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AN INTELLIGENT WEARABLE ROBOTIC DEVICE FOR KNEE REHABILITATION

S. Prabakar[1], K. Porkumaran[2], S. Ramanan[3], K. Cheranmadevi[4] and R. Karthikeyan[5]

[1]*Department of Biomedical Engineering, Dr. N.G.P. Institute of Technology, India*
[2]*Dr. N.G.P. Institute of Technology, India*
[3]*Department of Special Education, National Institute for Empowerment of Person with Multiple Disabilities, India*
[4]*Department of Therapeutics, National Institute for Empowerment of Person with Multiple Disabilities, India*
[5]*Department of Electronics and Communication Engineering, Dr. N.G.P. Institute of Technology, India*

Abstract

Around the globe, the population suffered with stroke and spinal cord injury are rapidly increasing who are in need of an effective and efficient solution for their day to day life management. Paraplegia is a form of paralysis in which function is substantially impeded from the waist down or lower extremities but not the arms and it is sometimes called as partial paralysis. More than 73% people with paraplegia have perfectly healthy legs. The main aim of this proposed study is to develop an efficient rehabilitation system to treat paralysis patients of paraplegia. In this proposed research work, an assistive knee exoskeleton is designed and developed as a wearable robot with One Degree of Freedom (ODF) movement. This system is attached with the disabled limb with the aim of delivering appropriate motion and pragmatic functionality to the affected knee for suitable rehabilitation. This exoskeleton knee is controlled by the instrumented cane as a wearable sensory system to establish the coordinated movement through patient's motion task estimation in order to control the trajectory of ODF exoskeleton robot. The computational intelligent control systems provides assisted rehabilitation motion in coherence with the motion of other unassisted upper limbs through the wearable sensors and switches in the instrumented cane. The instrumented cane is a helpful assistive device for rehabilitation in terms of balance and movement for those who suffering neurological disorders, in particular stroke and spinal cord injury. The pilot study on a subject using the proposed system describes utilization of instrumented cane as a feasible interface between the patient and exoskeleton to improve in terms of motion in their day-to-day activities. Also, the system is designed with inertial measurement module integrated with wireless communication device in order to assist real-time control of exoskeleton. The outcomes of the proposed research work validated and appreciated by the expert physicians and therapists. This study strives the purpose of an instrumented cane that able to contribute to the cognitively assisted locomotion technology as well as improves the mobility of physically challenged people.

Keywords:

Skin Cancer, Detection, Machine Learning, Support Vector Machine, Histogram of Oriented Gradients

1. INTRODUCTION

Paralysis is a common term represented as the abnormal performance of movement and the defective sensation due to damage of the nervous system. In biological term precise level of bruise square measure used that is succor in crucial the components of the body that plagued by dysfunction and conjointly loss of operation. In medical terms accurate level of injuries are used which is supportive in determining the parts of body that affected by paralysis and also loss of function. Generally, this disease can be within a temporary period or even worst to be permanent. Exactly, this illness will be inside an interim amount or may be worst to be permanent. In several cases, dysfunction have an effect on aspect of the dysfunction classification this condition is termed as paralysis.

In common cases, paralysis affects half side of human body, called as unilateral. Under classification of paralysis, there is a particular medical condition defined as Paraplegia [4]. Paraplegia is defect affecting the lower extremities of human body. This term describe the paralysis that affects both legs and partially the trunk, but not the arms. Contracting the study of Paraplegia, there is another form of paralysis that affect just one limb known as Monoplegia. Crural Monoplegia is scientific term for paralysis affecting the single lower limb [5]. Two leading causes to monoplegia are Cerebrovascular Accident (CVA), also well-known as Stroke and Spinal Cord Injury (SPI) [1]. In 2009, Centre for Disease Control and Prevention (CDC) [1] unveiled staggering statistics based on research into the prevalence of paralysis across the U.S population. Patients with this disabilities have trouble in walking as well as reflecting their muscle.

