

A Sensorless Control Strategy for an Active Assistive Walker: Design, Implementation, and Experimental Validation

Muhammad Ishaq, Francesco Cancelliere, Giuseppe Sutera, Dario Calogero Guastella, Giovanni Muscato

Abstract—With the increase in elderly population throughout the world, especially in the European Union, there is an utmost need for assistive technologies to help them achieving daily tasks in an independent or collaborative manner. This paper presents a novel sensorless control for an active assistive walker featuring a disturbance observer for the estimation of the force applied by the user (thus eliminating the need of external force sensors) and admittance control for smooth locomotion. The experimental validation is carried out in the ROS2 framework for data computation and analysis. The walker, driven by motorized wheels, is tested on flat and inclined surfaces. The results demonstrate accurate force estimation, efficient motion control, and stable assistance with a balanced tuning of the admittance control parameters, i.e. virtual mass and damping, thus ensuring responsive and smooth behavior of the system.

Index Terms—Assistive Robotics, HRI, Elderly Care, Sensorless Control, Disturbance Observer, Admittance Control.

I. INTRODUCTION AND BACKGROUND

A significant fall in the mortality rate globally has led to considerable changes in the age division among societies. The older population is consistently growing with a decrease in newborns, leading to an increase in the over-60 age group. It is predicted that by 2050, people aged 60 and over will surpass 1.5 billion [1]. Therefore, the effort of society, primarily dedicated to elderly people’s care, presents significant challenges with implications not only on social aspects but also on the economy [2]. These statistics prove the need for efficient elderly care solutions regarding different aspects such as activity planning, rehabilitation, therapies, and most importantly use of robotic assistance for healthcare, making them capable of aiding in routine tasks in a collaborative or independent manner [3].

Robotics plays an integral part in healthcare support by offering elderly people an independent life, avoiding the need for additional assistance. Over the past few decades, wearable and assistive robotics have helped elderly individuals by reducing their reliance on physical effort in daily tasks. Several robotic

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(Corresponding author: Muhammad Ishaq)

The authors are with the Department of Electrical Electronic and Computer Engineering, University of Catania, Catania, Italy.
(e-mail: muhammad.ishaq@unict.it,
francesco.cancelliere@phd.unict.it,
giuseppe.sutera@unict.it, dario.guastella@unict.it,
giovanni.muscato@unict.it).



Fig. 1. Active Assistive Walker Prototype
(Pink: Motorized Wheels, Yellow: Caster Wheels, Green: CPU, Red: Motor Control Board, Blue: IMU, Purple: Power Board)

devices have been presented in the literature engaging elderly people in a human-robot interactive environment, making them capable of achieving autonomy and supporting mobility.

A smart walker is an advanced mobility aid equipped with sensors, actuators, and intelligent control systems to help individuals with mobility challenges. In [4], a smart walker was proposed aiming to assist users intelligently through navigation of the surroundings with actuators and sensors for accepting commands through gestures. In [5], four different configurations of a smart walker were studied, targeted to the specific needs of the users, and validated by experimental results. Sierra et al. [6] introduced a novel human-robot interface for smart walkers integrating human intention detection, estimation of gait cadence and environment interaction such as obstacle detection for enhanced mobility. The proposed mechanism was dependent on sensors along with predefined maps limiting the efficacy and adaptability of the system in

given by:

$$F_t = \frac{g_r}{r} \left(K_t I - J \frac{d\omega_m}{dt} - D_m \omega_m \right) - mg \sin \theta \quad (2)$$

Here, r is the wheel's radius, while J , D_m , ω_m , and I are respectively the inertia, damping, angular speed, and the current of the motor. The force that the user applies on the platform is indicated as F_x . Therefore, the resultant force applied on the platform on the slope is given by 3.

$$F = F_x + F_t - F_r = mr \frac{d\omega}{dt} + D_w r \omega \quad (3)$$

Here, D_w is the damping of the walker. From 3, substituting 1 and 2 we get the force that is applied by the user on the platform.

$$F_x = mr \frac{d\omega}{dt} + D_w r \omega + cmg \cos \theta - \frac{g_r}{r} \left(K_t I - J \frac{d\omega_m}{dt} - D_m \omega_m \right) + mg \sin \theta \quad (4)$$

Thus, the force applied by the user can be estimated solely based on the motor's velocity and current.

