An intelligent rollator with steering by braking

Thomas Hellström
Department of Computing Science
Umeå University

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Thomas Hellström
Department of Computing Science
Umeå University, Sweden

Abstract

Walking aids such as rollators help a lot of individuals to maintain mobility and independence. While these devices clearly improve balance and mobility they also lead to increased risk of falling accidents. With an increasing proportion of elderly in the population, there is a clear need for improving these devices. This paper describes ongoing work on the development of ROAR - an intelligent rollator that can help users with limited vision, cognition or motoric abilities. Automatic detection and avoidance of obstacles such as furniture and doorposts simplify usage in cluttered indoor environments. For outdoors usage, the design includes a function to avoid curbs and other holes that may otherwise cause serious accidents. Ongoing work includes a novel approach to compensate for sideway drift that occur both indoors and outdoors for users with certain types of cognitive or motoric disabilities. Also the control mechanism differs from other similar designs. Steering is achieved by activating electrical brakes instead of turning the front wheels. Furthermore, cheap infrared sensors are used instead of a laser scanner for detection of objects. Altogether, the design is believed to lead to increased acceptability, lower price and safer operation.

1. Introduction

Assistive technology for the mobility impaired includes canes, wheelchairs and walkers, and has been around for thousands of years. An incised Chinese stone sculpture from about 525 C.E. illustrates an image of a wheeled chair made to carry people (Kamenetz 1969). Walkers are a much more recent invention, at least in their present form. US patents for both non-wheeled (Robb 1953) and wheeled versions (Sundberg 1957) were awarded in the 1950's. Today, the walker is a very common mobility device and is used by approximately 0.7 percent of the population (statistics for US in the mid 1990's) (Kaye et al. 2000). Corresponding statistics for Sweden show almost 4 percent (Brandt et al. 2003).

A user of a walker often requires assistance to safely use the device, in particular, to move outdoors and through cluttered areas. While walkers clearly improve balance and mobility, a large proportion of users have difficulties using their devices, leading to increased risk of falling (Bateni and Maki 2005). More than 47,000 accidents related to falls associated with walkers and canes occur each year in the US (Henry 2009). Apart from direct costs related to the accidents, increased and safer usage of walkers may delay transition of the elderly people to nursing homes. An average delay by one month is estimated to save almost $2.2 billion in US alone (1995) (Guralnik et al. 2001). Hence, technical improvements of walkers can lead to considerable cost savings for the society, in addition to greater convenience and safety for the users. Possible improvements include support for collision avoidance, automatic braking, navigational support, and additional functionality like automatic parking. In a Swedish user survey (Bremert and Hake 2011), navigating walkers in small passages and doorways were regarded as particularly problematic.

In this paper we describe ongoing development of an automated walking aid RObotically Augmented Rollator (ROAR). While *walkers* strictly do not have wheels, and *rollators* do, the two words are often used interchangeably. We refer to ROAR as a rollator, while other walking aids most often are referred to as walkers. ROAR's functionality for indoor use includes detection and avoidance of corners, doorposts, furniture and other obstacles. For outdoor use, the rollator has additional functionality to detect and avoid holes and curbs (a hole or curb is viewed as a negative obstacle). The design also includes a novel approach to detect and prevent sideway drift that may occur both indoors and outdoors. The technical solutions were described in a Swedish patent application from 2010, and patent was later granted (Hellström 2012). The target group of users includes people with limited vision, cognition or motoric abilities. Limited vision clearly increases the risk for collisions and accidents. Limited cognitive abilities, for instance due to dementia or brain damages, may lead to the same kind of problems if obstacles or curbs are not properly perceived by the user. Motoric problems, for example caused by strokes or muscular diseases, add additional problems of drifting to one side when attempting to drive straight.

In 2011 (Hellström 2011), we report on a number of interviews with Scandinavian manufacturers and distributors of walking aids. A major conclusion is that too high cost is a major obstacle for introduction of automated walking aids on the market. Guido (also see Section 2), one of the few large scale marketing attempts had a tentative pricing of $6000 in 2004 (Davenport 2005, p.78), to be compared to the price of a regular manual walker, which can be less than $100. Our hardware design differs from Guido, and also from other earlier work, by using simpler and cheaper sensors and control equipment. A basic design principle has been to build on established commercial rollator hardware, and to maintain the original operation of the rollator, with no added controls or displays. Another principle has been to only add passive control of the direction of motion, such that the rollator only moves if the user pushes it in the normal fashion. Altogether, the design aims at increased acceptability, lower price and safe operation.

