MECHATRONIC INTEGRATION FOR PORTABLE HARNESS AMBULATORY SYSTEM FOR REHABILITATION OF GAIT DISORDERS OF ELDERLY AND STROKE SURVIVORS

Neelesh Kumar [a,b]
neel5278@csio.res.in

Naresh Poudel[b]
naresh.poudel1@gmail.com

Philippe Moussavou[b]
philippemoussavou@gmail.com

Devdas Shetty[b]
devdas.shetty@udc.edu

Biomedical Instrumentation Unit, CSIR-CSIO, Chandigarh India[a]
School of Engineering & Applied Sciences, UDC, Washington DC USA[b]

Abstract: Innovation in design, safety and feature enhancement of medical devices and rehabilitation aids is persistent and growing. This paper reports the research investigations of portable harness ambulatory system. The system was integrated with wireless sensors for gait measurement. This paper shows the stages of design conceptualized for early gait rehabilitation of elderly and stroke survivors without fear of falling. For performance quantification of patient gait during such rehabilitation program, wireless sensor modules were introduced and explored for use on elderly patients. The inertial measurement sensors provide information on the range of motion, gait speed, and assess fall. Experimental results prove that sensor modules were successfully able to acquire and record the gait information. These sensor modules can also be integrated in the harness ambulatory system. The paper outlines the results of initial research and discusses possible alternatives.

Keywords: Gait rehabilitation, Ambulatory system, Wireless Gait Sensors

Introduction:

Human gait is most affected disorder due to ageing population and increasing number of stroke survivors each year. According to an estimate given by National Institute of Neurological Disorders and Stroke (NINDS), USA there are more than 795,000 strokes cases every year. Stroke is the fourth leading cause of death in the country and causes more serious long-term disabilities than any other disease. Nearly three-quarters of all strokes occur in people over the age of 65 and the risk of having a stroke more than doubles each decade after the age of 55. There were enough evidences through clinical research studies carried out in last two decades that gait rehabilitation using robotic devices like Harness Ambulatory System (HAS) were effective and efficient [1, 2] . In these types of gait supporting aids patients uses a body harness and lifted partially against gravity. The amount of support provided is dependent on the musculoskeletal strength and stability of the patient [3]. There are different HAS system available like Biodex Supported Ambulatory System (SAS), ZeroG, NaviGaitor, Lokomat, ALEX etc [4, 5, 6]. All of these device can be used only in rehabilitation Centre's, involves complex installation, and highly expensive. Except NaviGaitor these device allows the movement in single straight direction [7]. Devices like Lokomat, ALEX uses treadmill for gait rehabilitation. Advantages of gait rehabilitation on a level ground than treadmill is a question of debate. Gait rehabilitation in elderly and stroke survivors is length and costly process. Visiting rehabilitation centre for a 45 minutes to1hour therapy is time consuming and patients are dependent on assistance for travelling and meeting the expenses. The available device also lacks in quantifying the gait status of individual during the rehabilitation [8, 9]. Gait events are number of steps, total therapy time were recoded. No information about the gait pattern of individual joints or physiological analysis like EMG patterns or Oxygen saturation rate were recorded for detailed analysis of efficiency of rehabilitation program [10, 11]. This paper discusses development of a Portable HAS (PHAS) for rehabilitation of such patient in their home environment without fear of falling. The prime aim was to design a HAS which is easy to maneuver in house in every possible direction without limiting gait in all possible direction of movements. Another objective was to integrate wireless gait sensors which can record the patient gait information and informs the patient to correct the gait if patient is following abnormal gait patterns. The data was stored in a PC to be analysed offline by physiotherapist. The recordings were also uploaded to a website for remote monitoring by experts at rehabilitation centres. PHAS was intended to use at home so the design and components used to keep its cost affordable without compromising over safety, quality and efficacy of such rehabilitation programs.

