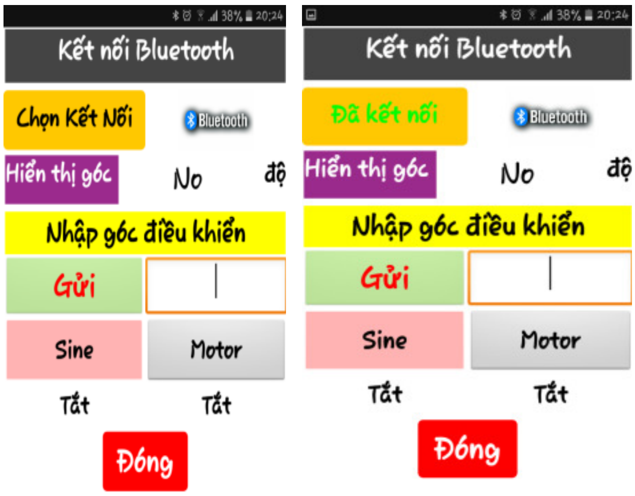
Fig. 5. Some pictures of the device

a) Pedal is lifted. b) Pedal is lowered.

Fig. 6. Device illustrates up and down moving

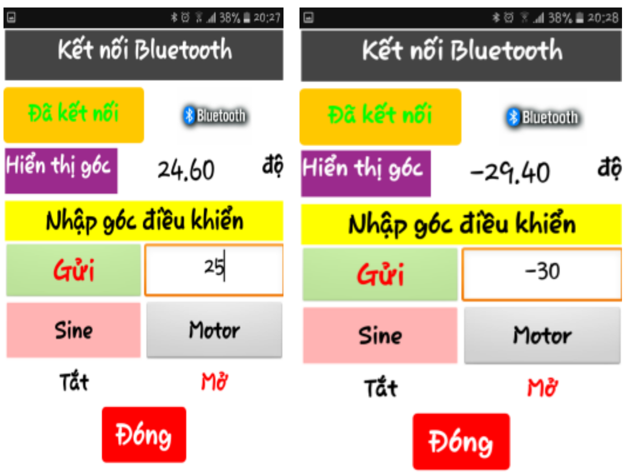
B. *Mobile app*

Outcomes of the mobile application are shown below. The very first GUI of app is exact as Fig. 7.



a) App is open. b) App is connected to Blue-tooth.

Fig. 7. The original interface of mobile application.



a) Current angle at 24.60 degree. b) Current angle at -29.40 degree.

Fig. 8. Result of current angle is updated on mobile application.

From the results through many test runs, in general, the system calculates and dis-plays the device's rotation angle, controls the device with the mechanical push button, and controls arbitrarily angle by smartphone.

The system at the moment still consists of some limitations. First, the difference between the read angle from Encoder and the angle to be rotated is still large and unstable. This originates from the arranging functions in the main program as well as the order of statements. It would be better to alter the algorithm more logically.

Second, the synchronizing between the state of the physical button and of the button on the application is still slow and sometimes crashes. Its key reason is the exchange data between Arduino and module HC-05 as well as mobile app and Blue-tooth network. This could be overcome by modifying the synchronizing algorithm.

V. Conclusion

System has been operated by impacts from foot or buttons. A mobile application on smartphone is an useful combination for controlling system and monitoring information of it. This deserves to be a considerable choice for the ankle joint training with an affordable expenditure. The proposed system operates exactly as design. This brings a promise for application with clinical trials on patients in the following studies.

Acknowledgment

This work belongs to the project grant No: T2021-60TĐ funded by Ho Chi Minh City University of Technology and Education, Vietnam. Sincerely thanks to the Department of Electrical Engineering of Faculty of Electrical and Electronics Engineering at Ho Chi Minh City University of Technology and Education for supporting the research during the study period.

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