B. Admittance Control

Admittance control defines the dynamic relationship between forces being applied on the platform (inputs) and resultant velocity (output), which makes the system to behave like a mass-spring-damper system. In the present work, the admittance control takes the estimated force applied by the user of the platform from the disturbance observer and computes the reference velocity V_{ref} for the motors. This allows the platform to deliver appropriate assistance taking into account the user's intention. The admittance of any mechanical system can be described as a transfer function given by 5.

$$G(s) = \frac{V(s)}{F(s)} = \frac{1}{Ms + D} \quad (5)$$

When there is a large admittance, it corresponds to the rapid motion induced by the forces being applied by the user, while a smaller admittance represents a slower reaction to acting forces. In our case, $G(s)$ is the transfer function of the overall system. V is the reference velocity or output speed of the platform, and F represents the force being applied by the user on the platform. M is the virtual mass of the system, and D is the virtual damping of the system. Therefore, the canonical step response can be given by 6.

$$V(t) = \frac{F}{D} \left(1 - e^{-\frac{t}{\tau}} \right) \quad (6)$$

Where $\tau = \frac{M}{D}$. Thus, D affects the force being applied by the user, while M influences the responsiveness of the platform.

The admittance control has been implemented in discrete time. Thus, the transfer function has been discretized using Tustin's method, i.e. by posing s as in 7.

$$s = \frac{2z - 1}{Tz + 1} \quad (7)$$

Here, T is the sampling time. Therefore, by substituting 7 in 5, the resulting discretized transfer function is given in 8.

$$G(z) = \frac{T}{2M + DT} \frac{z + 1}{z + \frac{-2M + DT}{2M + DT}} \quad (8)$$

The first order discretized transfer function has a unique pole given by 9.

$$z = \frac{2M - DT}{2M + DT} \quad (9)$$

For the stability analysis of the system, the condition given in 10 must be verified.

$$|z| < 1 \iff \begin{cases} M > 0, & M < \frac{DT}{2} \\ D > 0, & M > \frac{DT}{2} \end{cases} \quad (10)$$

By fine tuning through trial and error the values of virtual mass (M) and virtual damping (D), the platform is stabilized while ensuring proper assistance to the user. Specifically, with the chosen values the walker is reactive enough to compensate for sudden changes in the applied force while ensuring safety for the user by avoiding uncomfortable conditions, e.g. dragging the user.

III. PRELIMINARY TESTS

The proposed sensorless control scheme has been implemented on a commercial walker modified with active wheels, a processing unit, and the necessary sensors. Afterwards, primary assessment of the behavior of the proposed controller scheme has been performed.

A. Prototype

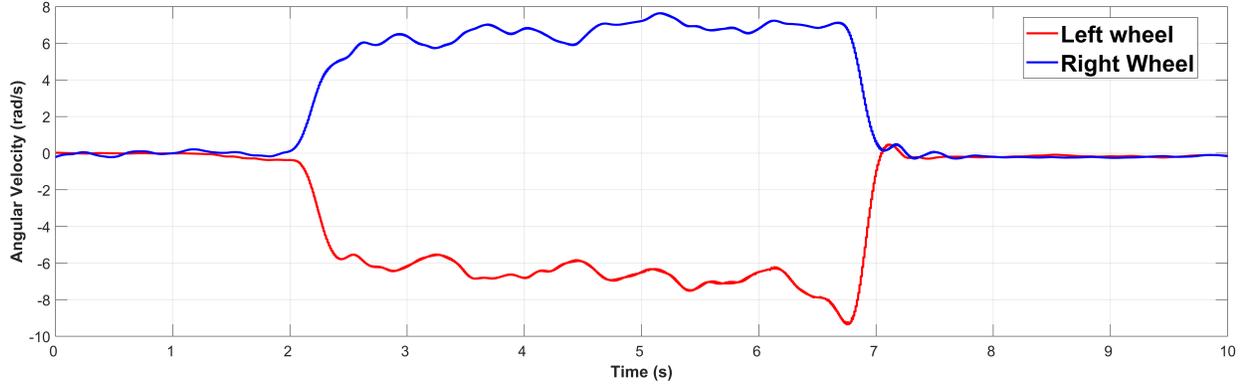
Figure 1 illustrates the prototype of our active assistive walker. It has a lightweight aluminum frame with two front caster wheels and two actuated rear wheels. The latter has hub brushless DC motors (BLDC) for driving the platform and replacing the original walker's passive wheels equipped with Hall-effect sensors for speed estimation. The mechanical braking system is eliminated because deceleration and stopping are implemented through the control of rear wheel motors.