Method and Materials:

Portable Harness Ambulatory System (PHAS): Design aim of PHAS was carried out to develop a body unweighing system that helps patients during gait rehabilitation. The overall design dimension allows subject to undergo exercise training or rehabilitation program without any assistance in their homes. The wide base was designed to keep center of gravity low enough to prevent the device from flipping over during usage. Standard component and subassemblies were used to keep the cost affordable. CAD model of the PHAS is shown in Fig.1a) and fig. 1b) shows the prototype developed.

Sensor for gait measurement: To quantify the progress made by the patients during his rehabilitation while using PHAS, gait sensors were developed. The range of motion of joint segments, gait speed, orientation and postural assessment of patient during gait was performed by inertial measurement sensors. These sensor modules consist of two 3-axis MEMS accelerometer which is recording the range of motion of joints in 0-360°. MEMS technology makes these sensors small, accurate and consumes low power. For dynamic recoding of gait the sensor modules should be wireless, small and portable with onboard power source. Wireless sensor module using a 3 axis accelerometer was developed and packaged to be attached to joints segment like shoulder and shank as shown in fig. 2a. The gait data were recorded on normal healthy individuals with prior consent. Gait data with sensors attached recorded in two gait experiment protocol as shown in fig 2b. Shoulder to Shoulder and Shoulder to below knee at Shank segment. Reference data for still standing was recoded. Subjects were asked to walk slow and fast speed on a level ground. The data was acquired using Arduino environment and logged to a computer hard drive. The data was also logged to a web server for logging and remote analysis by expert doctor or physiotherapist. Experiments were carried out by simulating the fall conditions in forward direction, right side and left side to prove the feasibility of the measurement system for fall assessment. These modules are capable for recording range of motion for any joint segment of human body.

Sensor module for intent monitoring: The curb weight of developed prototype is approximately 40kg with winch. Forward pulling force FPF (when patient is facing opposite to winch) is 10-12N and Reverse pushing force RPF (when patient is facing toward winch) is 14-16N on a level carpeted surface. Similar estimated FPF was in the range of 8- 10N and RPF was 10-12N. These force required to generate by the individual patient. In practice, a physiotherapist moves the PHAS by observing the walking intention of the patient. It may be difficult for a recovering patient to generate these pulling or pushing forces. One solution to the problem is when the PHAS moved along with patient by sensing its walking intention. This is a common feature in ceiling installed harness ambulatory system. To achieve this, sensor module for intent monitoring of patient was developed using a tilt sensor. The control schema for intent monitoring and forward and reverse motion control of PHAS was shown in fig. 3. The sensor is packaged and attached to the winch cable in suitable fashion so that sensor is able to sense the change in tilt of winch cable. Another option can be using a limit switch installed at PHAS, sensing the forward and reverse walking intent by contact of the winch cable. The sensor is interface with digital interface pin of xbee module. The sensor is able to sense the intention for forward walking and backward walking of patient. It transmits the sensed intent data to computer through a coordinator Xbee coupled with Arduino. The computer generates a command signal as forward or reverse motion of PHAS unit. We propose to use wheels with hub drives which can perform the motion, save space required by conventional electrical drive, easier to install and control.

Results:

Experimental gait analysis was carried on individuals with developed sensor modules attached to the muscle joint segments like shoulder and shank. The orientation and location as shown in fig. 4a, 4b & 4c of these sensors was important to determine the gait information. The subjects were asked to walk with slow and fast speed to observe the change in gait parameters. The gait data is recorded and analysed for all three axis of the accelerometer. Fig. 5 shows the sample of recorded data for slow speed at shoulder-shoulder position. The flexion and extension of shoulder and shank was best observed from Y axis of accelerometer data. The subject was asked to complete the same distance at slow and fast speed according to his comfort level. It can be well observed that the acquired data was highly repetitive, with minimal errors during the change of phase from stance to swing phase. This test and validates the performance of developed wireless sensor module. Fig. 6 shows the variation in slow and fast speed with sensor attached at shoulder-shoulder position. It is observed that at slow speed gait appears to be more rhythmic and smooth. With increase in speed high variation of 15° reported in z axis which is contributed by vertical hopping while walking. For optimizing the position of sensor for gait quantification, experiments were also conducted with sensor placed at shank as shown in fig 3c and result were reported in fig. 7. It depicts that range of motion at shank was higher than at shoulder. Fig. 8 reports the data acquired during the forward fall. The subjects were asked to simulate condition of fall from standing position. Similarly data were acquired for left side fall and right side fall. The range of motion of different joints was reported in table 1.

