National conference on Technology innovation in Mechatronics, Energy Management and Intelligent Communication (NCTIMEMIC-2017)

International Journal of Advanced Scientific Technologies , Engineering and Management Sciences (IJASTEMS-ISSN: 2454-356X) Volume.3, Special Issue.1, April.2017

Embedded Control System Based Intelligent Walking Assistance Device

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Abstract— In this paper, we present the design and implementation of a control system, that is used for a smart intelligent hoist, a therapeutic device that is used in the rehabilitation of walking after Injuries. Rehabilitation of walking is a multistep process that is aimed to return the freedom of motion to the patient. The control system features a unique human machine interface that allows the human to control the intelligent system just by moving or rotating his body. This paper includes the overview of complete system containing the design and implementation of sensors, communication interfaces, embedded-central control system, motor controllers and communication interfaces.

IndexTerms— Control design, walk assistance device, walk rehabilitation, user intention-based control.

I.INTRODUCTION

Robotics is the interdisciplinary branch of engineering and science that contains mechanical engineering, electrical engineering, computer science, and other branches. As we know, Robotics deals with the designing, construction, operation and use of robots as well as computer systems for their control, sensory feedback, and information processing. Nowadays various technologies are used to develop various machines that can be a substitute for human. Robots can be used in any situation and for many purpose. Here we develop an intelligent smart hoist, a therapeutic device that is used for the rehabilitation of walking after injuries or neural impairments. Rehabilitation of walking is a multi-step process that aims to return the freedom of motion to the patient.

Several approaches have been proposed and developed for the rehabilitation process. In 2003, this rehabilitation process was start with the therapy of muscular system and proceeds with the static and dynamic balance training. A muscle contracture emulation system is presented to assure repeatable gait pattern resulting from artificially induced muscle contractures in a neurologically and orthopedically intact person [14]. In 2005, J.F. Veneman et.al [13] design a series elastic and Bowden cable based actuation system for use as torque actuator in exoskeleton type training. In 2007, Derek et.al [12] develops a wearable pelvic sensor for drop foot treatment in post stroke patients. This was developed and evaluated in both normal and pathological gait.

In this paper, we will describe the simulation result of walking assistance device. The paper is organized as follows. The second section explains the literature survey of walking assistance device. Section III includes the description of proposed system design of the hoist device, the description of the base platform, hardware upgrades, embedded system and sensory system is given in separate sub-sections. Then a detailed description of the control system of rehabilitation platform that is built-upon in this project is given in the section IV. The simulation results are described in section V. Finally Section VI concludes the proposed design.

II.LITERATURE SURVEY

In 2009, Haibo Zeng et.al [11] develops and proposes a stochastic analysis of Controller Area Network based real time automotive systems. CAN is a message broadcast system that specifies a maximum signaling rate of 1 megabit per second (bps). It does not send large blocks of data point-to-point from node A to node B under the supervision of a central bus master. In 2009, Daisuke Chugo et.al [10] introduces a motion control of a robotic walker for continuous assistance during standing, walking and seating operation. This system focuses on the domestic use for persons who needs nursing in their daily life. In 2010, Xiaojun zhang et.al [9] develops a treadmill based lower limb rehabilitation robot , in which partial body weight of the user has been supported by using a counter weight. So that the person can practice numerous steps on the treadmill.

In 2011, Cleiton Caltran et.al [8] develops a sensor fusion strategy and that has been applied to estimate the position and gait identification of an ankle foot orthosis. In 2012, Saumya Puthenveettil et.al [7] introduces an integrating kinematic modeling and kinetics to quantify the hand motor performances in persons with stroke. In 2013, Seok Hun Kim et.al [6] suggest a gait modification technique called robot assisted balance training program, can change the human gait patterns.

Sensor sensitivity to posture transitions in a lower extremity orthotic device evaluates the sensitivity and relative timing of the system of sensors in detecting posture transition by a user wearing a lower extremity orthotic device [4]. In people with stroke, task-oriented and intensive rehabilitation strategies can drive cortical reorganization and increase activity levels. Development of RT-GAIT is the solution for that. It is a real time feedback device to improve gait individuals with stroke [3]. In 2015, Martins Martins et.al [2] proposes a real time gait assessment with an active depth sensor placed in a walker. In this paper he suggested a rollator type walkers are equipped with one active depth sensor for gait assessment.