Conversely, rapid development of technology has formed a solution with a design mechanism of exoskeleton in conjunction of instrumented cane for the wireless control. Development in this field creates an enthusiasm towards patients to experience the transformation from undergoing rehabilitation therapy to a real world walking practice. The difficulties in human mobility motion intention depend on certain bioelectrical signal of neurology system. Research community developed several wearable gait, exoskeleton, instrumented cane that will compute and estimate the motion intention due to disability. Nevertheless, there are several constrain on the design mechanism which includes modelling with variable electronic hardware modules are composite, in data transmission power supply for wireless is ineffectual, immense design and additional weight restrain, uncomfortable cane, and to deliver locomotion technology for patients with paralysis of paraplegia. Movement transparency is critical when wearing a robot for gait rehabilitation. In other words: when wearing the exoskeleton, its movement should be synchronized and consistent with a patient's natural movement. If not, it exerts extra forces on the human joint and this extra force causes patient discomfort and unnatural movements. More particularly, by narrowing the proposed study, the monoplegia patients have been considered, monoplegia which causes paralysis in one of the limb.

2. RELATED WORK

Few interfaces have been developed for lower limbs exoskeleton robots, with the target pathology being hemiplegia or paraplegia. The bioelectrical signals are reliable information to estimate human motion intention [1]. However, in the case of neuronal injury/dysfunction such as Spinal Cord Injury (SCI) or stroke related paralysis, bioelectrical signals are different from that of healthy people or even not available. Therefore, reference trajectory for the assisted limbs needs to be computed, and the motion intention need to be estimated in different ways [2] [4] [5].

Kawamoto et al. [4] developed a control system for single leg version of Robot Suit HAL by using Floor Reaction Force (FRF) sensors to detect the gait phase shifting intended by the user. The readings from FRF sensors embedded in the shoe insole of the wearer were used to determine the current phase and phase shifting during gait, and the robot is then operated by assembling segments of reference trajectories extracted from healthy people to restitute the motion of the impaired limb. The reference trajectories are earlier adjusted according to the user's physical conditions. More extended work has been realized for the case of paraplegia in [5]. In this work gyroscope, accelerometer and level sensors measure the tilting angle of the user's torso according to his anatomical lateral plane.

Krausser and Kazerooni [2] developed a Human Machine Interface for SCI people with an exoskeleton robot and two crutches. The user conveys his/her intention to the robot using the two crutches to perform Four-Point gait with assistance from the robot and the crutches. The sensor suit comprises load measurement mechanism on the crutches, inertial sensors on the arms, force sensors in the shoe insole, and angle sensors on the robot's actuators. The robot uses hip and knee angle measurements, foot pressure, arm angle, and crutch load to determine the current state and transition state.

Instrumented cane was developed whereby this system intended as an interface for real-time control of a respective exoskeleton [8] [9]. Primarily, cane was known as a mechanical support and weight reducing through a weaker limb. Development in this instrumented cane technology, enables instrumented cane to be used for forcing and braking portions for exoskeleton as well as provide necessary information to study on gait assessment [10].

3. PROPOSED SYSTEM

The proposed rehabilitation system is developed with the objectives of simple hardware connection and easy wireless transmission of control information, customised light weight knee exoskeleton and easy battery replacement with prolonged life time of the system.

There are two categories of rehabilitation robots, assistive robots and therapeutic robots [8]. Assistive robot usually used for remote assessment, in which the robot delivered training task-specification to aid the patients muscle motion. In this paper, authors have described an assistive robot that will aid patient with lower limb paralysis (monoplegia). This assistive robot is an exoskeleton type robot that provides controls on individual joints so that the patients can reduce irregular motion or posture. Conversely, there is certain requirement in developing therapeutic robots due to complicated modelling of individual's body weight and height. The toughest part is to extract a clean as well as an accurate signal that designate the activities and force that development by muscle in order to make motion.

3.1 SCOPE OF THE PROPOSED SYSTEM

The computational intelligence and wearable technology based system is proposed in this research work which is intended as an interface for real-time control of an exoskeleton robot by paraplegic people. The inertial locomotion measurement sensors are fixed in the lower limb locations which is above knee i.e. thigh and below knee i.e. shank to control the real time motion of knee exoskeleton model. In this research work, an instrumented cane is interfaced wirelessly intended to capture, estimate and control the motion of exoskeleton knee. While in other wearable systems the cane is not considered, we propose that in the case of paraplegia the cane is incorporated in rehabilitation and, therefore, can provide valuable information for motion intention estimation and interfacing with an exoskeleton robot.

The expected result of this project is to develop an instrumented cane that able to communicate and control a lower limb knee exoskeleton together with artificial intelligent control algorithm that able to notice human motion trajectory. This work is to contribute in the use of rehabilitation for remote assessments as well as for the disable with their day-to-day activities. Throughout this project, research will be performed on the required balance in motion, ability, upper body strength, and the use of arm strength with the instrumented cane. Besides, the scope of this project is also to concentrate on the wireless communication system to assist in real-time control of exoskeleton via a standard I2C serial communication protocol.