Conclusions:

The developed PHAS will enhance the quality and ease of rehabilitation of elderly and stroke patient. This portable system is designed according to the present day requirement and accessing the limited space available in house. Quantification of rehabilitation program based on gait data of patient in real time will certainly increase the efficacy and suggest new methods for patients to reach the near natural gait. Wireless sensor modules were developed which can be attached to the PHAS or the patient. The modules are portable and have onboard power. These modules can also be used to record the range of joint motion of any human body segment with little modification. The gait data was reported on a normal healthy person acts as a reference database.

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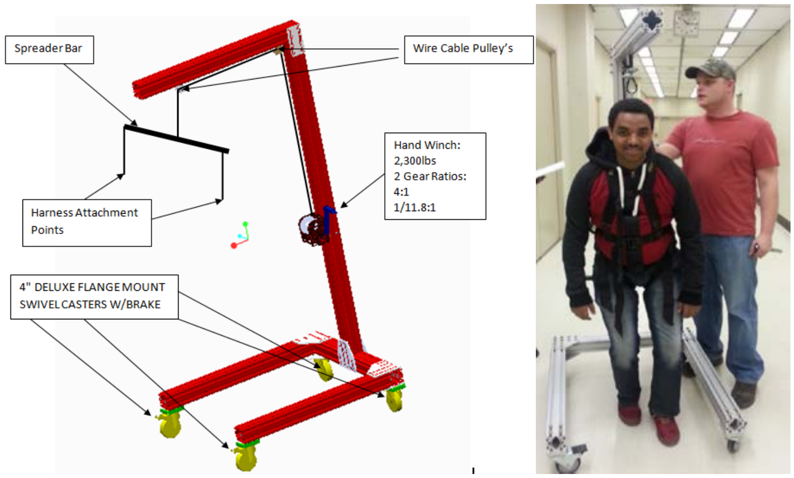