The paper is organized as follows. Section 2 gives an overview of earlier work and how the presented work differs. Section 3 describes the proposed design of hardware, software and basic functionality. Section 4 gives a background to the design principles, compares the result with earlier work and reports on the progress of the project.

2. Earlier work

Researchers and developers have suggested several so-called *smart walkers* during the last fifteen years. Frizera et al. (2008) provide an overview of several important systems. A major line of development started with the *Personal Adaptive Mobility Aid* (PAM-AID), a walking aid system designed to prevent collisions and thereby reduce the number of falls as well as increase independence and activity of users with visual impairments. Several versions of the PAM-AID were developed, starting in 1998 (Lacey, et al. 1998, MacNamara and Lacey 1999). Rentschler et al. (2003) describe and evaluate the VA-PAMAID, a further development of the PAM-AID. It has electrical motors guiding the front wheels of the walker, and the direction of travel is determined from the direction of the handlebars, combined with obstacle information obtained from laser and ultrasonic sensors. A further developed version was later marketed under the name Guido (Rentschler 2008). Guido was withdrawn from the market in early 2002 but is still being developed and extended with functions such as simultaneous localization and mapping (SLAM) (Lacey and Rodriguez-Losada 2008).

The main functionality of the walkers above is to avoid collision by detection and avoidance of obstacles. Several projects deal with other types of functionality. Wasson et al. (2001) describe a number of projects aiming at developing walkers with varying degrees of automation; walkers with warning systems, safety braking and path following. Glover et al. (2003) present a walker that can park and return to the user when signaled by remote control. The walker also supports navigation by providing simple directions to previously mapped target locations. Kulyukin et al. (2008) describe the iWalker, a device designed to support wayfinding in an intelligent environment equipped with embedded sensors. Avoiding advanced sensors mounted on the walker itself can reduce the total cost, especially if several walkers are used in the same environment.

The rollator ROAR described in this paper differs from the projects described above in several respects. First, control of direction of motion is performed by activating brakes instead of rotating the front castor wheels of the rollator - the method used in most similar work. Second, low-priced sensors are used. Detection of obstacles is performed by a number of simple infrared sensors instead of the commonly used laser scanner. For motion detection, a low-priced inertial measurement unit (IMU) is used instead of mechanical wheel encoders. Third, the implemented functionality is different and extended compared to earlier work, as described in detail in the next section.

3. Design

The ROAR rollator is a retrofit on a commercial four-wheeled rollator with two castor wheels in the front and two regular wheels in the rear (Figure 1). The added equipment comprises an embedded computer C, two electrically controlled brakes, and a series of sensors. The sensors are used to detect obstacles and direction of motion, and brakes are used to influence the direction of motion as described below.

Controlling driving direction

Propulsion and turning of the rollator is normally totally under the control of the user. The control program in C affects direction of motion indirectly by 1 second long activations of one of the brakes B_L and B_R mounted on the two the rear wheels rw_L and rw_R. B_L and B_R are electromechanical solenoids that push a metal piston against the rubber part of the wheel in an on/off fashion. Activation of the brake on one side causes a turn in the same direction when and if the user proceeds by pushing the rollator forward. The front castor wheels fw_L and fw_R will then automatically turn, such that the motion of the rollator is changed in the desired direction, even when the brake is released. The brake power is adjusted such that the affected wheel rotates slower, rather than stops completely. The design principle is to assist the user by suggesting and initiate turns, rather than taking over control of the rollator. Furthermore, the control algorithm for activation of the brakes makes sure that the brakes are not activated too often, and also not for too short or too long periods. Also, activation of brakes is only allowed when the rollator is moving forward. These additional control rules contribute to a better user experience by minimizing the interference with the user's normal operation of the rollator.

