# Development of a Human-Friendly Walking Assistive Robot Vehicle

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*Abstract*—Up to now, the embodiment of bodily-kinaesthetic, perceptual and cognitive capabilities for assistive robots has been scarcely studied. This research aims to incorporate and develop the concept of robotic human science and to enable its application in a human-friendly robot for assistive purposes. In this paper, the author describes a human-friendly walking assist robot vehicle developed at Karlstad University designed to provide physical support to the elderly. The proposed system is composed by two-wheeled inverted pendulum mobile robot, a 3-DOFs haptic interface, a mobile computer and a wireless module for communication purposes. Preliminary experiments to verify the stability of the whole system and to validate the feasibility to exert force feedback under dynamic conditions are presented.

## I. Introduction

Even though the market size is still small at this moment, applied fields of human-friendly robots (e.g. assistive robots) are gradually spreading from the manufacturing industry to the third industry. Several companies have introduced assistive robots into the market. Some examples are the GiraffPlus telecare platform designed to help the elderly to stay in touch with care givers, relatives and friends [1], the robotic eating device Bestic designed for persons with reduced or no capability in their arms or hands [2], etc.

On the other hand, most of the research has been mainly focused in developing assistive robots for the elderly in terms of telepresence robotic platforms designed for maintaining the elderly social contacts ([3] and [4]), wheeled walker platforms designed for turning away from obstacles and prevent elderly from accidents ([5], [6] and [7]), pet-like robots designed for raising the quality of life among people with dementia in the later stage of their illness ([8]).

In particular, different walking-aid robots have been proposed during the last decades [9-14]. In particular, the walking-aid robots can be classified in two main groups according to the mobility factor [9]: active-type walkers driven by a servo motor (e.g. [11-12]) and passive-type walkers driven by a servo brake (e.g. [13-14]). Spenko proposed in [10] the PAMM system together with a smart cane robot with a relative small size but the maneuverability is compromised by the cost. Fukuda introduced in [9] an intelligent cane robot consisting of a stick, a group of sensors for recognizing the user's intentions and an omnidirectional mobile platform. However, the physical support is provided by means of a fixed length and stiffness aluminum stick and cannot be customized depending on the needs of the specific user (required level of physical support during their daily activities) and environmental conditions (indoor/outdoor). From those researches; a special focus has been done in terms to increase the level of multimodal interaction, sensing and control to facilitate the perception of the environment for a better guidance and provide a static physical support to avoid falling down. However, dynamic physical support (e.g. by means of a variable stiffness mechanism), the adaptability to the user/task needs (e.g. human-in-the-loop control), and the multipurpose design concept (e.g. provide support to the elderly and/or care gives) have been scarcely studied.

For this purpose, at Karlstad University, the author introduced in [15] to incorporate and develop the concept of robotic human science introduced by Takanishi in [16] and to enable its application in a multipurpose human-friendly robot designed to provide physical support to the elderly as well as assisting care givers. On the one hand, models of human motor control and learning, as well as cognition should allow creating truly interactive human-friendly robots; on the other hand, modelling human-friendly robots allows the development for reverse engineering and scientific understanding of human motion, perception and cognition. The focus of the research is embodying perceptual (sensing the incoming stimuli), cognitive (processing the incoming stimuli) and bodily-kinaesthetic (response to the incoming stimuli as a result of combining perceptual and motor skills) capabilities. Due to the complexity of the proposed research, currently two assistive robots vehicles are under development aiming to integrate them into a single platform: an intelligent carrying-medical tools robot vehicle [17] and a human-friendly assistive robot vehicle for supporting physically elderly [18]. In particular, a RGB-D camera and a haptic interface will be mounted in a two-wheeled inverted pendulum robot vehicle.

As for the development of a human-friendly robot vehicle for carrying-medical tools (*iCAR*) [17], the robot is designed for assisting care givers in order to transport medical tools. *iCAR* is composed by a mobile robot vehicle with two-actuated motors and four-passive wheels. A simplified fuzzy logic controller has been implemented for the navigation control and a Time-delay neural network (TDNN) was implemented for the 3D gesture recognition.