In 2015 ,Matevz Bosnak [5] et.al develops a smart walking assistance device that allows the user to control the device by the body movement. But the rapid starting and stopping action will cause a fall of user during the rehabilitation process. In 2016, Tyler Susko et.al [1] develops a novel gait rehabilitation robot for stroke and cerebral palsy, called MIT Sky walker. That means, these papers are not provide any solution for the prevention of falling of users during rehabilitation. That is; there is no systems which are provided to the body weight support for the user. The intelligent hoist device prototype presented in this paper will provide a constant fail safe and patient engaging approach to gait rehabilitation.

III.PROPOSED SYSTEM DESIGN

This paper is focused on the functional extension of existing rehabilitation platform. It will be cost effective device ,which offers the support for persons with neural impairments or motor disabilities. This device will provide an user-machine interface in which the user can control the device just by moving or rotating his body. The idea behind the Hoist project was to overcome problems in the manual control mode of the existing walking assist system by observing the patient and adapting the control system accordingly. For achieving this goal, user position determination and intention based control system was designed that allows the user to control the movement of the smart hoist.

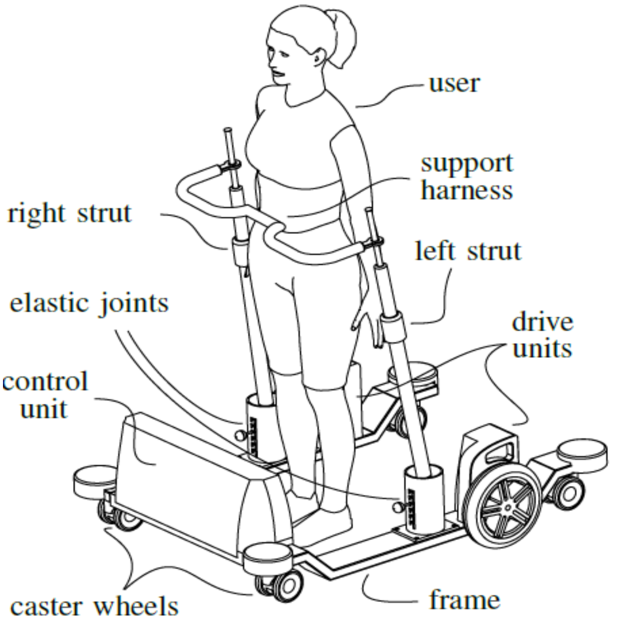

Fig:1 Parts of the Smart hoist (source: Embedded control system for smart walking assistance device Matevz Bosnak and Igor Skrjanc et.al, 2016)

The main parts of this smart hoist device are left and right struts with elastic joints, a support harness, a control unit, abase frame and drive units. The hoist device prototype is built as a stable chassis with four caster wheels, equipped with battery power supply, electronics and two electrically driven wheels as shown in figure 1. The interface between base frame and vertical struts are made by using the ball joints that have limited degrees of freedom for ensuring safety to the user. The final product is a system that follows the motion of the user, which ensure a constant fail safe support for the user. In this device multiple sensors are placed on the left strut, right strut and base frame. These multiple sensors observes the device's and user's motion and position.

The main building block of the smart hoist is the ARM processor. Here we using three MEMS angular rate and linear acceleration sensors to measure the support struts orientation.

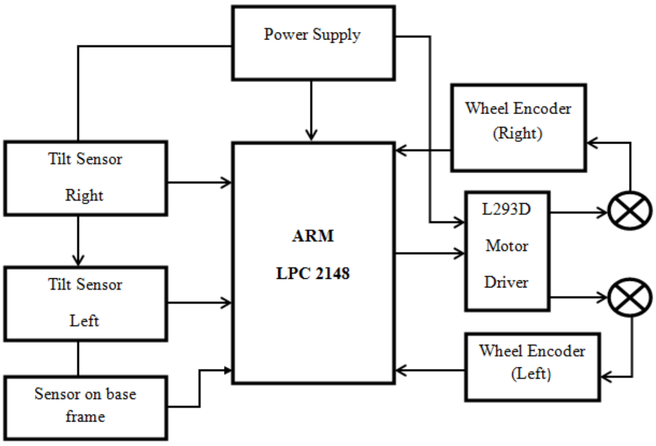

Fig: 2 Block diagram representation of smart hoist

Electrical and Drive system

The main power supply consists of 12V battery that power the motor drives through relays. 5V regulated power supply are provided for the sensors and 3.3V power supply are given to the ARM processor. Each wheel has its own electric motor with a shaft position encoder and a speed controller.

