Reactive Navigation of an Intelligent Robotic Walking Aid

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Abstract

This work presents the intelligent walking aid system Care-O-bot. Care-O-bot is the prototype of a multi functional home care system, to be used by elderly people in order to live independently in their homes. In order to enable easy manipulation of the robot platform, the way to use it as a walking aid has been adapted to conventional walking aid systems. The robot drives in reaction to input forces given by the user, for example if the user "pushes" the robot forward, it will start moving in the required direction. As an improvement to conventional walking aid systems, intelligent behaviours, as for example autonomous obstacle avoidance and path planning are included.

1. Introduction

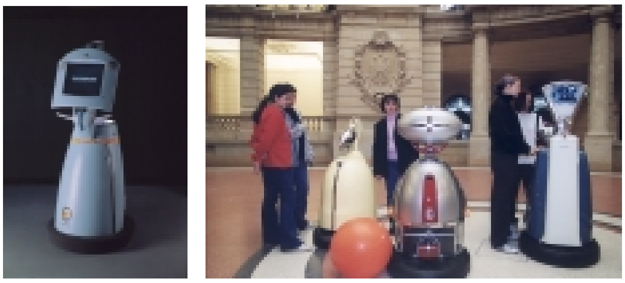


Figure 1. Care-O-bot I and museum robots

Care-O-bot (Figure 1) is the prototype of a robotic home care system developed at Fraunhofer IPA. A first mobile platform has been built in 1998 [24]. Care-O-bot has already proved its ability to operate safely and reliably in public environments. Three robots based on the same hardware platform have been installed in March 2000 for constant operation in the "Museum für Kommunikation Berlin" where they autonomously move among the visitors, communicate to and interact with them [7] [10] [26].

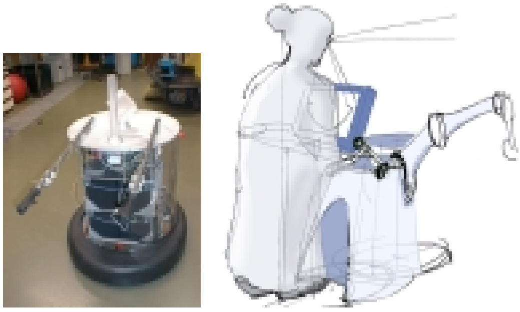


Figure 2. Care-O-bot II prototype and design

Care-O-bot II (Figure 2) will be equipped with a manipulator arm and moveable walking sticks. The basic platform has already been built. In order to provide support for walking and standing up, two arms adjustable in height have been attached to the mobile platform.

Figure 3. Walking aid handles with sensor

To measure forces applied by the user, the handles attached to each arm can slightly be moved. The distances covered are measured by displacement transducers integrated in the walking supports (Figure 3).

2. Background

Throughout the last few years, various research institutes started the development of intelligent robot prototypes, which could make life for the elderly and disabled more comfortable [5] [6] [8] [23] [27] [29]. The "Handy 1" system [30], for example, assists the most severely disabled with several everyday functions. "Movaid" [3] is a mobile manipulator designed as a mobile home care system whereas the development of the "Nursebot" [1] is only the first step of a project aimed at the development of personal service robots for the elderly and disabled.

Several walking aid systems have been developed to provide orientation for blind people in new and highly unstructured environments [11] [28].

The “GuideCane” [2] is probably the most advanced system of that kind. It comprises of a long handle and a “sensor head” unit that is attached at the distal end of the handle. The sensor head is mounted on a steerable but unpowered two-wheeled steering axle. Ultrasonic sensors detect obstacles and steer the device around them. The user feels the steering command as a very noticeable physical force through the handle. Further information is given by auditory feedback.

“Hitomi” [15] is another prototype of a robotic travel aid for blind people. It can be used for orientation, mobility, and map based guidance. It provides information about obstacles, present location, landmarks and future parts of the route to its user.

Only few prototypes have been developed for providing secure walking support to elderly and frail people by enhancing existing walking aid systems through the integration of sensor based autonomous navigation (Figure 4).

Figure 4. Intelligent walkers PAM-AID, Smart Cane PAMM, and prototypes by Hitachi and KAIST

The “PAM-AID” system [16] [17] [20], developed at Trinity College, Dublin, provides a smart mobility aid for frail, blind and visually impaired users. Similar to conventional walkers, the system consists of a metal walking frame with a handrail for physical support and for turning the robot. The vehicle is further equipped with several safety sensors and a safety button that must be pressed constantly during operation. No motorised locomotion is used, however, motor controlled steering of both front wheels can be activated for secure obstacle avoidance. The system further comprises a multi-modal user interface and audio feedback to the user.