In this paper, we present the current research development of a human-friendly walking assist robot vehicle for supporting physically elderly.

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## II. Development of an Human-Friendly Assistive Robot Vehicle for Supporting Physically Elderly

The human-friendly WALKing assist robot vehicle (*hWALK*) developed at Karlstad University [18]. The *hWALK* is composed by (Figure 1): a mobile platform with on board controller and two actuated wheels, a commercial available 3-DOFs desktop haptic interface, a mobile computer and a ZigBee wireless module. In order to place the 3-DOFs Haptic Interface (HI) into the two-wheeled inverted pendulum robot, an ABS holder has been designed with ProEngineer and constructed with a 3D printer.

A desired system's response under terrain even conditions is considered as a constant distance ($d_z$) between the ground and the HI's gripper; a null feedback force ($F_z$ = 0) exerted by the HI should be expected in order to allow free walking motion. However, under uneven terrain conditions, a constant $d_z$ should be maintained by means of an applied force feedback ($F_z \neq 0$). The proposed control system is composed by 4 modules (Figure 2): gravity compensation, force feedback processing, velocity estimation and the wireless communication module (acting as master).

As for the gravity compensation, the mass of the gripper has been computed by using the recursive algorithm proposed in [19]. In particular, during the off-line mass estimation, the direction of the gravity force has been computed; a cubic grid (30 x 30 mm) partition has been defined in the center of the workspace and the apparent mass at each vertex has been estimated. For the on-line mass estimation, a trilinear interpolation has been used to estimate the mass inside the cubic grid

The model reference of the proposed system is shown in Figure 3. In order to compute the force feedback for providing support to the user, the total force is computed by Eq. 1. In particular, the feedback force $F_z$ was computed by means of a spring model as shown in Eq. 2, where $z_{ref}$ is determined as Eq. 3 and $k_{stifness}$ has been experimentally determined ($k_{stifness}$ = 5.91 N/mm). The position of the gripper of the HI along the z-axis respect to the world coordinate reference system ($z_{Pos\_Wcs}$) is computed as Eq. 4. In order to define the desired position of the gripper of the HI ($z_{Pos\_Fcs}$), the user must manually bring the gripper to the desired position and then press the lightning bolt button in the HI.

$$F_{Total\_z} = F_z + F_{z\_comp} \quad (1)$$

$$F_z = k_{stifness} * z_{ref} \quad (2)$$

$$z_{ref} = z_{Pos\_Wcs} - z_{Pos\_Fcs} \quad (3)$$

$$z_{Pos\_Wcs} = (L + z_{Pos\_Fcs}) * \cos(\theta_m) - y_{Pos\_Fcs} * \sin(\theta_m) \quad (4)$$

Figure 1. *hWALK* developed at Karlstad University.

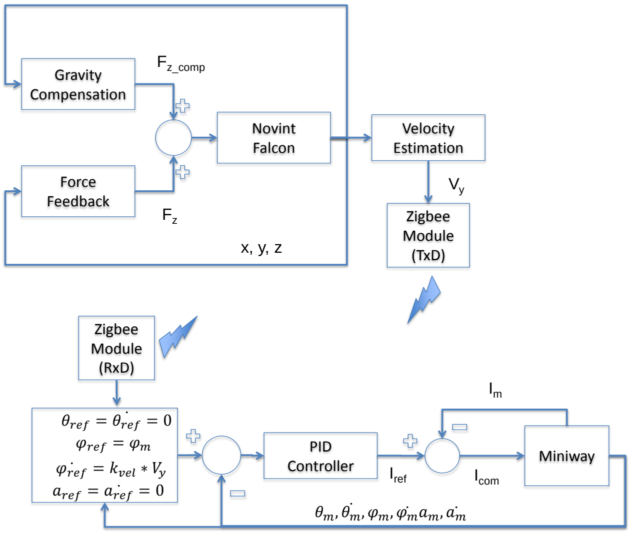


Figure 2. Block diagram of the proposed control system.