Data analysis on the movement intension which is from the instrument cane, transmitted using several wireless communication medium whereby it provides real-time feedback control to the exoskeleton's motion as well as necessary data for the research community to develop and study on assistive technologies for the paralyze. Implementation of wireless communication enable the disable to use instrumented cane together with wearable gait in a comfortable manner. The main system of instrumented cane consist of push button and embedded system. The inertia measurement module (IMM) is used to sense the pressure of button at the bottom and indicates through led in Arduino UNO.

3.2 MATERIALS AND METHODS

Generally, there are several different types of instrumented cane with different design mechanism in order to control the trajectory of exoskeleton. Two major factors is considered in this project, first the sensor for angle reflective properties and second on the communication medium. Real-time assessments on the motion intension can be establish sing rotational attributes computing sensing technology integrated with radio-communication technology in order to control the trajectory of exoskeleton. Wireless communication medium plays an important role as exoskeleton response based on acquired real-time data signal that receive from the cane.

System block diagram is divided into two main sections which are major system of instrumented cane and associated knee exoskeleton system as shown in Fig.1. The complete system consists of the instrumented cane to support the paralysis patients in rehabilitation purpose. The information is passed to exoskeleton through wireless communication using the Arduino.

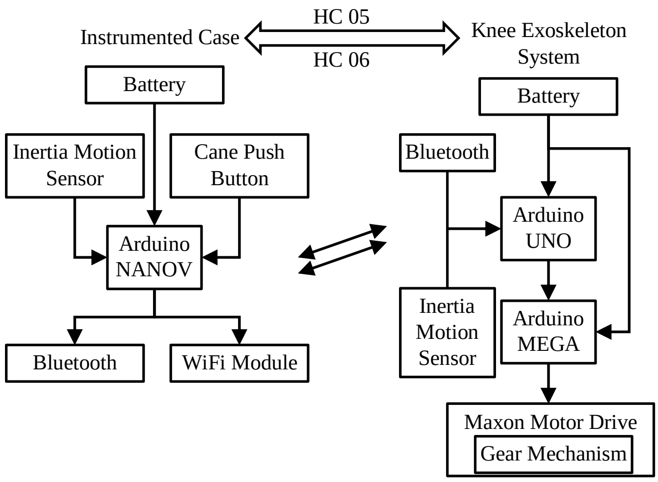

Fig.1. Functional Block Diagram of Instrumented Cane Controlled Knee Exoskeleton Robot

3.2.1 *Hardware Implementation:*

The development of exoskeleton design comprise of instrumented cane which control the knee trajectory of one degree of freedom motion using the exoskeleton. The degree of freedom that the exoskeleton can perform is flexion and extension.

