Design and Implementation of Intelligent Crutches for Medical Applications

Rajesh Kannan Megalingam, Greeshma MG and Soumya S Pillai

***Abstract*—Intelligent crutches will be a breakthrough in the medical field for the patients undergoing therapy due to various ailments and accidents. In this paper we present a forearm crutch with sensor technology to monitor the proper usage of the crutch by these patients. The correct usage of the crutch will improve the recovery rate of the patients. So it is very necessary to monitor the usage of the crutch during the rehabilitation period. In this design only two external sensors are incorporated to avoid the complexity of using many sensors or optical motion capturing system or cameras etc. A force sensitive resistor (FSR) is used to measure the amount of force applied to the crutch and an accelerometer is used for determining the speed of movement of the patient. Based on the medical experts report the percentage of weight that a person can apply to the crutch is predetermined and is used as the reference value. The controller can check whether the applied weight is greater than the reference value and can take decision to warn the patient about the misuse of the crutch via speakers.**

***Index Terms*—Crutches, force monitor, speed monitor, forearm crutch, rehabilitation**

I. Introduction

IN our day to day life there are many situations where people are suffering from physical challenges because of some kind of accidents they are recently met with. In this scenario they undergo some kind of rehabilitation treatments for their recovery. Crutches are one among the most important rehabilitation devices. Correct the usage of crutch faster will be the recovery rate. Improper usage of the crutch may lead to secondary issues such as bilateral radial nerve compression, crutch palsy, catching tip and falling, joint or muscle pain. Bruised ribs, hand or wrist injury, artery damage, atrophy for lower body parts etc. So it is very necessary to monitor the usage of the crutch. Crutches are of mainly three types, auxiliary crutch, elbow crutch (forearm crutch) and gutter crutch. In this research, we are dealing with a forearm crutch. A forearm crutch with sensor technology is developed to balance the body weight and speed of motion of the patient. To avoid the complexity of the design only two external sensors are incorporated. For this purpose an FSR and an accelerometer are incorporated. The sensors used measure the respective parameters of force and speed. The sensor data is collected and is compared with preset values that have been setreferring to medical reports. Whenever the patient exceeds the reference value of force and speed he/she will be notified by the system via the headsets provided. This will be a better way of rehabilitation since the users can monitor their exercises and can improve by themselves. The rest of this paper Section II is describes the Motivation.Section III is briefly explained the Literature review. Methodology is explained in the Section IV. Results are discussed the Section V. Concludes the paper in Section VI. Future work gives the the Section VII.

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II. Motivation

In most of the cases people are facing extended rehabilitation periods mainly because of their improper usage of the crutch. Studies show that proper usage of the crutch can improve the recovery rate. So it is very necessary to guide the users about the use of the crutch in the early stage itself. As a social being it is our duty to help our co beings. With this fact in mind we are developing the intelligent crutches that can monitor the usage of the crutch by the users and help them to self-monitor their exercise. We are happy to dedicate this work to our society.

III. Literature Review

Instrumented crutches incorporate a vibratory feedback to notify the user whenever the applied weight on the crutch exceeds the safe limit, so that the user can apply the proper amount of weight among the limbs, avoiding the risk of secondary injuries[1]. Health care monitoring systems incorporate sensor technology to measure the health care parameters during rehabilitation such as force and speed of motion of the crutch[2]. Smart crutches are actually instrumented crutch system that uses a motion capture system and force plates for its calibration. The device can measure the weight that the patient applies on his lower extremities and provides a vibration feedback in response to the measured weight[3]. Measurement of the crutch parameters such as force and motion requires several external sensors such as a motion capturing system which includes a lot of cameras and a computer. This is a great deal of effort, so the authors developed a crutch that can measure the angle and angular

978-1-5386-7595-3/19/$31.00 ©2019 IEEE

velocities of the crutch as well as the pressure and acceleration of the user based on internal sensors embedded in a crutch[4]. Instrumented crutches with strain-gauge bridges, communication interface and tri-axial accelerometer can measure the axial forces and shear forces, tilt angles, and time of impact on the ground in real time[5].

Movement of the patient can be easily analyzed by measuring the tilt angle of the crutch. A gyroscope can be used for this purpose [6]. Portable kinetic systems are used to directly measure the true load applied on the crutch during assisted walking and the information about the measured parameters is derived from the raw loading of data [7]. Telescopic crutches are able to provide a standing posture. on even or uneven ground [8]. Virtual prototyping is a cost-effective way of improving the crutch design [9]. Hands free dynamic walking experience can be obtained by incorporating feedback design [10]. Incorrect usage of the crutch leads to an extended recovery period. So it is very necessary to monitor the usage of the crutch [11].

If the system is incorporated with graphical interface the collected usage data can be easily converted to graphical plots and can be analyzed by the therapist [12]. Visualization and adulation of the collected data after comparison with the safe limit will be good for allowing the user with self-monitoring freedom [13]. Interfacing with mobile apps will be even better to have a better user friendly experience. In this a communication interface such as Bluetooth module can be incorporated [14]. Specially designed crutches that incorporate telemetry systems along with infrared sensors for measuring force, multiple receivers and an intelligent summing unit will allow the user to walk freely in a large room and staircases as well. Different channels of collecting data are presented on a pc monitor [15-17].