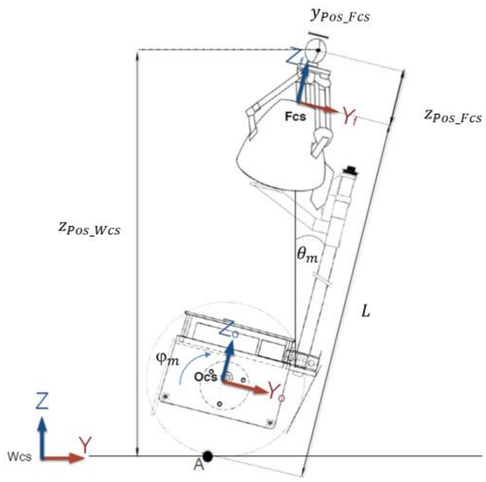


Figure 3. Model reference for *hWALK*.

In order to estimate the reference velocity of the Miniway's chassis, the angular rotation of the chassis with respect to the ground ($\theta_m$) and the position of the gripper ($x_{Pos\_Fcs}$ and $y_{Pos\_Fcs}$) transformed with respect to the ground have been used as shown in Eq. 5, where $\dot{\varphi}_{ref}$ is the desired wheel angular velocity with respect to the ground, $k_{vel}$ is the velocity gain constant that has been experimentally determined ($k_{vel}$ = 100) and $\Delta y$ is the command displacement with respect to the ground which is determined as Eq. 6. Finally, the wireless communication module (acting as master) was programmed to update the HI gripper position ($x_{pos}$, $y_{pos}$ and $z_{pos}$) every 5ms.

$$\dot{\varphi}_{ref} = k_{vel} * \Delta y \quad (5)$$

$$\Delta y = L * \sin(\theta_m) + y_{Pos\_Fcs} * \cos(\theta_m) \quad (6)$$

On the other hand; the control system for the two-wheeled inverted pendulum mobile robot is composed by 2 modules: the PID controller and the wireless module (acting as slave).

In order to assure the stability of the two-wheeled inverted pendulum with an estimated load of 5kg in the top of the pendulum, the integral part has been included in the proposed PD controller implemented in the commercial version as shown in Eq. 7 and Eq. 8, where $\alpha$ and $\alpha_{REF}$ is the measured and desired heading direction respectively, $i_{outR}$ and $i_{outL}$ is the control signal for the right and left motor current motor respectively, $i_R$ and $i_L$ is the measured right and left motor current motor respectively, $k_1$ is the chassis tilt angle control gain, $k_2$ is the chassis tilt angular velocity control gain, $k_3$ is the wheel angle control gain, $k_4$ is the wheel angular velocity control gain, $k_5$ is the chassis yaw angle control gain, $k_6$ is the chassis yaw angular velocity control gain, $k_7$ is the left motor current control gain, $k_8$ is the right motor current control gain, $k_9$ is the angular rotation chassis integral control gain and $k_{10}$ is the wheel angular rotation integral control gain. The gain parameters for the PID controller implemented for the *hWALK* were determined experimentally ($k_1$ = 186.3; $k_2$= 28.6; $k_3$= 5.8; $k_4$= 4.8; $k_5$= 0.024; $k_6$= 0.015; $k_7$= 1.942; $k_8$= 1.942; $k_9$= 0.01 and $k_{10}$= 0.001).

$$
\begin{aligned}
i_{outR} &= k_1 \cdot \theta_m + k_2 \cdot \theta'_m + k_3 \cdot (\varphi - \varphi_{REF}) + k_4 \cdot (\varphi' - \varphi'_{REF}) \\
&+ k_5 \cdot (\alpha - \alpha_{REF}) + k_6 \cdot (\alpha' - \alpha'_{REF}) + k_9 \int_0^T \theta_m dt + k_{10} \int_0^T \varphi dt \\
u_R &= k_7 \cdot (i_{outR} - i_R)
\end{aligned}
\tag{7}
$$

$$
\begin{aligned}
i_{outL} &= k_1 \cdot \theta_m + k_2 \cdot \theta'_m + k_3 \cdot (\varphi - \varphi_{REF}) + k_4 \cdot (\varphi' - \varphi'_{REF}) \\
&- k_5 \cdot (\alpha - \alpha_{REF}) - k_6 \cdot (\alpha' - \alpha'_{REF}) + k_9 \int_0^T \theta_m dt + k_{10} \int_0^T \varphi dt \\
u_L &= k_8 \cdot (i_{outL} - i_L)
\end{aligned}
\tag{8}
$$

## III. EXPERIMENTS AND RESULTS

In order to verify the system stability under static conditions, the chassis of the *hWALK* was held for about 5 seconds until the calibration procedure for the rate gyro was finished. After releasing the chassis, the proposed control system was activated automatically and the system response was verified by logging the chassis tilt angle, chassis tilt angular velocity, wheel angle and wheel angular velocity.