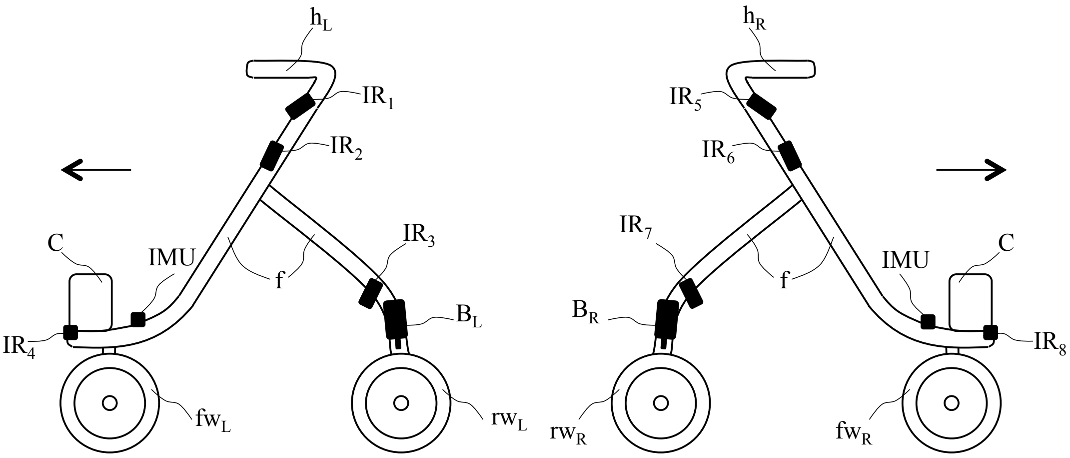

Figure 1. Left and right view of rollator ROAR with retrofitted infrared sensors IR_1–IR_8, inertial measurement unit IMU, computer C and electrically controlled brakes B_L and B_R that are used for steering. The front wheels fw_L and fw_R are freely rotating castor wheels, while the rear wheels rw_L and rw_R are regular wheels that are affected by the brakes. Arrows indicate forward direction of motion.

Detecting and avoiding objects and curbs

The ROAR rollator is equipped with a number of infrared (IR) sensors IR_1–IR_8 for detection of obstacles. Each IR sensor emits an infrared light beam, detects possible reflection, and estimates the distance to the object causing the reflection. The sensors are mounted at different positions and point in different directions, such that obstacles can be detected with sufficient coverage and accuracy. IR_1 and IR_5 point downwards in front of the rollator and are primarily used to detect obstacles in that area. IR_2, IR_3, IR_6 and IR_7 point downwards to the sides, such that obstacles on the left and right hand side respectively are detected. IR_4 and IR_8 point straight to the sides to detect walls and other obstacles in that direction. The distance reported by each sensor is compared to the nominal distance determined from reflection against a surface (wall or floor). A shorter distance indicates presence of an obstacle such as a wall or piece of furniture. Negative obstacles such as curbs and holes in the ground cause the distance to be longer than normal and can be detected in a similar fashion.

The information from the sensors is used to control the brakes and thereby affect the direction of motion. A detected obstacle to the left causes activation of the right brake, causing the rollator to turn away from the obstacle if and when the user continues to push the rollator forward. Detection of an obstacle straight in front of the rollator will activate both brakes such that the rollator rather stops than turns.

Detecting and correcting for drift

Some cognitive or motoric disabilities, for instance caused by strokes, affect the motoric abilities asymmetrically for left and right side of the body. When trying to maneuver a rollator straight ahead, the result may then be a slow drift towards one side, sometimes resulting in collision with an obstacle (indoors) or driving off the pavement (outdoors). If a caregiver accompanies the user, the drift can be manually corrected for by repeated adjustments of the heading of the rollator. This is problematic for both the user of the rollator and the caregiver. We are currently equipping the ROAR rollator with an automatic function for this kind of heading adjustments. Three methods to estimate drift are being developed and will be compared. Method 1 and 2 estimates the turning radius of the rollator path to distinguish between controlled turns and unwanted drift. Straight motion corresponds to a very large turning radius (infinite in the case of a completely straight motion), and a controlled turn corresponds to a comparatively small turning radius. An estimated radius in between these two extremes indicates unwanted drift. Method 1 uses data from accelerometers and gyroscopes in the IMU unit (Figure 1) to estimate the radius, while Method 2 uses wheel encoders in combination with kinematic equations for the same thing. Method 3 uses the sideways mounted sensors IR_4 and IR_8 to estimate the distance to the walls on the side when using the rollator indoors in narrow corridors. A slowly decreasing distance indicates unwanted drift. With all three methods, unwanted drift is compensated for by activation of one of the brakes, such that the rollator turns back towards the wanted path.