Serial Communication Bus

Serial communication is defined as the process at which it sends the data of one bit at a time, sequentially, over a communication channel or computer bus. Serial communication is used for all long-haul communication and most computer networks, where the cost of the cables and synchronization difficulties will make parallel communication impractical.

Serial computer buses are becoming more common even at shorter distances, as improved signal strength and transmission rate in newer serial technologies have begun to look through the parallel bus's advantage of simplicity and to overcome its disadvantages. Universal Serial Bus (USB) is an industry standards that defines the cables, connectors and communications protocols used in a bus for connection, communication, and power supply between computers and electronic devices.

Here USB is used to interconnect the communication system inside the smart hoist completely as shown in figure 3.
USB is an attractive solution for embedded control systems because of its low cost, light protocol management and high speed data transmission capability.

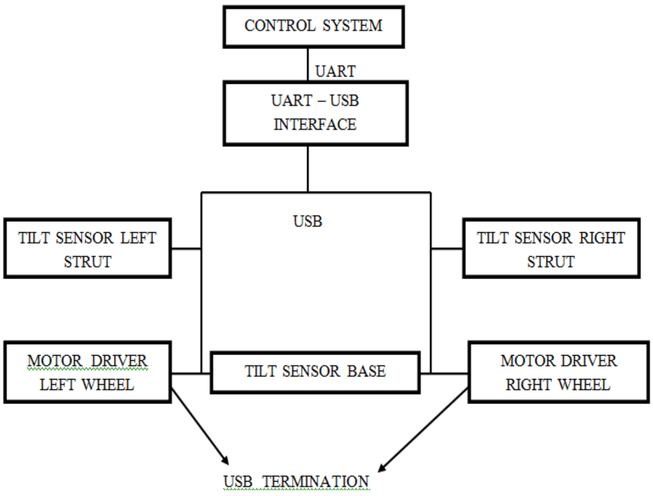

Fig: 3 USB Network on hoist

Tilt Sensors

Here we using three tilt sensors, two of which are placed on the vertical struts and one is at the base frame of the hoist. This sensor arrangement will provide a simple method of measuring the relative orientation between the base frame and two support struts. The motion in each axis is restricted to ±10 degrees from vertical. Then the tilt angles are calculated independently for each axis. Here we using a small, low power three axis accelerometer. The ADXL335 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product will measures the acceleration with a minimum full-scale range of ±3 *g*. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration.

Embedded system

The most important block of this hoist is the microcontroller. It is a small computer on a single integrated circuit contains processor core, memory and programmable input or output peripheral. Here we use LPC 2148 ARM based processor. ARM, originally an Advanced RISC Machine, is a family of reduced instruction set computing (RISC) architectures for the computer processors that are configured for various environments. A RISC based computer design approach means processors require fewer transistors than the typical complex instruction set computing (CISC) processors in most of the personal computers. This approach reduces costs, heat and power use. These characteristics are desirable for light, portable, battery-powered devices including, smart phones, laptops and tablet computers, and other embedded systems. For supercomputers, which consume large amounts of electricity, ARM could also be a power-efficient solution.

LPC 2148 microcontrollers are based on a 32 bit ARM7TDMI-S CPU with real time emulation and embedded trace support, that combine microcontroller with embedded high speed flash memory that ranging from 32kB to 512 Kb. Serial communications interfaces ranging from a USB 2.0 Full-speed device, multiple UARTs, SPI, SSP to I2C-bus and on-chip SRAM of 8 kB and up to 40 kB, which will make these devices very well suited for communication gateways and the protocol converters, soft modems, voice recognition and low end imaging, providing both large buffer size and also high processing power. Two 32-bit timers, single or dual 10-bit Analog to Digital Converters (ADC), 10-bit DAC, PWM channels and also 45 fast GPIO lines with up to nine edge or level sensitive external interrupt pins make these microcontrollers suitable for industrial and our system control.