The experimental results while testing the system on a surface with carpet padding are shown in Figure 4. As it may be appreciated Figure 4a, the chassis tilt angle was stabilized in about 16 seconds to the desired angle position (Figure 4a). On the other hand, it can be observed that the first 12 seconds, both the chassis tilt angle (Figure 4a) and chassis tilt angular velocities (Figure 4b) were oscillating periodically around the desired position every 5 seconds (mainly caused by the effect of the load of about 2.7 kilograms corresponding to the ABS holder and HI). Similarly in Figure 4c and 4d, it may be observed that the wheel angle and the wheel angular velocity respectively were deviated around the desired position (mainly caused by the effect backlash of the DC motors as well as the friction of the carpet).

On the other hand, a ramp was constructed (with an inclination angle of 6.7 degrees with a length of 50 cm and a width of 120 cm). A healthy subject was requested to hold the gripper of the HI and set the desired height by pressing the lightning bolt button. Then, the subject was requested to drive up the hWALK. The experimental results are shown in Figure 5. As it can be observed, the desired position of the gripper of the HI set by the subject was 18 mm. During the motion, it can be observed that a maximum force feedback of -4 N was exerted by the HI in order to compensate the height error (due to the inclination of the ramp) within a range of 4 mm. At the end of the top of the ramp, the height error was around 2mm.

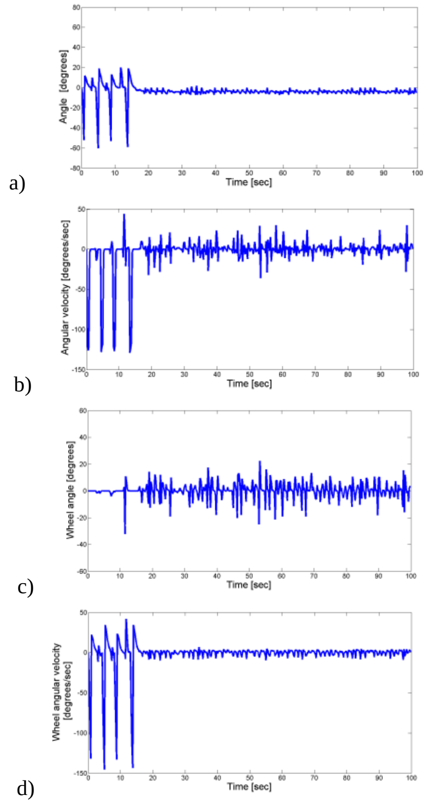


Figure 4. Experimental results obtained under static conditions on a surface with carpet padding: a) chassis tilt angle; b) chassis tilt angular velocity; c) wheel angle; d) wheel angular velocity

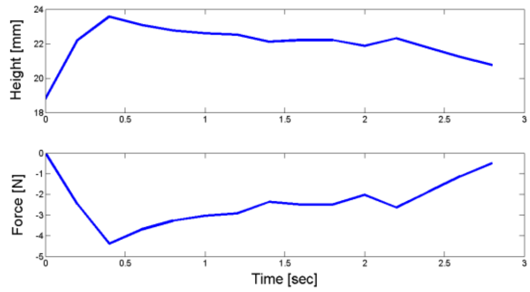


Figure 5. Experimental results with force feedback

## IV. CONCLUSION & FUTURE WORK

In this paper, the development of a human friendly walking assist robot vehicle for providing physical support to the elderly has been described. Preliminary experiment were proposed in order to verify the stability of the whole system as well as to validate the feasibility to exert force feedback under dynamic conditions

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