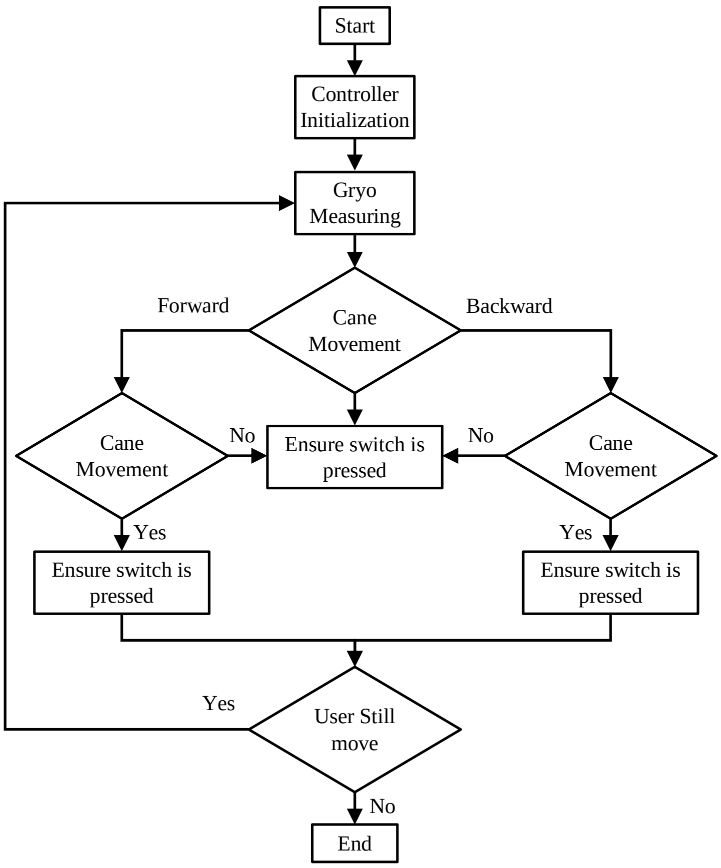

Fig.2. Workflow of the exoskeleton robot

The instrumented cane consist of IMM sensor which is unavoidable and provide best information about body motion. It detect the movement trajectory of push button. It consist of two major speciality, compatible with Arduino and low power intelligent consumption. The sensor consists a single chip which is embedded with accelerometer and gyroscope that provide information with high accuracy. The chip uses I2C (inter integrated circuit) protocol for serial communication to function according to various body condition. The weight of sensor is 5g which is helpful in reducing the weight of the prototype.

Arduino NanoV3, interpret information from MPU6050 and sends through I2C protocol to Bluetooth HC05 transmitter module. This module is user friendly and compact which require 5volts.The Bluetooth module HC05 act as the transmitter and has the capacity to act as both master and slave according to the preference. In this work, it performs as master and can be paired with any slave device automatically. The consumption of power is low and the average current fluctuation range of 25mA.The communication range of distance is 1m to 3m and it is applicable for HC05 module.

The HC06 Bluetooth module in exoskeleton acts as the receiver and performs as slave. It weighs 0.9g and suitable for wireless communication. The exoskeleton consist motion sensor and intelligent controller units Arduino UNO and MEGA. The UNO act as intermediate device which converts the information from Bluetooth receiver to a corresponding digital signals and transferred it to Arduino MEGA. The intelligent algorithm in MEGA unit estimates the suitable rotatory angle using inertia motion sensors and drives the maxonservo/cylindrical motor unit as resultant output based on the cane control signal. The controller circuit controls the torque and provide flexion and extension for the knee by the exoskeleton robot. The work flow of the proposed system is illustrated in Fig.2.

4. RESULT AND DISCUSSION

The design and development of electromechanical system for instrumented cane was done by modifying the mechanical design of a regular cane and fastened with suitable sensor, battery and Arduino UNO board. The main objective is to modify an off-the-shelf cane such that it can house position, orientation and force sensor together with wireless microcontrollers to interpret and send data in order to control the exoskeleton trajectory.

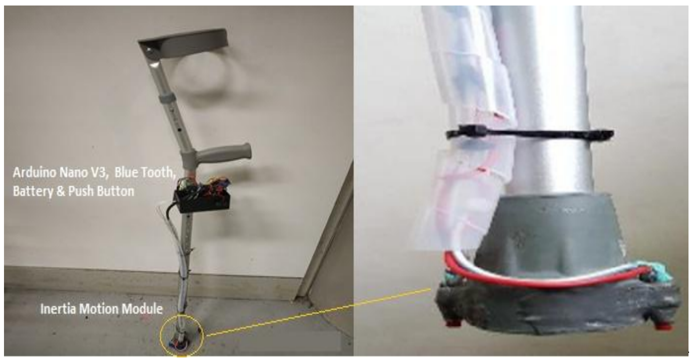

Fig.3. Mechanical Cane Design with Inertia Motion Sensor

Based on the design of instrumented cane as illustrated in Fig.3, additional weight factor on the cane is considered in order to achieve one of the targeted objective. Execution on this project, believed to deliverable an instrumented cane that able to sense the motion trajectory either forward or backward by the user and sends the real-time data in order to initiate trajectory of exoskeleton. This instrumented cane is developed a strong spirit to experience real-time walking especially for those who suffering in Cerebro Vascular Accidents (CVA) and Spinal Cord Injury (SPI). Critical consideration on the design specification whereby the instrument cane should be wireless, portable, light in weight as well as meets clinical requirements so that this cane is used comfortably.

