AGoRA Robotic Walker: Smart Navigation System for Gait Assistance

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Abstract

The constant growth of pathologies affecting human mobility has led multidisciplinary teams to develop different robotic assistive devices to provide physical and cognitive assistance. Intelligent walkers have emerged as a great alternative. They integrate navigation systems, shared control strategies, trajectory tracking algorithms and user interaction modules to ensure a natural and intuitive interaction with the user. For this reason, this paper presents the AGoRA robotic walker, its features, modules, sensors, actuators, processing units and a usability test with a healthy subject.

Index terms: Smart Walker, Human Mobility, Older Adults

1. Introduction

In recent years, the incidence and prevalence of health conditions and pathologies affecting human gait have been significant and vital growing (Vaughan, 2003). Among these conditions, several neurological and musculoskeletal impairments are found. For instance, pathologies such as Cerebral Palsy (CP), Stroke and Spinal Cord Injury (SCI) compromise mobility (Cifuentes and Frizera, 2016). Similarly, due to the natural weakening of the musculoskeletal system, the older population also presents mobility limitations. According to the World Health Organization (WHO), is estimated that 15% of the population suffers from some form of impairment, and the global proportion of adults aged 65 years and older is expected to increase to 16% by 2050 (Organization, 2015).

For this reason, some assistive devices have been designed and deployed in clinical and rehabilitation scenarios (Sierra M et al., 2021). Specifically, devices such as canes, crutches, rollators, wheelchairs, and ambulatory training devices constitute the conventional fleet of gait assistive tools. Conventional walkers or rollators have been usually identified as a valuable tool as they provide higher stability and decrease the risk of falling. However, not enough support could be provided to people with cognitive impairments with this type of device (Cifuentes and Frizera, 2016). Multiple advances in robotics and electronics allowed the incorporation of actuators and sensors in conventional walkers to offer better guidance, orientation, and localization. These walkers with robotic capabilities are often called robotic or smart walkers (SW) (Jimenez et al., 2018).

2. Development

2.1 Statement of the problem

One of the motivations of this project is the constant growth of pathologies that affect human mobility and that of the worldwide proportion of older adults. For this reason, the implementation and preliminary evaluation of a robotic walker for pathological gait support is proposed.

2.2 Materials and Methods

This section describes the robotic platform, its features, modules, sensors, actuators and processing units. It also presents the interaction strategy proposed to provide an adequate level of assistance to the user. Besides, this part details the tests performed and the experimental setup and the data collected in each of them.

2.2.1 Robotic Platform Design

Regarding the construction of the walker, a preliminary design was made in SolidWorks (Dassault Systèmes, France) to define the dimensions of the platform and the spaces available for the electronic components. This design was proposed to ensure user safety and ensure that the platform can support the subjects' weight. Subsequently, the materials were defined (steel base and the storage area in medium-density fibreboard sheets) and construction began. On the other hand, after an exhaustive review of electronic components, those that would allow the platform to interact efficiently and safely with the environment and the user were chosen.

2.2.2 Human Robot Interaction Strategy

Admittance controllers, widely used in SW, are dynamic models that allow the robotic device to respond effectively to the user's movement intentions (Jimenez et al., 2018). This type of strategy makes it possible to virtually modify the impedance of the walker, emulating different levels of assistance. With these controllers, it is possible to generate speed commands based on the force and torque exerted by the user. Depending on the controller constants, the SW can resemble a light or heavy device (Sierra M et al., 2021). Thus, these strategies aim to provide users with feelings of ease and naturalness during physical interaction with the robotic walker.

This study implements two admittance controllers to generate linear and angular velocities considering user-applied torque and force signals. The outputs are linear (v) and angular velocities (ω), as described in Equations 1 and 2:

$$L(s) = \frac{v(s)}{F(s)} = \frac{1/m}{s + b_1/m} \quad (1)$$

$$A(s) = \frac{\omega(s)}{\tau(s)} = \frac{1/J}{s + b_A/J} \quad (2)$$

Where m is the walker’s virtual mass, J is the virtual moment of inertia of the walker, and $b1$ and b_a are damping constants, F the force and τ the torque. These equations describe the transfer function of each controller. *L(s)* stands for Linear System, and *A(s)* stands for Angular System. For this purpose, the virtual mass (m), inertia (J), and damping constants (b_1 and b_a) were adjusted after several experimental tests with healthy subjects (Sierra M et al., 2021). In particular, the following values were used: m = 0.5kg, b_1 = 4N.s/m, J = 2.1kg.m2/rad and b_a = 2N.m.s/rad.

2.2.3 Experimental Protocol

For the test to evaluate the walker, a healthy subject (20 years old, weight of 74.5 kg, height of 1.73 m) without any physical limitation, was recruited.

For the usability test, three path-following tasks were posed, a right turn (RT), a left turn (LT) and a straight (ST). It is essential to highlight that the subject had to repeat each of the tests three times. For this, different kinematic parameters (such as speed and duration of the test) and physical interaction parameters (such as force and torque impressed by the user on the arm supports of the walker) were measured.

3. Results and Discussion

Figure 1 shows the final version of the robotic device and its main' sensors and actuators. It is important to highlight that this platform has an approximate weight of 60 kg, height of 1.18 m, width of 0.79 m and depth of 0.85 m.

