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EMBEDDED CONTROL SYSTEM FOR SMART WALKING ASSISTANCE DEVICE

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ABSTRACT:

The design and implementation of a unique control system for a smart hoist, a therapeutic device that is used in rehabilitation of walking. The control system features a unique human-machine interface that allows the human to intuitively control the system just by moving or rotating its body. The paper contains an overview of the complete system, including the design and implementation of custom sensors, DC servo motor controllers, communication interfaces and embedded-system based central control system. The prototype of the complete system was tested by conducting a 6-runs experiment on 11 subjects and results are showing that the proposed control system interface is indeed intuitive and simple to adopt by the user

Introduction (*Heading 1*)

The popularity of the assisted living research topics resulted in presentation of multiple similar devices that were designed for walking assistance to elderly people and those with motor disabilities. Such devices are usually based on a movable platform that is either actively steered or fully motorized and may combine additional features, such as active assistance for standing up and sitting down, or even help with other everyday tasks, such as picking up items. Most of these systems are controlled with the use of steerable handle bars or static handles, equipped with force sensors. Since gait and balance instability is one of the most common sources of fall induced injuries, it is essential that the falls are prevented during the rehabilitation – systems that cannot provide the support for patient's full body weight during a failure event (loss of balance, tripping, stumbling etc.) are since constant supervision and presence of the physiotherapist is required. The Hoist device prototype presented in this article provides a fail-safe and patient-engaging approach to gait rehabilitation.

The device itself is built as a stable chassis with four caster wheels, equipped with battery power supply, electronics and two additional electrically driven wheels that enable it to move as a two-wheel robot (two of the caster wheels are lifted once driving wheels are attached). The interface between the device chassis and the vertical support frame is made of a ball joint, equipped with adjustable coaxial springs that have limited range of motion in terms of off-vertical deflection angles. The interface enables the user a certain degree of freedom in motion, but it also limits the user's motion if needed in order to prevent injuries in cases of tripping, stumbling or falling. The idea behind the Hoist project was to augment the manual control mode of the existing walking assist system (illustrated in Fig. ??) by observing the patient and adapting the control strategy accordingly. For this purpose, user position determination and intention-based-control system was designed that allows the patient to control the motion of the device by

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perturbing its position in regards to the platform base. This approach equates to a very intuitive way of controlling the device, since the control system works towards maintaining the neutral position of the user in regards to the platform.

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 manoeuvres. Thus, the controller combines a regular P-controller and a filtered P-controller (PfP controller), a combination that allows the user to have the feeling of an immediate control (regular P part) and smooth changes in the average speed of the platform (filtered P part, that simulates the effect of an integrator. Such controller has a continuous transfer function of $H(s) = K_P + K_{P,f} (\tau s+1)^{-1}$. Input dead-band with variable width was added to the controller to tackle the problem of measurement (input) noise in vicinity of the user's neutral position and allow the user to keep the platform stationary when needed. Motion direction reversal situation is also handled separately, improving the deceleration during braking action.

Electrical and drive system

Main power supply consists of two 12 V, 18 Ah lead acid batteries that power the motor drivers via an emergency cut-off relay, the embedded computer via a 5 V switching power supply and CAN (Controller Area Network) devices via separate 12 V switching power supply. The propulsion system basically mimics a two-wheeled robot with a differential drive. Each driven wheel has its own 100 W geared electric motor with a shaft encoder and a dedicated speed controller that is attached to the shared CAN bus on the device. Each motor driver executes a closed loop speed control algorithm with adjustable current limits. Motor parameters (e.g. position, speed, motor current, etc.) are adjustable and observable using the CAN bus protocol.

CAN communication bus

CAN is a broadcasting digital bus designed to operate at preselected speeds from 20 kbit/s to 1 Mbit/s with the transmission rate selected depending on the bus length, topography and transceiver capabilities. CAN is an attractive solution for embedded control systems because of its low cost, light protocol management, the deterministic resolution of the contention, and the built-in features for error detection and retransmission. CAN has a proven reliability in automotive and process industry and was therefore a preferred option for a network between different low-level subsystems in the Hoist system. A relatively conservative bus speed of 250 kbit/s was chosen for the CAN bus in this project (illustrated in Fig.??) that has a total length of 4 m with two 1 m long stubs (unterminated bus ends). Split-type bus termination was used on left and right motor driver CAN nodes, as suggested in A simple bi-directional gateway between CAN bus and UART (Universal Asynchronous Receiver/Transmitter) was designed in order to simplify the access to the CAN bus from the high-level control system, which lacks support for CAN bus communication.