Fig. 1a): CAD model of PHAS; 1b) Developed prototype

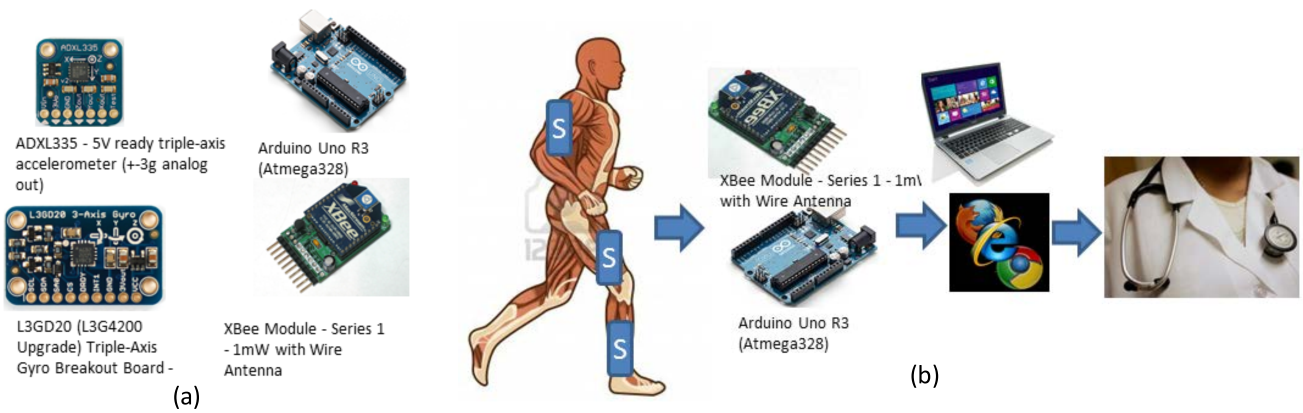

Fig 2: Wireless data acquisition system using inertial measurement sensor, a) Sensor module b) Sensor acquiring, logging & transmitting it over internet for remote analysis by an expert

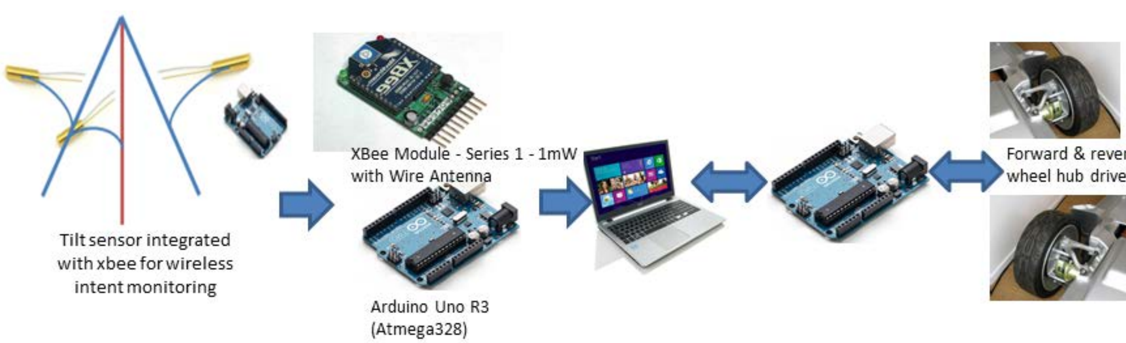

Fig. 3: Control schema for intent monitoring and motion control of PHAS unit

Fig. 4: a) Sensor orientation; b) Sensor attached to subject's shoulder; c) Shank