Here we use C language for the embedded programming. C is a general purpose, imperative computer programming language, which is also a supporting structured programming method, and a lexical variable scope, while a static type system will prevent many unwanted operations. By design, C provides or constructs that map efficiently to the typical machine instructions, and therefore it has been found that lasting use in applications that had formerly been coded in assembly language, including operating systems, as well as various application software for computers that are ranging from supercomputers to the various embedded systems. Keil software is used to write the program. The Keil MDK-ARM is the complete solution for software development of embedded applications for the ARM processor-based microcontrollers.

Servo Drives

High current quadruple half-H drivers for the 12V,100 rpm motors with built in shaft encoders were embedded into the control box hardware in front of the platform. A servo motor controller is designed to operate at low rotational speeds. Here we using L293D motor driver which can be provides bidirectional drive currents of up to 600-mA at the voltage ranges from 4.5 V to 36 V. Each output is a complete totem-pole drive circuit, with a Darlington transistor sink and a pseudo-Darlington source. The application running on the servo controller allows the access to all controller parameters, current position, speed and motor current via USB. The servo controller is built around Cortex-M0 microcontroller with an integrated USB transceiver and smart H-bridge.

The servo control loop is shown on Figure 4. It is a semi-cascaded controller with current limit in internal loop and velocity-mode PID servo controller in external loop. Current shaft rotational velocity is obtained by differentiating the shaft position and filtering the result using a first order low-pass filter. The reference speed as the input variable is rate-limited to limit the maximum motor acceleration in order to reduce the mechanical stress of the components and limit the electric current spikes.

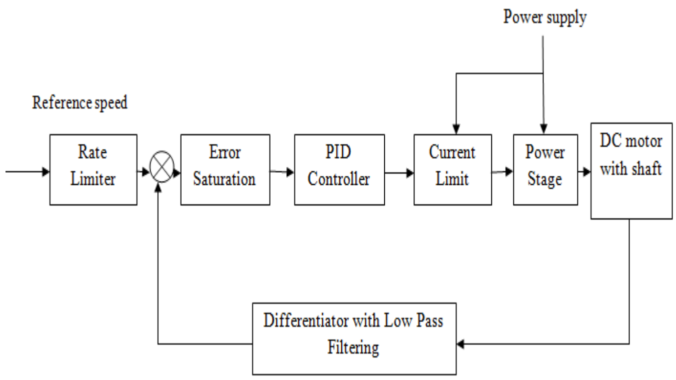

Fig: 4 Servo control loop. (source: Embedded control system for smart walking assistance device Matevž Bošnak and Igor Škrjanc et.al, 2016)

There is an additional feedback loop from current limit controller back to integral of the PID controller to avoid saturation effects. The servo control loop is executed at a fixed frequency of 1 kHz.

IV.HOIST CONTROL SYSTEM

The control system must be robust enough to ignore normal oscillations in the signals that result from walking dynamics, however special care must be taken for allowing the user to execute controlled rapid stopping. Here we use PID controller for the controlling operation. Proportional Integral Controller have fast response on change of the input (Derivative mode of operation), increase the signal for zero error (Integral mode of operation), and suitable action for the elimination of oscillation (Proportional mode of operation). Derivative mode improves the stability of the system which increases the gain K and decrease in integral time constant Ti, which increases speed of the controller response. PID controller is used when we dealing with the higher order capacitive processes that means, processes with more than one energy storage when their dynamics will not similar to the dynamics of an integrator, like in many thermal processes. PID controllers will be usually used in industry, but also in the mobile objects control systems (course and trajectory following included) when stability and precise reference following are required. The choice of controller parameters greatly depends on the walking ability of the current user. The information obtained from accelerometer or sensors attached to the hoist is given to the Rate limiter. A reference speed is set to the rate limiter will helps to limit the speed of hoist. Errors will be saturated by the error saturation module. Current limiter is used to limit the current and thus limit the speed of the smart hoist. The power supply will be given to DC motor with shaft by using a power stage. Differentiator with low pass filters are used to reduce the speed of hoist.