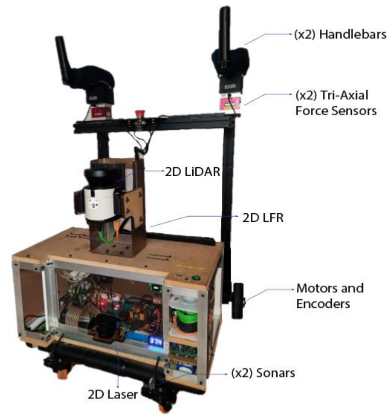

Figure 1. AGoRA Robotic Walker description.

The platform is equipped with an onboard computer running a Linux operating system distribution compatible with the Robotic Operating System (ROS) framework. Moreover, it is endowed with different sensors, actuators, and processing units such as (1) two motorized wheels and two caster wheels that provide propulsion and stability to the walker; (2) two encoders and an inertial measurement unit (IMU) to estimate the position and orientation of the device; (3) a 2D light detection and ranging (LiDAR) sensor (S300 Expert, SICK, Waldkirch, Germany) to sense the environment and detect obstacles; (4) two ultrasonic plates to detect objects at low height; (5) two triaxial load cells (MTA400, FUTEK, Irvine, CA, USA) to estimate the user's navigation commands; (6) an HD camera (LifeCam Studio, Microsoft, Redmond, WA, USA) for human detection; and (7) a 2D laser rangefinder (Hokuyo URG-04LX-UG01, Osaka, Japan) to estimate the user's gait parameters.

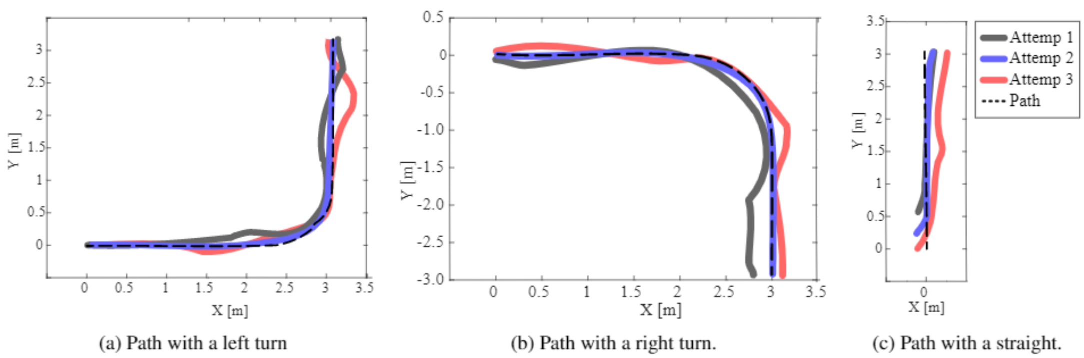

Figure 2. Path following task results.

As for the usability test, Figure 2 presents the results obtained by the subject in each of the trials performed in the proposed path following tests. Overall, these demonstrative results suggest that there was not much discrepancy between each of the attempts. On the other hand, Table 1 presents the results of the kinematic and physical interaction data between the user and the walker. Regarding the duration of each test, it can be observed that the tests that included a twist showed longer times, which was to be expected.

Parameter	ST	RT	LT
Duration [s]	4.67±0.23	9.84±0.83	9.96±0.68
Speed [m/s]	1.59±1.05	1.62±0.55	1.61±0.96
Mean Force [N]	0.58±0.24	1.67±0.60	1.65±0.09
Max. Force [N]	1.24±0.36	4.47±1.23	4.31±0.31
Mean Torque [Nm]	0.14±0.17	0.38±0.10	0.37±0.19
Max. Torque [Nm]	0.22±0.06	1.56±0.40	1.55±0.75

Table 1. Summary of kinematic and physical interaction data between the user and the AGoRA Smart Walker. Right turn (RT) left turn (LT) and straight (ST).

However, for RT and LT, the times did not differ so much. This may indicate that, regardless of the orientation of the turn, the walker effectively assisted the participant, allowing him to finish the test at similar times. This result is supported by the speed obtained during the test (see Table 1), since for the three tasks, similar values were presented. These results are supported by the literature, as (Frizera Neto, A et al., 2010) they highlight the importance of controllers for these devices to give the correct level of assistance for subjects to successfully complete the tests.

Among the most important results, we can highlight the increase in force and torque in the tests that included turns. Specifically, the maximum values were recorded when the subject was spinning. This indicates that the participant needed to lean on the walker to maintain stability and complete the test. These results suggest that the walker can help compensate for the user's support and stability in path-following tasks that require more significant physical effort.

4. Conclusions and Future Work

Human-Robot Collaboration has been widely exploited in several application fields of robotics. Some studies have described the benefits of physical interaction between robotic agents and humans and the need for active user involvement in rehabilitation settings. In this regard, a smart walker was proposed and evaluated as a promising alternative for gait assistance.

The results obtained in terms of the force and torque that the user applied to the walker during the tests suggest that the walker can assist, support, and provide stability during the most physically demanding tasks, including turning.

Finally, as future work, we hope to evaluate the walker in a larger group of subjects, preferably pathological or with some type of physical limitation. Besides, we intend to include standardized usability questionnaires to find out their perception of the device.

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