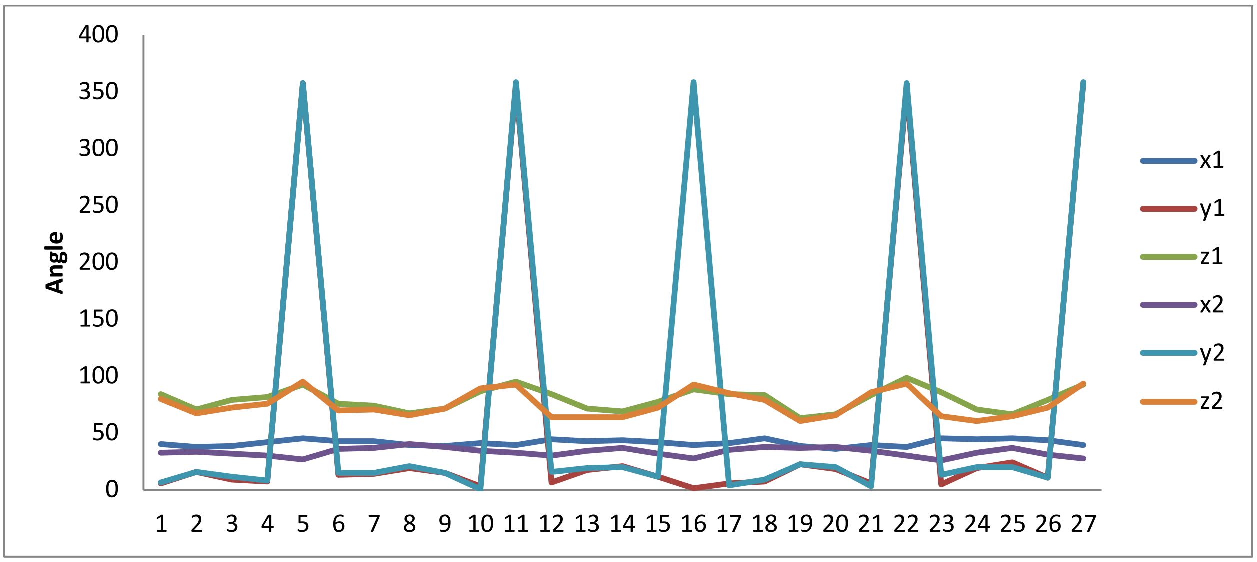

Fig. 5: Angular variations recorded by gait sensor attached at shoulder-shoulder position at slow speed

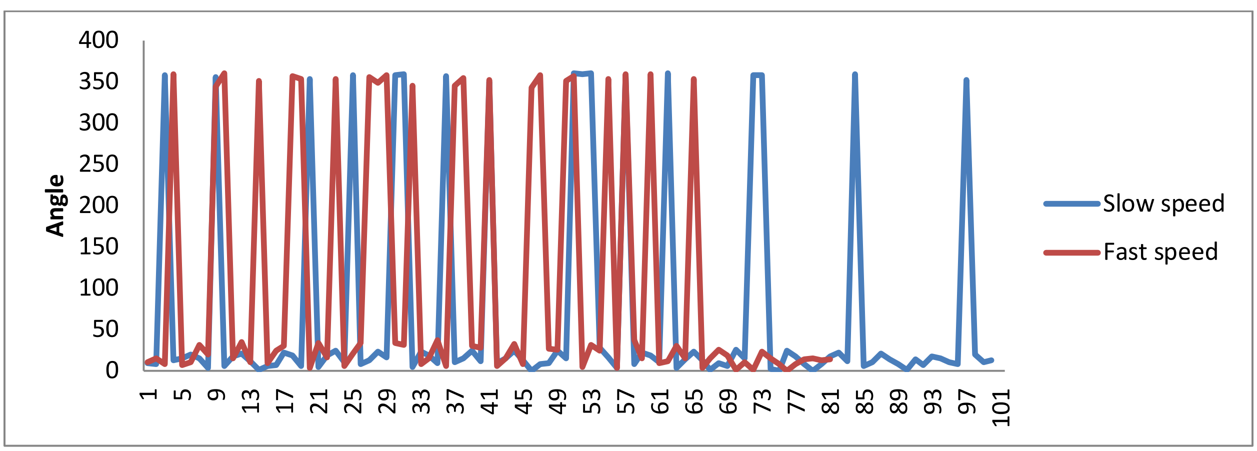

Fig. 6: Gait speed variation recorded at shoulder-shoulder position at slow and fast speed