4. Discussion and results

As opposed to many other proposed smart walkers, the ROAR rollator is not equipped with a laser scanner but rather with a number of low priced IR sensors for detection of obstacles. In addition to the lower sensor price, this type of sensors demands much less data processing power than does a laser scanner. This means that a cheap microcontroller can be used instead of a much more expensive embedded computer. Another advantage with IR sensors is that they can be mounted such that the sensed area is not confined to a 2D plane as in the case with a laser scanner. This leads to safer object detection. A drawback with IR sensors is that the data is not sufficient to construct a detailed map or model of the environment. However, rather than the common approach of relying on a map for obstacle avoidance (e.g. Glover et al. 2003, Huang et al. 2005), the approach is inspired by *reactive control*, commonly used in other fields of robotics (Matarić 2007, pp. 162-166). To understand the general idea, consider a simplified rollator design with one sensor on each side, sensing the distance to objects near the rollator (Figure 3). IR sensor IR_1 is connected to the right wheel brake B_R, and IR_5 is connected to left wheel brake B_L. An obstacle sensed in front of the left side of the rollator reduces the distance reported by IR_1 below the nominal calibrated value, which causes B_R to be activated. The rollator then turns away from the obstacle when being pushed forward. The brake will then be released and the rollator continues in the direction chosen by the user. This basic behavior resembles a *Braitenberg vehicle* often used as a source of inspiration in reactive robotics (Pfeifer and Scheier 2001, pp.181-195, Braitenberg 1984). We further develop this basic control principle by allowing several sensors on each side affecting the brakes such that all functionality can be implemented.

The used method of turning the rollator by means of the brakes has several advantages compared to the commonly used method of turning the front castor wheels by means of electrical motors. Both hardware cost and power consumption are typically lower. Furthermore, short activations of brakes is a more passive method than the commonly used method of turning the front wheels, and thus interferes less with the user's control of the rollator. Another advantage is that activation of brakes informs the user, both by the sound from the brake and by the mechanical vibration transferred from the brake through the rollator frame to the handles. This alerts the user that an unwanted situation is about to happen, and contributes to manual correction of the direction of motion. A similar effect can be achieved by attaching small vibrating motors in the walker's handles (Wasson et al. 2001).

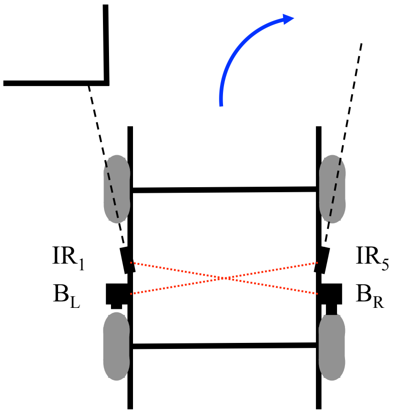

Figure 3. Simplified control mechanism for a rollator (top view). Red dotted lines indicate symbolic control lines from sensors to brakes. The obstacle sensed by IR_1 (measuring distance to reflection by the infrared ray shown as a dashed line) activates brake B_R such that the rollator turns away (blue arrow) from the obstacle when being pushed forward.

A consequence of using brakes to turn is that the amount of turning is up to the user to control. It is possible to estimate the actual turn by using data from the IMU or wheel encoders, and activate the brakes until the desired change of driving direction is achieved. However, this makes the rollator more active and harder to use. Therefore, the current approach is to activate the brakes for a constant preset time, regardless of how much the rollator actually turns as a result of the activation. The user controls the amount of turning since the brake only initiates a turn such the rollator starts moving in the desired direction. It is then up to the user to direct the rollator in the desired direction.

A prototype of ROAR has been developed. The basic functionality for obstacle detection and avoidance has been satisfactorily tested. Implementation of the described methods for drift detection is under way. The relatively low hardware cost, the indirect steering control by braking and the novel functionality for drift detection and correction has potential to enable lower end-user price, increased acceptability, and safer operation.

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References

Bateni H. and Maki, B. E. (2005), Assistive devices for balance and mobility: benefits, demands, and adverse consequences, Archives of Physical Medicine and Rehabilitation 86(1): 134-145.

Braitenberg V. (1984), Vehicles: experiments in synthetic psychology, MIT Press, Cambridge, MA, USA.

Brandt A., Iwarsson S., Stahl A. (2003), Satisfaction with rollators among community-living users: A follow-up study. Disability and Rehabilitation, Vol. 25, No. 7, pp. 343–353.