Two prototypes of the walking aid system “PAMM” [4] have been developed at MIT, Boston. A first version is the cane-based system “Smart Cane PAMM”. A second version, “Smart Walker PAMM”, was adapted to conventional walking frames and includes omnidirectional drives. Both systems are to be used to “provide physical support and guidance to elderly with mobility difficulty due to physical frailty and/or disorientation due to aging and sickness”. They can operate in known structured indoor environments with random obstacles such as furniture and people.

Another walking support system developed by Hitachi, Japan [22] supplies moderate support in standing up, walking around, and sitting down. Special efforts have been put in gravity compensation on slopes (up to 5°, short time 10°). A compensation for unbalanced force input is further provided. Assistance during walking is given by an electrically power assisted arm supporter. Driving/steering is done by pushing/pulling/turning the supporter, the driving speed of the vehicle is controlled through the applied force.

Finally another walking support system for elderly or handicapped people in rehabilitation [19] has been introduced by KAIST, South Korea.

The reviewed walking aid systems have one thing in common. A mobile platform has been build specifically as an intelligent walking aid. It is an even larger challenge to add the functionality of being a walking aid to a mobile robot which also comprises numerous other functionalities. To function as a walking aid the navigation software for such a robot must be adapted to fit dynamic and geometric constraints without restricting essential mobility features.

3. System Requirements

Figure 5. Conventional walking aid systems

In order to make the use of a robotic walking aid as similar as possible to widespread conventional walking aids (Figure 5), the geometry of the walking sticks attached to the robot must be consistent with ergonomic restrictions given to conventional walkers. In order to use the robot as a walking aid in the most intuitive way, forces applied to the robot must result in a movement identical to motion patterns generated by the non-driven walker.

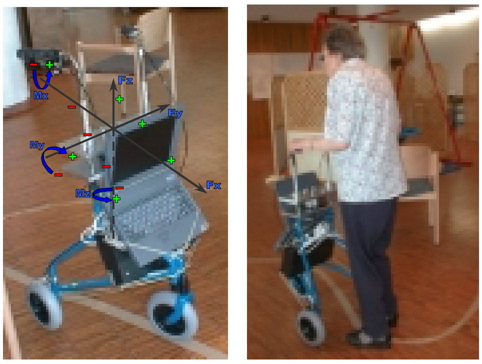


Figure 6. Test platform for force and torque measurements

In order to measure the forces and torques which are applied to a conventional walking aid system during motion, we created a test model consisting of a three wheeled walker and a force torque sensor mounted between the handles and the base of the walker. A field test was done with six people from a nursery home that walked the vehicle along an S-shaped test route (Figure 6). For the tests we only chose people who use walking aids in their daily life.

The following results could be read from the test: the average load of the walker (physical support) varied between 20 and 80 N depending on the user. Maximum loads between 30 and 120 N could be observed. To turn the walker in curves, maximum torques between 6 and 13 Nm together with maximum lateral forces between 10 and 38 N were applied. Forces applied in and against moving direction fluctuated between 10 and 20 N. A mean value of about 2 N in moving direction was used to push the vehicle along its path. None of the subjects used the handbrakes of the vehicle to stop it at the end of the test route.

4. Concept of the Navigation System

Two major modes of operation can be differed: direct user control, enabling the user to “push” the robotic walking aid to a certain direction, and target mode, with the user following the robot to a specified goal along a preplanned path.

In the first operation mode, the robot moves exclusively according to forward pressure applied to the walking supporters. Due to fluctuations of the applied pressure, values read from the sensors need to be filtered. Our approach uses the filtered input values to directly influence the speed of the robot.

If an obstacle has been detected in the assigned moving direction of the robot the calculated velocity vector must be modified to lead the robot along a collision free path. It is further important that the robot can be moved close enough to objects for the user to be able to touch them, e.g. pick up things from a table. To enable this, parameters for obstacle avoidance must be chosen carefully and the heading of the robot towards an obstacle must be considered.

If the user specifies a target within the known operation area of the robot, the latter must find and follow the best path leading to this position. Hereby “best” does not in any case mean shortest; safety issues e.g. require the robot not to drive backwards autonomously. Also, the planned path must not include sharp turns as the user might not be able to follow this movement. Furthermore, restricted operation areas have to be considered. Path modifications due to dynamic obstacles or user request (sensor input) are necessary.

5. Realisation of the Intelligent Walking Aid

Control Mode	**Speed**	**Direction**
1: No Target		
1a	Constant	User Controlled
1b	User Controlled	User Controlled
2: Target Given		
2a	Constant	Path Planning
2b	User Controlled	Path Planning
2c	User Controlled	Path Planning, modified by user

Figure 7. Control modes

In order to find optimal control parameters more easily, two major control modes (Figure 7) have been implemented: moving with and without a given target (with or without path planning). In a first step, for both operation modes the speed of the robot is set to a constant value, whereas only the direction of movement is determined by the user input. Secondly, both, speed and direction are set by the user.