User Position Determination Method

User's position with respect to the platform is obtained by observing the angles between the vertical struts and the base frame. For this purpose, struts and frame are equipped with tilt sensors allowing the relative angles between the frame and struts to be determined. The x-axis of the platform frame coordinate system is oriented towards the front of the device and the z-axis is oriented vertically in the up direction, while the y-axis is oriented towards the left side of the frame, creating a right handed Cartesian coordinate system. While at the rest position, the coordinate system axes of tilt sensors are aligned with the platform frame coordinate system. Deflection angles of the vertical support struts are mechanically limited to approximately 10° from the vertical direction and the angular velocities of the struts are relatively low due to the long length of the struts. By using the small angle trigonometric functions approximation and the rotation transformations between the platform frame coordinate system to tilt sensor coordinate system can be handled individually for the rotations around the x and y axes.

Let α denote the angle of rotation around the sensor's y axis that rotates the platform frame coordinate system to a tilt sensor coordinate system and β denote the angle of rotation around the sensor's x axis that rotates the platform frame coordinate system to a tilt sensor coordinate system as shown in figure 5.

Perturbations of the user harness attachment point origin (Δx;Δy) and orientation ΔΨ is therefore calculated using the following equations (1), (2) and (3).

$$\Delta x = \frac{d(\tan\alpha_{l+} \tan\alpha_T)}{2} \qquad (1)$$

$$\Delta y = -\frac{d(\tan\beta_l + \tan\beta_r)}{2} \qquad (2)$$

$$\Delta\Psi = arctan\frac{d(\tan\alpha_r - \tan\alpha_l)}{2d_s} \qquad (3)$$

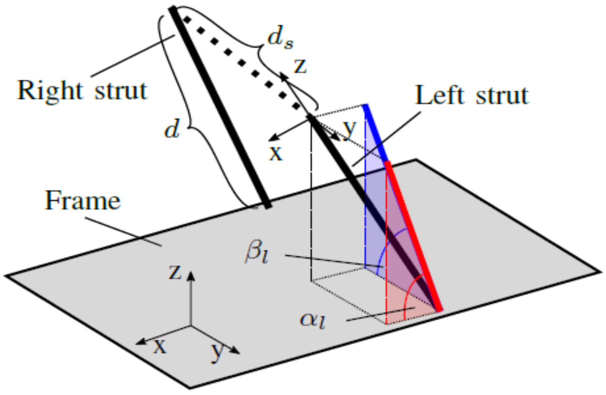

Fig: 5 Illustration of hoist platform. (source: Embedded control system for smart walking assistance device Matevž Bošnak and Igor Škrjanc et.al, 2016)

where d is the vertical distance between the elastic joints and horizontal user support strut, ds is the length of that strut (i.e. horizontal distance between the two vertical struts), while α_l, β_l, α_r and β_r are α and β angles for the left and right strut, respectively. These perturbations are used for estimating the position of the user in reference to the platform, which is directly indicates the intention of the user for his motion. This is justified by the following assumptions:

- When the user intends to move in the forward direction, the user will initiate a move in that particular direction which will cause a change in its relative position in regards to the platform to move forward.
- When the user needs to speed up or slow down, user's speed will also increase or decrease, respectively. It will directly results a change in relative position of the user in regards to the platform to more forward direction (user is accelerating) or more backwards direction (user is slowing down) position.
- When the user intends to change the direction of motion, then the user can, rotate his/her pelvis in that direction, according to this movement the device can be controlled.

Based on these assumptions, the values of Δx and $\Delta\Psi$ can be used directly as an estimation of user intent for acceleration and turning, while the side motion Δy can be used as a measurement of the user's walking (gait) quality. Translational motion controller algorithm and rotational motion controller algorithm are designed to obtain the required controlling mechanism.