Bremert C. and Hake, J. (2011), Rollatorer – undersökning och utveckling kring framkomlighet i hemmet, Halmstad University, Biomechanics and Biomedicine.

Cribbs R.W. (1953), Walking Aid US Patent 2656874, US Patent Office.

Davenport R.D. (2005) Robotics. In Mann, W.C. (ed.) Smart Technology for Aging, Disability, and Independence: The State of the Science. pp. 67–110. John Wiley & Sons, Inc., Hoboken, NJ.

Frizera A., Ceres R., Pons J.L., Abellanas A. and Raya R. (2008), The Smart Walkers as Geriatric Assistive Device. The SIMBIOSIS Purpose. The 6th Conference of the International Society for Gerontechnology - ISG08.

Glover J., Holstius D., Manojlovich M., Montgomery K., Powers A., Wu J., Kiesler A., Matthews J. and Thrun S. (2003), A robotically-augmented walker for older adults. Technical Report CMU-CS-03-170, Carnegie Mellon University, Computer Science Department, Pittsburgh, PA.

Guralnik J.M., Alecxih L., Branch L.G. and Wiener J.M. (2002), Medical and long-term care costs when older persons become more dependent, American Journal of Public Health 92(8): 1244-1245.

Hellström T. (2011), SLUTRAPPORT FOKUS Verifiering, Projektnumer 300368, Business report Hellström Innovation. In Swedish.

Hellström T. (2012), Styrutrustning för hjulförsett gånghjälpmedel, Swedish patent SE 535373. Available at http://www.prv.se/spd/search?lang=en&tab=1. Accessed at July 10, 2012.

Henry D. (2009), Study Warns of Hazards for Elderly Using Walking Aids, New York Times, June 29, 2009. Available at http://www.nytimes.com/2009/06/30/health/30fall.html?_r=1. Accessed at June 23, 2012.

Huang C., Wasson G., Alwan M., Sheth P., Ledoux A. (2005), Shared Navigational Control and User Intent Detection in an Intelligent Walker, AAAI Fall 2005 Symp (EMBC).

Kamenetz H.L. (1969), A Brief History of the Wheelchair, Journal of the History of Medicine and Allied Sciences, Volume XXIV, Issue 2, pp. 205-210.

Kaye H.S., Kang T. and LaPlante M.P. (2000), Mobility device use in the United States. Washington (DC): National Institute on Dis- ability and Rehabilitation Research, U.S. Department of Education.

Kulyukin V., Kutiyanawala A., LoPresti E., Matthews J., and Simpson R. (2008), iWalker: Toward a rollator-mounted wayfinding system for the elderly, in RFID, 2008 IEEE International Conferenceon. LasVegas, NV: IEEE Computer Society.

Lacey G., Mac Namara S., and Dawson-Howe K.M. (1998), Personal adaptive mobility aid for the infirm and elderly blind, Lecture Notes in Computer Science, 1458:211 – 220.

Lacey G. and Rodriguez-Losada D. (2008), The Evolution of Guido, Robotics & Automation Magazine, Volume 15, Issue 4, pp. 75-83.

MacNamara S. and Lacey G. (1999), PAM-AID: A Passive Robot for Frail Visually Impaired People. Proceedings of RESNA 1999.

Matarić, M.M. (2007), The robotics primer, MIT Press.

Pfeifer R. and Scheier C. (2001), Understanding Intelligence, MIT Press.

Rentschler A.J., Cooper R.A., Blasch B. and Boninger M.L. (2003), Intelligent walkers for the elderly: Performance and safety testing of VA-PAMAID robotic walker. Journal of Rehabilitation Research and Development Vol. 40, No. 5, September/October 2003, Pages 423–432.

Rentschler A.J., Simpson R., Cooper R.A. and Boninger M.L. (2008), Clinical Evaluation of Guido Robotic Walker, Journal of Rehabilitation Research and Development, Vol. 45, No. 9, pp. 1281-1294.

Sundberg O.M. (1957), Orthopedic Walker US Patent 2792874, US Patent Office.

Wasson G., Gunderson J., Graves S. and Felder R. (2001), Effective shared control in cooperative mobility aids. In Proceedings of the 14th International Florida Artificial Intelligence Research Society Conference, AAAI Press, pp. 509–513.