5.1. Direct Control of the Robot

In a first approach, input from the displacement sensors is directly being transferred into the speed of the robot (Mode 1b). In order to specify the robot’s linear speed, several approaches were tested. Using the mean of both sensor values for determining the linear speed of the vehicle resulted in too fast linear movements of the vehicle during turns. Therefore, the minimum of both values is now being used. The rotational factor of the robot speed is set according to the difference between both sensors’ input values. With s_l, s_r being the analog sensor values for left and right sensor, s_{max} being the maximum value for the sensors, depending on maximum speeds v_{linmax}, v_{rotmax}, linear and rotational speeds v_{lin} and v_{rot} can be calculated as follows:

$$v_{lin} = v_{linmax} * min(s_l, s_r))/s_{max}$$
$$v_{rot} = v_{rotmax} * (s_l - s_r)/s_{max}.$$

About 16 values per second were used during experiments. Due to fluctuating input forces, the movement of the robot appeared unstable during the tests. Therefore, input from the sensors has been filtered, more stable results could be achieved by using the mean of the last *n* sensor values:

$$s = \sum_{i=0}^{n} s_i / n$$

A constant speed mode can be activated (Mode 1a). In this mode the robot will only accelerate according to user input up to a specified percentage of the given maximum speed.

5.2. Reactive Obstacle Avoidance

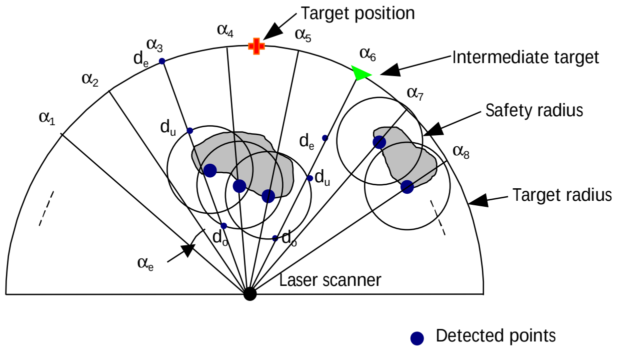


Figure 8. Reactive obstacle avoidance using the “PolarBug” algorithm

Obstacles detected in the moving direction of the vehicle must be surrounded in advance. The reactive obstacle avoidance algorithm PolarBug [25] is being used. This algorithm has been developed especially for detecting obstacles by using a laser scanner and provides an efficient method for fast reaction and navigation in unsteady environments (Figure 8).

5.3. Follow a Planned Path at Constant Speed

An intelligent path planning system based on a static map of the robot’s environment has been developed (Figure 9). It enables to set the current dynamic properties of the robot on the fly and therefore provides different paths for the robot if or if not a person is following it.

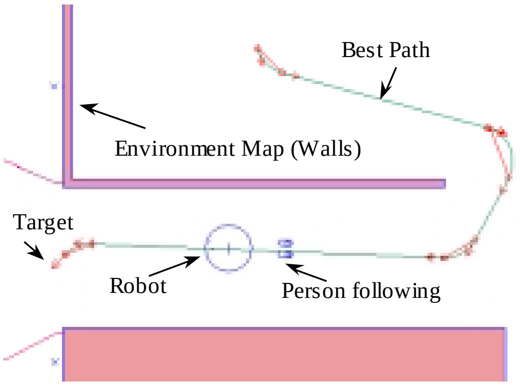
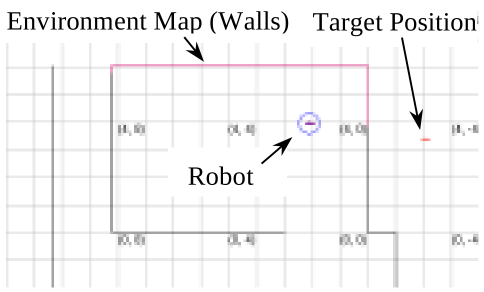


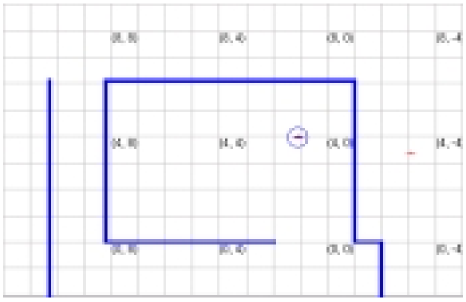
Figure 9. Collision free path planned for the robot while being used as an intelligent walking aid

The planner is based on the algorithm presented in [13] (Figure 10). It employs a global-local strategy, and solves the problem in the 2D workspace of the robot, without generating the configuration space. Firstly, a visibility graph is constructed for finding a collision-free shortest path for a robot the size of a point. Secondly, the found path is evaluated to find out whether it can be used as a reference to build up a feasible path for the given mobile robot. If not, this path is discarded and the next shortest path is selected and evaluated until an appropriate reference path is found. Thirdly, robot configurations are placed along the selected path in a way that the robot can move from one configuration to the next avoiding all obstacles given by the map.