V.SIMULATION RESULTS

The simulation result shows that the speed of the motor can be adjusted according to the movement of hoist. Here checking whether the speed of smart hoist system is controllable or not. Here taking set of values for representing the constant, accelerated and decelerated speed of hoist and the corresponding variations are shown in the simulation result graphs. The angle between the base and struts of hoist is limited to ±10°. When the struts will move in forward direction , the obtained angle is assumed as -10°. When the struts are moving in backward direction, the obtained angle is assumed as +10°. By using these assumption, we can calculate direction of motion of smart hoist.

In the linear motion of the device, raw data of acceleration that are collected from the sensors are plotted between time and acceleration due to gravity as shown in figure 6. Normalization is done in the raw acceleration graph for avoiding the influence of acceleration due to gravity, and to get the original acceleration. Also the tilt angle is calculated from these acceleration values and is plotted in the figure 7. Here we are assumed that the speed is directly proportional to the angle obtained. When both of the wheels are rotating in constant speed, the obtained graph for acceleration is also constant as shown in figure 7.

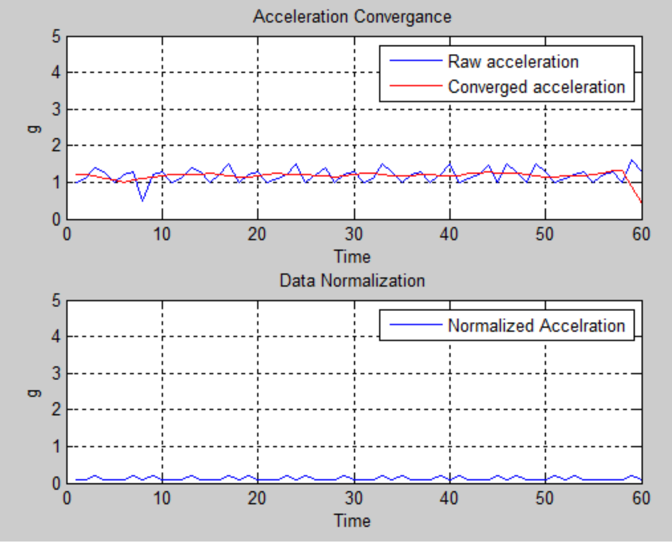

Fig: 6 Graph obtained when wheels rotated in a constant speed.

The angle made between the struts and base is not varying, thus we can say that the speed is constant otherwise the speed is changing as shown in figure 7.

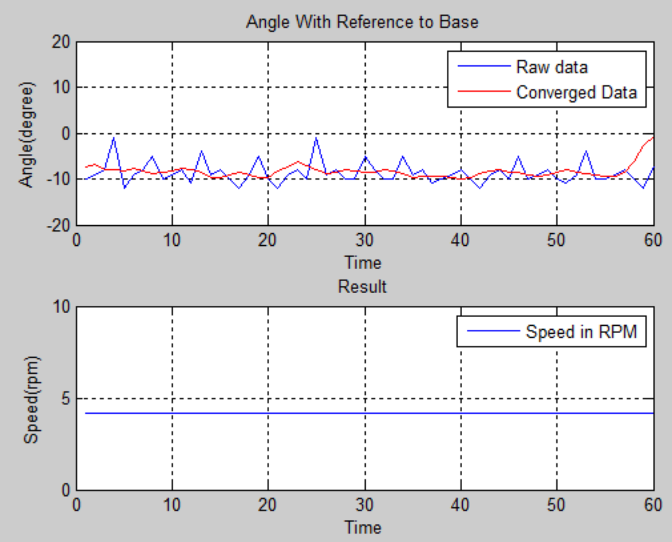

Fig: 7 Graph shows the angle and speed of smart hoist with respect to time.

Considering the rotational motion of the device, the acceleration values of both sensors are collected. Angle of struts with respect to base frame are calculated and are plotted in the graph shown below. If the hoist is rotating in left side, the speed of left wheel is greater than that of right wheel. This is shown in figure 8.