The motor drive control board is a dual-channel motor driver capable of torque, position, and velocity control with the help of cascaded PID control loops¹. In our work we have used only the velocity control and implemented the disturbance observer with the motors' angular velocities ω and currents I measured by the motor control board.

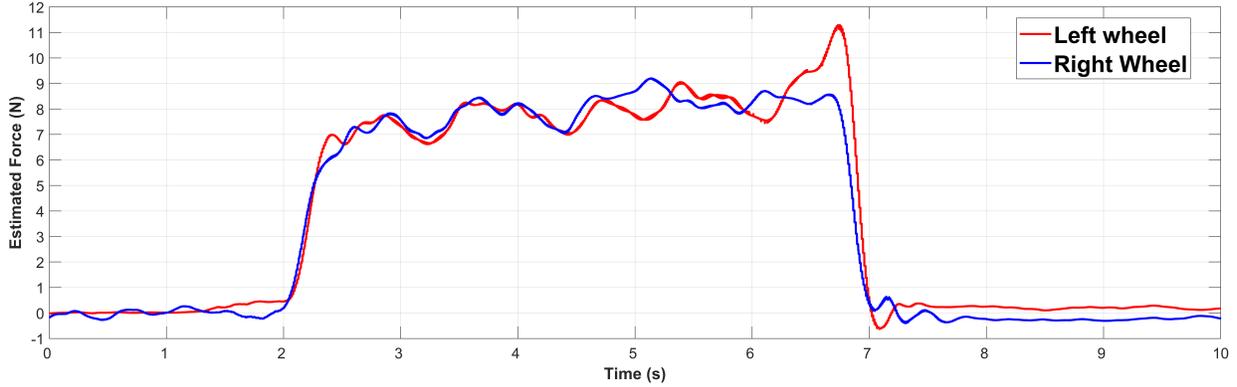
A Raspberry Pi 4 board is used as the main central processing unit of the platform. The whole software framework of the smart walking assistance is implemented through Robot Operating System 2 (ROS2), which is used for handling the control algorithms, processing data, and communicating with the motor drive controller.

An inertial measurement unit is integrated to acquire the platform's inclination, allowing the control system to compensate for terrain slopes.

¹<https://docs.odriverobotics.com/v/latest/manual/control.html>



(a) Angular Velocity



(b) Estimated Force

Fig. 4. Angular velocity and estimated force when going straight from stationary position.

The control scheme works only on one wheel at a time, so it is applied to both wheels independently. This does not change the behavior of the walker, since when going straight the force applied by the user will be sensed by both wheels. When turning, most of the force is applied on one side of the walker, opposite to the direction of the turn i.e., if turning right then push is on left wheel and vice-versa, since it has to move more than the latter. Thus there is no need of interaction between the controls of both sides.

B. Experimental Procedure & Results

The values of the parameters used for the sensorless control implementation are reported in Table I. All these values were either measured or calculated, with the exception of the virtual mass (M) and virtual dampness (D), which are design parameters and were experimentally tuned. The values of D were varied between 8 to 12, and for M were varied between 1 to 3. The final values were chosen as a compromise between the stability of the platform and the user's perceived assistance.

Initial assessment of the platform has been performed with a qualitative analysis of the estimated torque and the reference speed given by the admittance controller when the walker is being pushed on a flat surface. Two tests have been conducted

TABLE I
PLATFORM AND CONTROL PARAMETERS

Parameter	Value
Platform's mass (m)	14 [kg]
Rolling Friction Constant (c)	0.08
Radius of Wheel (r)	0.08 [m]
Motor's Inertia (J)	2.01×10^{-4} [kg · m ²]
Motor's Damping (D_m)	4.141×10^{-5}
Gear Ratio (g_r)	1
Platform's Dampness (D_w)	0
Motor's Torque Constant (K_t)	4 [Nm/A]
Sampling Time (T)	40 [ms]
Virtual Dampness (D)	10
Virtual Mass (M)	1

to evaluate the behavior: moving forward and turning. This gives a good intuition of the behavior of the walker.