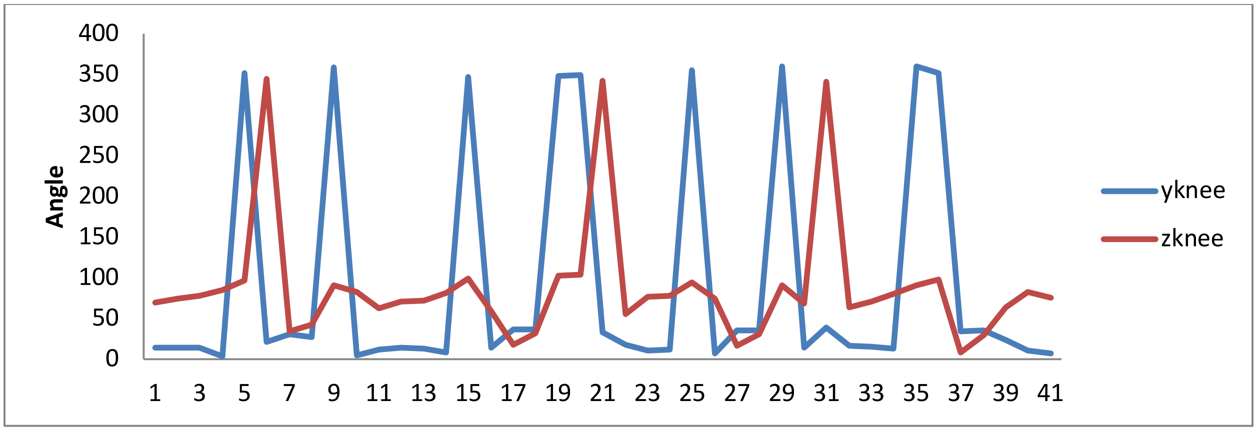

Fig. 7: Angular variation recorded at shank position at slow speed

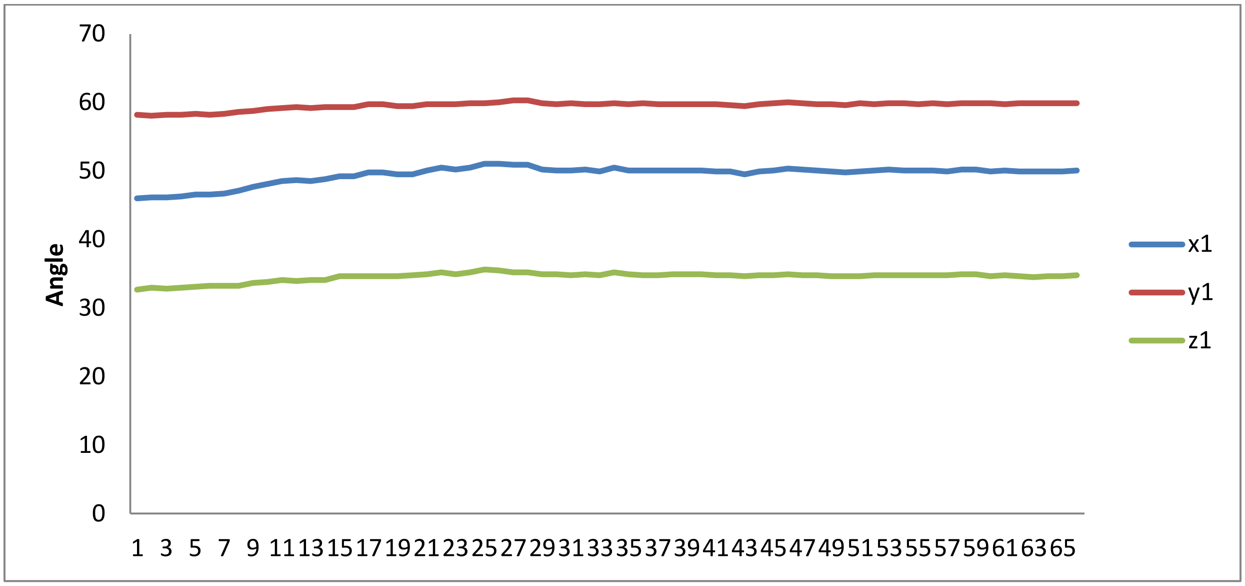

Fig. 8: Forward Fall assessment sensor placed at shoulder

Gait activity	Range of motion X (in degrees)	Range of motion Y (in degrees)	Range of motion Z (in degrees)
Gait Slow speed, Sensor at Shoulder	19.32	360	40.15
Gait Fast speed, Sensor at Shoulder	17.46	360	64.48
Gait Slow speed, Sensor at Shank	301.12	347.17	285.74
Gait Fast speed, Sensor at Shank	317.65	344.13	275.35
Forward Fall	4.89	2.13	2.84
Fall Right Side	2.64	2.53	2.61
Fall Left side	2. 48	2.30	2.42

Table 1: Range of motion recorded by developed sensor at different joints and speed