Fig.4. Cane Controlled Knee Exoskeleton Robot

The inertia motion sensor has been attached with the instrumented cane to detect the movement trajectory that is discharged. The output signal obtained from the sensor has been interpreted in Arduino NOVAV3 and transmitted through wireless communication module. The data will then be mediated and manipulated by the Arduino UNO and MEGA embedded in the exoskeleton in order to control the trajectory. Instrumented cane and integrated exoskeleton as shown in Fig.4, enhance the compatibility using Bluetooth communication protocol as the best option. As the information is conveyed to the exoskeleton at real-time, it begins to initiate the motor to act as actuator in order to make motion. The trajectories on exoskeleton show close to normal assisted motion trajectory on the cane's inertia motion sensor and pushbutton which is compared with the motion of normal knee trajectories. However, the Range of Motion (ROM) in the robot's knee is smaller than that on the other side.

Fundamentally, humans target in motion triggers first, in sequence to command the robotic structure make motion. The push button will be assigned as a safety circumstance if there is any sudden detach or drop of cane from the arm, it will not send any trajectory control data to the exoskeleton robot. This prevents the exoskeleton to make any false motion trajectory which could cause weakness.

4.1 KNEE MOVEMENT ANALYSIS WITH PROPOSED EXOSKELETON ROBOT

The knee movement is studied in three stages such as Knee Extension, Knee Hyperextension, and Knee Flexion at seated position along with the developed instrumented cane controlled exoskeleton robot. The normal starting position for knee extension is with the knee extended and the hip in 0 degrees of abduction, adduction, and rotation. The ankle on the side being measured should be supported slightly off of the surface of the seat to allow for any passive knee hyperextension which may exist. ROM is recorded when the knee relaxes into its full passive position. If a subject can extend his knee beyond 0 degrees, this is called hyperextension. Record how many degrees beyond 0 the subject's joint can move. This measure is recorded as a positive number for this data collection. If a subject does not have any hyperextension, the value recorded is 0. The normal starting position for knee flexion is with the subject at seating with the hip in 0 degrees of abduction, adduction and rotation and the knee in full extension. Both the hip and knee move into the flexed position, with the foot coming off of the seat. ROM is recorded when the knee can bend no further, usually when the muscle bulk of the calf and thigh contact each other.

To verify and evaluate the function of the developed knee exoskeleton model and the proposed intelligent method, we extracted and compared the trajectories according to the information from cane and knee movement i.e. flexion and extension at sitting posture of the patients. The patients are in sitting position and the seated knee flexion signal acquired as illustrate in Fig.5. The extracted signals are processed with artificial intelligent motion estimation algorithm based on linear approximation technique to estimate the exact Range of Motion (ROM) of a patient. The estimated ROM is then compared with the bench mark clinical reference values of knee flexion ROM to assure the progress of therapy for rehabilitation of paraplegic patients.

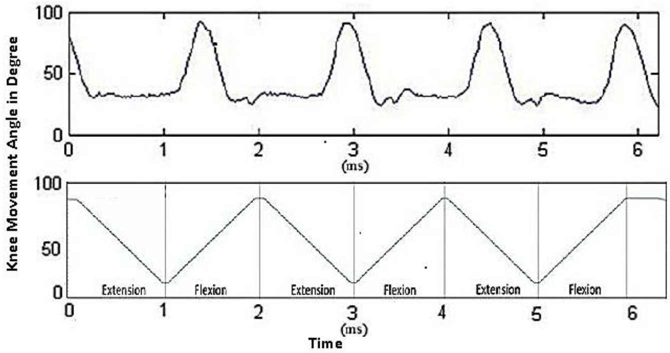

Fig.5. Knee Movement Signal using Exoskeleton Robot

In this proposed study we have 14 paraplegia cases which include 6 women and 8 men with different age groups. The standard ROM reference values of knee flexion and extension for various sexes and different age groups are represented in Table.1.

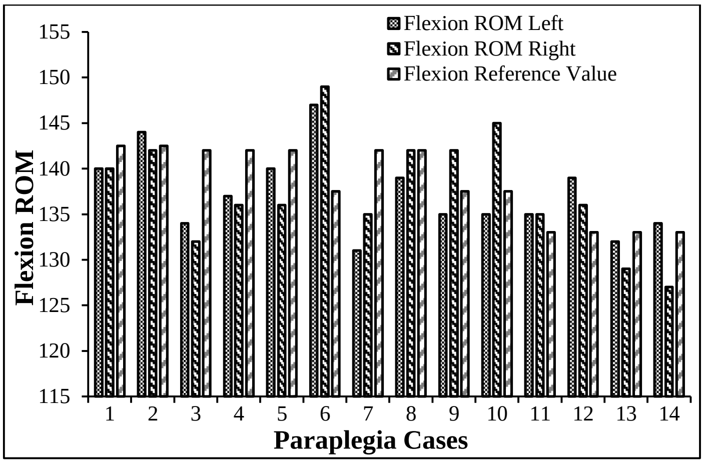

Fig.6. Knee exoskeleton Flexion ROM comparison

The recorded signals of various cases have been processed and estimated the knee flexion, extension and hyperextension to analyse the progress of rehabilitation delivered by the developed exoskeleton model as shown in Table.2.