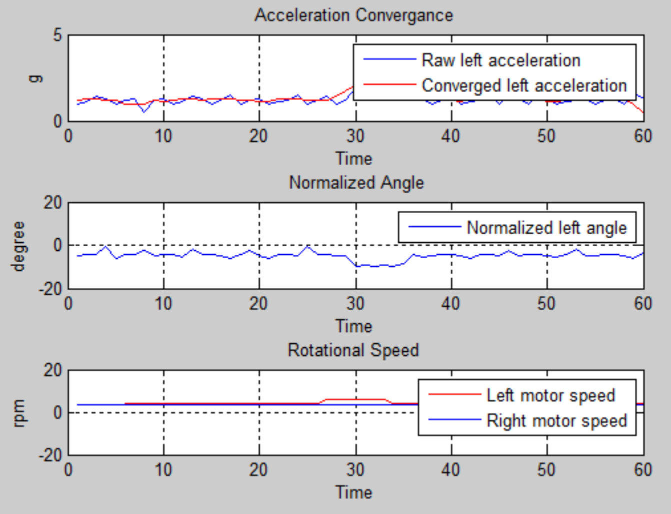

Fig: 8 Graph shows speed variation in left and right wheel.

VI.CONCLUSION

The smart hoist is a therapeutic device that is developed for the use in rehabilitation of walking after injuries, neural impairments or motor disabilities. Rehabilitation of walking is a multi-step process that is aimed to return the freedom of motion to the patient. It is a complex undergoing, mostly based on repetitive tasks Execution. The control system features a unique human-machine interface that will allow the human to intuitively control the system just by moving or rotating his body. The system is a human- machine interface. The prototype of walk rehabilitation system with the implementation of the control system that will being very intuitive and easy to adopt by the users. The device will only instructed to follow the motion of the patient.

REFERENCES

[1] Tyler Susko, Krithika Swaminathan, “MIT skywalker :A novel gait neuro rehabilitation robot for stroke and cerebral palsy”, IEEE 2016.

[2] Martins Martins, Cristina P, “Real-time gait assessment with an Active Depth sensor placed in a walker”, 978-1-4799-1808-9/15/$31.00_c 2015.

[3] Nagaraj Hegde, “Development of the RT-GAIT, a real time feedback device to improve gait of individuals with stroke”, IEEE 2015.

[4] Mathew Gawlik, Edward Sazonov, “Sensor sensitivity to posture transitions in a lower extremity orthotic device”, Proceedings of the IEEE SoutheastCon 2015, April 9 - 12, 2015.

[5] Matevz Bosnak, Igor Skrjanc, “Embedded control system for smart walking assistance device”,IEEE transaction on neural systems and rehabilitation engineering, 2015.

[6] Seok Hun Kim, “Robot assisted balance training for gait modification”, International Conference on Rehabilitation Robotics, 2013.

[7] Saumya Puthenveettil, “Integrating kinematic and kinetics to quantify hand motor performance in persons with stroke”, IEEE 2012.

[8] Cleiton Caltran and Adriano A. G. Siqueira, “Sensor fusion applied to position estimation and gait identification of an ankle foot orthosis” , IEEE 2011.

[9] Xiaojun Zhang, Xiangzhan Kong, “Research on the walking gait coordinations of the lower limb rehabilitation robot”, Proceedings of the 2010 IEEE International Conference on Robotics and Biomimetics 2010.

[10] Daisuke Chugo, “A motion control of a robotic walker for continuous assistance during standing, walking and seating operation”, IEEE/RSJ International Conference on Intelligent Robots and Systems October 11-15, 2009.

[11] Haibo Zeng, Marco Di Natale, “Stochastic analysis of CAN based real time automotive systems”, IEEE transactions on industrial informatics, vol. 5, no. 4, november 2009.

[12] Derek. T. O’Keeffe, Deanna H. Gates, and Paolo Bonato, “A wearable pelvic sensor design for drop foot treatment in post stroke patients”, Proceedings of the 29th Annual International Conference of the IEEE EMBS Cité Internationale, Lyon, France August 23-26, 2007.

[13] J.F. Veneman, R. Ekkelenkamp, “Design of a series elastic and bowdencable bsed actuation system for use as torque actuator in exoskeleton type training”, IEEE 9th International Conference on Rehabilitation Robotics June 28 - July 1, 2005.

[14] Andrej OlenSek, Zlatko MatjaEiC, Tadej Bajd, “Muscle contracture emulsion system”, IEEE 2003.