Tilt sensors

The device is equipped with three tilt sensors, two of which are mounted on the vertical support struts and one mounted on the base (platform chassis). This sensor arrangement provides a simple method of measuring the relative orientation between the support frame struts and the base. Since the motion in each axis is restricted mechanically to approximately _15 degrees from vertical and corresponding angular velocities are low, tilt angles are calculated independently for each axis (producing angles _ and _, as indicated in Fig.??). Since the support struts are mechanically restricted from rotating around the third (vertical) axis, estimation of the third orientation angle is not required for this application.

Servo drives

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Original motor drivers for the 40 V, 100 W geared electric motors with built-in shaft encoders were embedded into the control box hardware in front of the platform. Since there was no external interface available to control them, various commercial compact servo motor controllers were initially evaluated for this application, but most failed to work properly at low operating speeds. Therefore, a custom servo motor controller was designed, which operates appropriately at low rotational speeds and also fits into the tight space in the drivetrain housing itself (Fig. ??). The application running on the servo controller allows the access to all controller parameters, current position, speed and motor current via CAN bus messages.

Embedded system

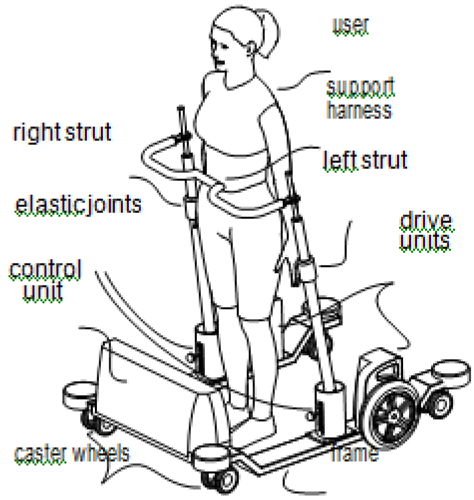
Initially a compact embedded system Beagle Bone Black was selected as the main computational platform for the project, but was later replaced by a more capable Odroid XU3 embedded system. Additionally, a small wireless router was used to provide a reliable WiFi connection between the Hoist system and the external monitoring and control computers. To interface the CAN bus devices, a USB-UARTconverter was used to talk to our custom UART-CAN gateway. Battery voltages, bumper switches and other configuration switches were connected to a PoKeys57U USB device, which is interfaced by the embedded computer with the help of a cross-platform open-source communication library PoKeysLib

Environment sensing

Three parts of the primary hoist system are used to sense the physical environment – wheels odometry information, bumper switch sensors and platform tilt sensor. Each driven wheel of the hoist is equipped with an encoder, whose position is constantly tracked by the servo drive (for the purpose of closed-loop speed control and position tracking) and broadcasted over CAN bus. The main ROS node receives both left _EL;k and right _ER;k wheel encoder information from servo drives and combines this information into odometry data.

HARDWARE REQUIREMENTS:

System : Intel Core i3 2.8 GHz.
Hard Disk : 250 GB.
Monitor : 15" VGA Colour.
Mouse : Logitech.
Ram : 1 GB.
SOFTWARE REQUIREMENTS:
Operating system : Windows 7.
Coding Language : ECE
Data Base : SQL Server 2008



CONCLUSION:

The prototype of walk rehabilitation system with the implementation of the presented control system has been proven in experimental study for being very intuitive and easy to adopt by the users. Most indicative are the experimental runs executed in External control mode (remote control by the operator), which produced data, that clearly show a positive correlation between the user's intention (pelvic rotation) and the rotational velocity along the prescribed reference trajectory. The subjects were only instructed to follow the motion of the platform along the trajectory and since the pelvic

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rotation clearly exceeded the platform's orientation changes along the path, we assume that the presented approach to the prediction of the user's intention is valid and allows natural motion control of the platform. Precision of the reference trajectory shape execution improved by a large margin when the control was handed over to the subjects themselves, indicating their ability of precise control over the motion of the system. Interestingly, although leg injury simulation was used in run 6, results generally improved over those from run 3. This can be explained by additional experience gained during runs 4 and 5 and system's ability to cope with stray input signals, originating from the injury-induced changes in their walking patterns.

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