IV. Methodology

The design of the proposed crutch is done on the basis of acceleration and force exerted by the patient. The design mainly focuses on reducing the period of rehabilitation time for the patient. Measuring acceleration is a key to control the speed of movements. Also force exerted by the patient or the user has to be controlled. Accelerometer and FSR are used to measure the design parameters like acceleration, force. The crutch is designed in such a way that the user can correct his movements without any external guidance. So the crutch is said to be totally user friendly. This crutch can be used by a patient who is guided by a physiotherapist or a doctor. It is also useful for a person who has some visual impairment.

When the crutch is activated with a power supply it starts detecting the force of the crutch and speed of its movement. As per the results of experiments that we have done maximum and minimum force a person can exert on a crutch varies. Whenever a person walks using this crutch, it will check whether the user is moving correctly or not. An audible feedback will be given if the force applied or the speed of his movement exceeds the possible limits. The system architecture of intelligent crutches is shown in Fig. 1. It includes an FSR, accelerometer, controlling unit, communication interface, and feedback.

A. *System Architecture*

i. *The control unit*

The controller used here is Arduino Uno. It is powered with a 5v supply. The controller is the one that collects the sensor data and compares it with the reference value and gives the respective audio output.

ii. *Force sensor*

The force sensor used in this design is the force sensitive resistor that can measure the applied force. One end of the FSR is connected to the 5v pin of the Arduino and the other end is connected to A0 pin and to the ground via a 10K resistor to the Arduino. If we connect the Arduino to the PC and upload the Arduino-FSR interfacing code we can see the FSR reading on the serial monitor.

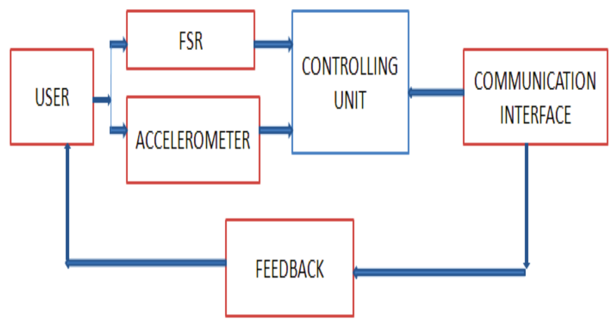

Fig. 1. System architecture of intelligent crutches

iii. *Accelerometer*

The accelerometer (ADXL 3xx) has three inputs X, Y, Z to measure the motion in the three axes X, Y, Z. The X pin of the accelerometer is connected to pin A3 of the Arduino. Similarly the Y, Z pins of the accelerometer is connected to pin A2 and A1 of the Arduino respectively. ST pin to A0,Vcc to A5 and ground of the ADXL to A4 of the Arduino. Again if we connect the Arduino to the PC and upload the Arduino-accelerometer interfacing code we can see the ADXL reading on the serial monitor. The headsets are connected to the D3 pin of the Arduino and to the ground pin. This designing is done in such a way that crutch is made totally user friendly. Controlling unit is designed to produce an audible feedback to the user whenever force exerted by the user exceeds the offset. The offset is different each and every person (here offset means constant force that can be applied by a person who has injured in the legs). The FSR measures the force applied by the user on the crutch. The accelerometer measures the acceleration of the crutch. Both parameters are at every instant of time so that the user can correct the crutch walks himself. The detailed description of the system is represented in the flow chart in Fig. 2. One can easily understand the various processes in the design.

B. Flow chart

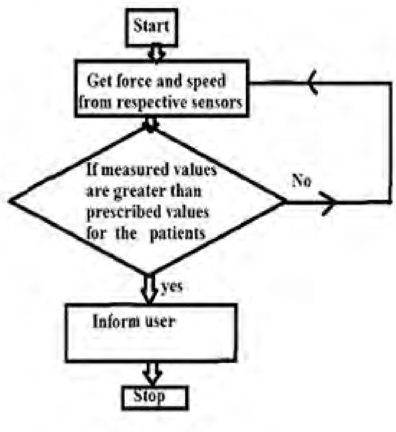

Fig. 2. Flowchart of the control system.

The flow chart itself describes the working of our design. The safe limit of force that a person under rehabilitation can apply on the crutch and speed with which the person can move with the crutch is calculated based on the reference from medical reports. These values are stored in the controller. The next step is to measure the amount of force the person applies on the crutch and his/her speed of motion. This is achieved by means of the sensors (FSR and accelerometer). The measured values are then compared with the safe limit values that have been already set. If any of the measured parameter exceeds the safe limit, the user is informed via the head sets provided to him. The user will be informed as "Balance Your Weight" in case if the applied force exceeds the safe limit and "Slow" in case if the speed of motion exceeds the safe limit. If the measured parameters are within the safe limit the user can continue his exercise as well. The same result was analyzed true by the 10 different users. The users were able to hear the audio notification via the head sets provides to them. The main features of Intelligent crutches are low power consumption, the possibility of self-monitoring, economical, reduces strain of the patient, light weight, user friendly, useful for the people having different weights.