Table.1. ROM reference values for Knee Motion

Age Group	Female		Male	
	Knee Flexion	Knee Extension	Knee Flexion	Knee Extension
02-08	152.6 (151.2-154.0)	5.4 (3.9-6.9)	147.8 (146.6-149.0)	1.6 (0.9-2.3)
09-19	142.3 (140.8-143.8)	2.4 (1.5-3.3)	142.2 (140.4-144.0)	1.8 (0.9-2.7)
20-44	141.9 (140.9-142.9)	1.6 (1.1-2.1)	137.7 (136.5-138.9)	1 (0.6-1.4)
45-69	137.8 (136.5-139.1)	1.2 (0.7-1.7)	132.9 (131.6-134.2)	0.5 (0.1-0.9)

Table.2. Estimated Values of knee flexion, extension and hyperextension for various paraplegia cases

Cases	Sex	Age	Weight	Height	Flexion ROM Left	Flexion ROM Right	Extension ROM Left	Extension ROM Right	Hyperextension Left	Hyperextension Right
1	Female	18	59.1	175	140	140	0	-3	0	0
2	Female	19	68.2	170	144	142	0	0	0	0
3	Female	20	79.5	173	134	132	0	0	0	0
4	Female	34	68.2	155	137	136	-4	-5	0	0
5	Female	43	75.9	163	140	136	-8	-5	0	0
6	Female	64	60	163	147	149	0	0	8	8
7	Male	18	67	178	131	135	0	0	3	2
8	Male	19	74.1	175	139	142	0	0	7	4
9	Male	28	120.5	193	135	142	-1	-3	0	0
10	Male	36	87.3	183	135	145	0	-6	0	0
11	Male	51	70.5	165	135	135	0	0	7	8
12	Male	59	73.2	170	139	136	0	0	0	0
13	Male	62	108.2	188	132	129	-2	-2	0	0
14	Male	69	79.5	170	134	127	0	0	0	0

These values are compared with the standard ROM reference values and identify the improvement in the rehabilitation process of the paraplegic patients. The estimated values of knee flexion, extension and hyperextension for 14 various paraplegia cases are compared with the standard ROM reference values and is showing in Fig.6 and Fig.7.

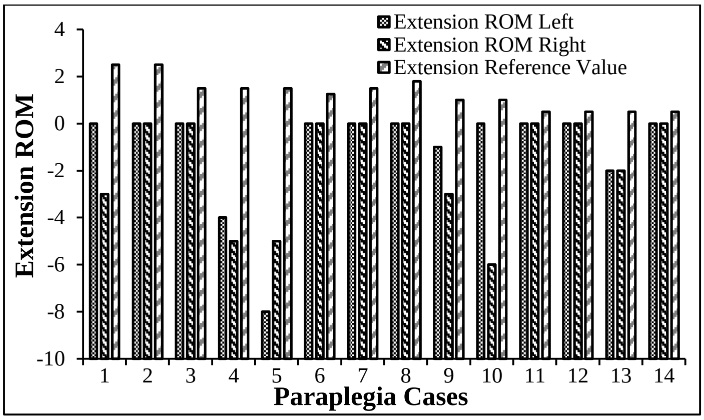

Fig.7. Knee exoskeleton Extension ROM comparison

5. CONCLUSION

The computational intelligent instrumented cane developed to automatically sense the motion trajectory either forward or backward which transmits the real-time data in order to initiate exact motion trajectory for knee exoskeleton robot. The instrumented cane is a helpful assistive device for rehabilitation in terms of balance and movement for those who suffering neurological disorders, in particular stroke and spinal cord injury. The pilot study on various subject using the developed system describes utilization of instrumented cane as a feasible interface between the patient and exoskeleton for the improvement in terms of motion in their day-to-day activities. The outcomes of the proposed research work validated and appreciated by the expert physicians and therapists. This study proves the purpose of an instrumented cane which is useful for the cognitively assisted locomotion technology as well as improves the mobility of physically challenged people.

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