

# SmartWalker: Towards an Intelligent Robotic Walker for the Elderly

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**Abstract**—This paper presents SMARTWALKER and evaluates the appropriateness and usefulness of the walker and its gesture-based interface for the elderly. As a high-tech extension of a regular walker, the SMARTWALKER aims to assist its user intelligently and navigate around its environment autonomously. Equipped with sensors and actuators, the prototype accepts gesture commands and navigates around accordingly. The gesture-based interface uses a  $k$ -nearest neighbors classifier with dynamic time warping to recognize gestures and the Viola and Jones face detector to locate the user. We evaluated the walker with 23 residents and eight staff members at five different retirement homes in Zürich. The elderly found the SMARTWALKER useful and exciting, but few were willing to replace their walkers by robotic walkers. Their reluctance may stem from the walker’s size and weight and their unfamiliarity with technology.

**Keywords**—ambient assisted living; robotics; user study

## I. INTRODUCTION

The percentage of the global population aged 60 years or over has been increasing steadily, and it is projected to rise further to 21 percent by 2050 [1]. As the population ages, it becomes increasingly important that people continue to stay active and mobile. Impaired mobility of older adults is linked to a loss of independence, decreased quality of life, institutionalization, and a higher risk of mortality. Unfortunately, impaired mobility is prevalent in 44% of older adults [2]. Thus, ensuring mobility of the elderly is critical to our aging society.

Mobility aids range from simple external devices such as canes to mobile vehicles such as wheelchairs. Canes can reduce falls in patients by increasing gait stability, but they provide minimal weight support. Wheelchairs can transport people who cannot move by themselves, but excessive sitting can cause deterioration of health. In between the two lie walkers. Walkers provide support for weight and balance but require patients to use their own locomotion, thus minimizing deterioration of mobility. Rollators, or wheeled walkers, are particularly liked for their usability and support for natural gait patterns [3].

Advancement of technology has given rise to smart walkers – rollators equipped with sensors and actuators for better assistance and support. Most research on smart walkers has been in providing better physical support, sensory assistance, cognitive assistance, health monitoring,

or human-machine interface [3], and little attention has been given to smart walker as an autonomous robotic device. In certain situations, however, a non-autonomous walker becomes clumsy to use. For instance, when many walker users gather in one space for a meeting or a meal, placing the walkers without hindering the social situation becomes difficult. Indeed, at retirement homes, where many residents use walkers, each walker has to be moved out of a room when residents gather for a meal so that they can eat more comfortably; at the end of the meal, the walkers are brought back to the room one at a time. An autonomous walker, as the one proposed here, which is able to park itself and return to its user when required, would eliminate such a repetitive and laborious task.

We propose SMARTWALKER, a high-tech extension of a regular walker, designed to help the elderly lead more independent lives. Equipped with sensors and actuators, our walker can function as a mobility aid as well as an autonomous robot. In particular, the SMARTWALKER can receive user commands through its real-time gesture-based user interface and navigate around its environment accordingly. The underlying algorithm uses a  $k$ -nearest neighbors ( $k$ -NN) classifier with dynamic time warping (DTW) to classify gestures. As people can unintentionally make gestures similar to the commands, the interface ignores unintentional gestures by detecting the user’s attention along with the gesture recognition. To investigate the viability of the robotic walker as an alternative to traditional walkers, the appropriateness of its gesture-based user interface, and the usefulness of an autonomously moving walker, we evaluated the prototype with 23 residents and eight members of the staff at five different retirement homes in Zürich, Switzerland. In the study, the elderly found the SMARTWALKER exciting and useful, but they had difficulties with the gesture-based interface. They were also reluctant to switch to the robotic walker, possibly because it is bigger and heavier than traditional walkers and they are less familiar with technology.

## II. RELATED WORK

The first publication on a smart mobility aid was a personal adaptive mobility aid for the infirm and elderly blind (PAM-AID) in 1998 [4]. Since then, researchers have proposed many different smart walkers. Most are purely assistive, offering physical support, sensorial assistance,

<sup>†</sup>This work was conducted while the author was at the Chair of Software Engineering, Department of Computer Science, ETH Zürich.

cognitive assistance, or health monitoring [3]. Few have an additional capability to move around autonomously. Notable work is by Glover *et al.* [5], whose walker can park itself and return to its user according to the user’s control via a remote button. The SMARTWALKER that this paper presents also aims to be autonomous but without requiring an external controller; it achieves this through its gesture-based user interface.