V. RESULTS

The After finishing the design and calibrating the sensors the device is tested on 10 people who have varying weights of around 5 kg. The minimum weight of the person is selected as 45 kg, and the person with maximum weight is selected as 90 kg. Obviously the force that can be applied by the maximum weight person will not be same as that of the person with minimum weight. The force exerted by these people on the crutch versus their acceleration is plotted in Matlab. The person with maximum weight can apply only the least safe limit of force and speed. The person with minimum weight can have the maximum allowed safe limit of force and speed. Arduino coding is done to collect the sensor data and to compare it with the reference values. After completing the proper connections and uploading the code to the controller the design is tested for its correct working and the test passed successfully. In the hardware design headsets are incorporated for the audio output and also to make the design user friendly. The crutch is then tested with 10 people having different weights. The safe limits of force and acceleration that each person can apply is calculated experimentally and is listed in the Table I.

TABLE I
EXPERIMENTAL RESULT OF CRUTCH WALK MADE BY 10 DIFFERENT PERSONS.

Participant	Acceleration (m/s)	Actual Weight (Kg/s)	Max. Applicable Force (g/m)
1	3.49	40	372.78
2	3.34	43	400.74
3	3.27	49	456.65
4	2.52	53	493.93
5	2.29	55	512.57
6	2.23	62	577.81
7	2.21	65	605.77
8	1.98	69	643.05
9	1.67	72	671.004
10	1.56	75	698.96

Fig. 3 shows the variation of force in accordance with acceleration for different persons. As the actual weight of person increases the crutch force can be controlled by adjusting the acceleration. From the plot it can be seen that the argument is true. The allowable force for 10 different people having different weights is not the same.

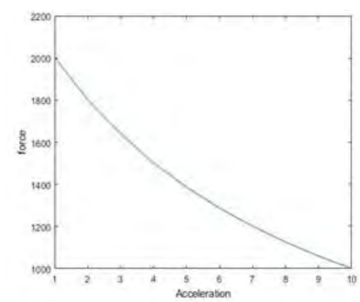

Fig. 3. Force versus acceleration for 10 people having linearly varying weights.

The users were able to hear the audio notifications when they exceeded the parameters safe limit. Fig. 4 shows the final setup of the intelligent crutch. An accelerometer and a force sensor are used which is controlled by Arduino Uno.

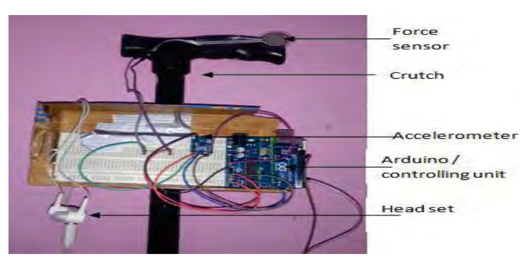

Fig. 4. Intelligent crutch setup

The controller is programmed in such a way that it analyses each crutch movement it gives an audio feedback to the user whenever he exceeds the safe limit. In such a way the crutch is made user friendly.

VI. CONCLUSION

In this research, a forearm crutch with sensor technology is developed to monitor the correct usage of the crutch. The user will be notified about the incorrect usage of the crutch via the audio system (speakers) provided along with the crutch. The crutch is user friendly and economical. Intelligent crutch is developed using external sensors. It eliminates the complexity of using internal and external sensors. It makes use of a force sensor and an accelerometer to measure the respective parameters.The design is for balancing the walk on the basis of weight exerted on the crutch and speed of movement of the patient using the crutch. The collected data are compared with the reference values and the user is notified whenever the patient exceeds the preset limit. The main advantages of the design include low power consumption, the possibility of self monitoring, economical, reduces strain of the patient, light weight.As a conclusion of this paper, we have confirmed that the developed system can measure and adulate the motion of a crutch based on only external sensors embedded with the crutch.

VII. FUTURE SCOPE

In this work, the Intelligent crutches are developed for normal people. But the design can be extended to blind people by incorporating an ultrasound sensor or IR sensor to measure the distance between the patient and the obstacle. In this case one more audio notification should be provided to the user about the obstacles in his way to avoid possible accidents. One more possibility is to send the usage data to doctors so that the patient can improve his rehabilitation exercise under his doctor's guidance. In this approach a memory module and a communication module should be incorporated with the crutch, so that after the usage of the crutch for the day the user can send his usage statistics to his doctor and the doctor can guide him throughout his rehabilitation period.In this research we are considering the forearm crutch. The same design is possible for every type of crutches such as canes, auxiliary crutch, and gutter crutch. The audio feedback can be replaced with display feedback.

ACKNOWLEDGEMENT

We thank Amrita University and Humanitarian lab for providing us this wonderful opportunity to direct our thoughts into a real prototype. We thank Dr. Rajesh Kannan Megalingam for providing us space and infrastructure needed to complete this project. We thank all the people who have helped us to accomplish this project in time.

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