Figure 4 reports each wheel's angular velocity and estimated force when going straight. When the walker is stationary with no external force being applied, the estimated force is 0, as expected. When the user starts pushing forward, the estimated force is being detected, and then each wheel starts moving. It is worth noticing that when moving forward, one wheel is moving clockwise, and the other counterclockwise propelling

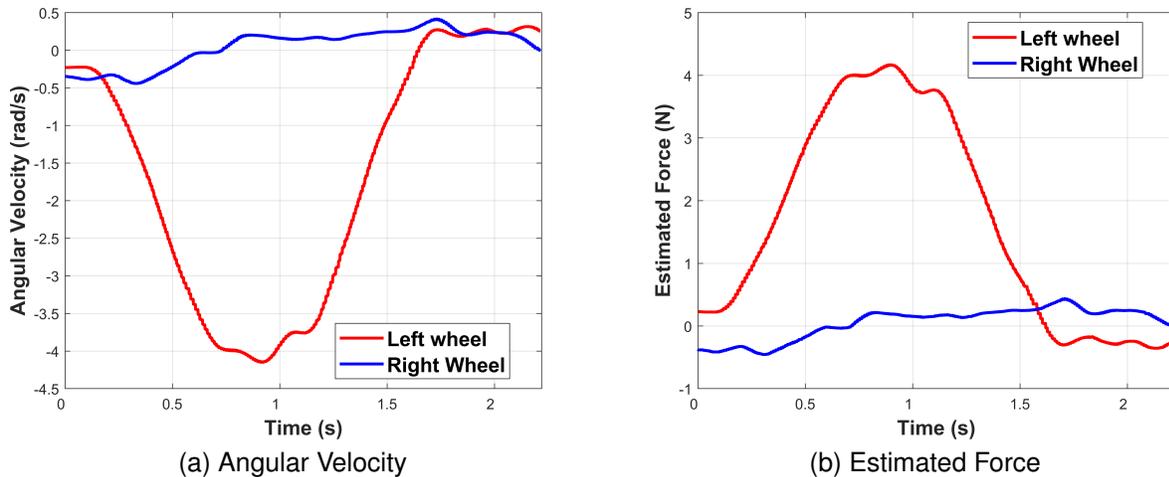


Fig. 5. Angular velocity and estimated force when turning

the motion. This is resulting in the estimated force to be positive, but the velocity commands to be mirrored.

It is worth mentioning that the values of the estimated force have been validated with a handheld gauge, ensuring authenticity of computed values. When turning (Figure 5) the estimated force on one wheel is zero, whilst the other is sensing a force, so it moves.

Similarly, the prototype platform was tested on inclined path as well and the results featured same trend as Figure 4. Hence, for the sake of avoiding repetition, such results are not shown in the paper. Overall, both tests show that the expected results match with the behavior of the real platform.

IV. CONCLUSIONS & FUTURE WORK

This paper presents the implementation and initial testing of a sensorless control method for an active smart walker with an ambition of helping elderly people achieve independence. The proposed method uses a disturbance observer to estimate the pushing force applied by the user and admittance control for smoother movement. The experimental results have demonstrated that the proposed strategy can provide a reliable estimation of the force applied by the user, thus eliminating the need for any external force sensor. Admittance control of the platform's velocity ensures smooth movement through properly tuned values of virtual mass and damping. The robotic walker was able to deliver smooth assistance to the user on both straight and inclined surfaces.

Although preliminary tests show promising results, these values have to be validated with more analysis. First of all, the force estimation has to be compared with a reference sensor and with a known force. Overall, this control scheme is a good initial point that, once properly validated, can be further expanded with a shared control architecture having obstacle detection from LIDAR to further enhance the user's safety. Future prospects also comprises of investigating the fact that when a common user uses the platform may exerts a downward

vertical force on it which may cause changes in the rolling friction force. Another aspect worth of investigation is related to battery autonomy and power consumption. The cases of uncertain situations such as autonomous condition of platform on slope or when walker pulled by the user is to be studied in future, along with control behavior in presence of motor parameter uncertainty.

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