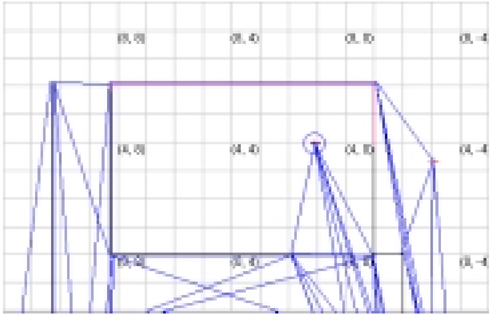
Initial robot position and map of surroundings



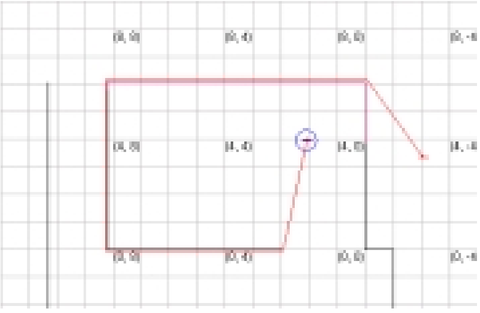
Step 1: Polygon detection



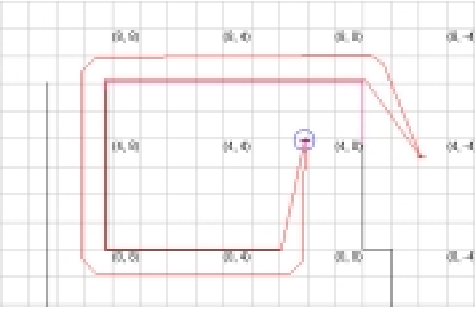
Step 2: Visibility Graph



Step 3: Shortest Path



Step 4: Path modification (robot geometry)



Step 5: Path modification (kinematic constraints)

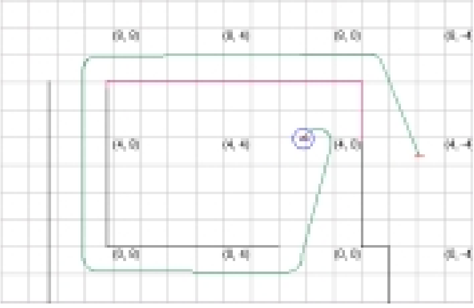


Figure 10. Path planning step by step

The algorithm works either at constant linear speed (Mode 2a) or with the speed set by user input (Mode 2b).

5.4. Reactive Path Modification

The path planning algorithm has been extended by a method of dynamic path modification with elastic bands as described in [12][14]. This common algorithm has been extended for robots meeting the restrictions of a Dubin’s car (nonholonomic robot that can only move forward) [9]. This method is being used for smoothening a path, for dynamic obstacle avoidance (Figure 11) as well as reacting to the user input while following a path (Mode 2c).

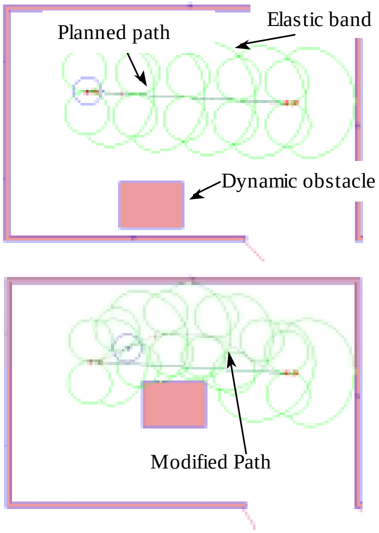


Figure 11. Dynamic path modification using an “Elastic Band”

6. Conclusion and Outlook

A reactive navigation system of an intelligent robotic walking aid has been presented. It features two major operation modes: direct user control, enabling the user to “push” the robotic walking aid to a certain direction, and target mode, with the user following the robot to a specified goal along a preplanned path.

Currently, we are working on the implementation and test of the navigation system. A mechanism for automatically moving the walking supporters up and down is being developed. After completion of the mechanics, detailed field tests with elderly people in a nursery home are planned.

7. Acknowledgements

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