Smart walker interfaces range from direct interfaces such as a joystick [6] and modified handlebars [7] to indirect interfaces such as a gate detection system [8]. Direct interfaces that do not require any physical contact are particularly relevant to our research. Gharieb [9] proposed a voice-based interface for visually-impaired people that enables its user to command the walker verbally, thus eliminating the necessity for physical contact. Similarly, our gesture-based interface receives commands from its user located at a distance. Gesture recognition is a well-researched area within the field of computer vision; however, to our knowledge, no work has investigated the viability of a gesture-based interface for smart walkers.

The proposed interface uses an RGBD camera as the input sensor. Using an RGBD camera for image processing has gained momentum since the release of affordable devices. In terms of hand gesture recognition, Suarez and Murphy [10] categorize different techniques that use RGBD data as input. Work of particular relevance is a probability-based dynamic time warping approach for gesture recognition using RGBD data [11]. The authors employ a Gaussian Mixture Model to model the variance within a training set. The proposed work also uses dynamic time warping on RGBD data, but we do not explicitly model the variance; instead, we use  $k$ -NN to classify gestures. In this way, our work is more similar to Ten Holt *et al.* [12], who expand dynamic time warping to a multi-dimensional space and classify gestures using  $k$ -NN. Our recognition system computes the warping distance from three-dimensional feature vectors with  $k$ -NN.

The interface also has face detection and recognition. The face detection ensures that the system classifies gestures only if the user is looking at the walker whereas the face recognition ensures that the walker accepts commands only from its owner. The face detection approach is similar to Monajjemi *et al.* [13] in that it computes a face score for detected faces and accepts only those faces with face scores higher than a threshold as frontal faces. The face recognition uses Local Binary Patterns Histograms (LBPH) Face Recognizer [14].

### III. SMARTWALKER

The SMARTWALKER is composed of a walker frame enhanced with sensors, actuators, and appropriate software to control these hardware components.

#### A. Hardware

The SMARTWALKER has a front wheel, two motorized rear wheels, and two sensors (Figure 1(a)). The front wheel has no motor and is for stability and maneuverability. The

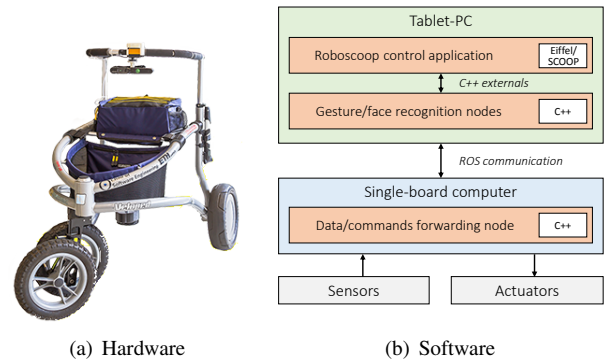


Figure 1. The SMARTWALKER hardware and software. In (a), below the handlebars is the RGBD camera for gesture recognition. (b) shows the executable nodes (orange) and the data flow (arrows).

rear wheels are powered with e-bike motors and can be controlled to move the walker as desired. The SMARTWALKER has a Carmine 1.08 RGBD camera<sup>1</sup>, which is attached to a motor for 360° rotation and placed below the handlebar, for gesture recognition. It also has a laser sensor harvested from a vacuum cleaner by Neato Robotics<sup>2</sup>, at the bottom of the frame, intended for obstacle avoidance.

The SMARTWALKER uses two processing units connected via the local network. The first one is a tablet-PC, where most of the computation is run. The tablet also provides the user with graphical applications and a touch interface. The second device is a BeagleBone<sup>3</sup> single-board computer for message passing between the tablet and the sensors and the actuators.

#### B. Software

The SMARTWALKER software is distributed between the tablet-PC and the single-board computer (Figure 1(b)). The tablet runs the “brain” of the system – the main control application and the gesture recognition module – whereas the single-board computer receives raw data from the sensors and forwards commands from the tablet to the actuators. The SMARTWALKER control application is written in Roboscoop [15], a robotics programming framework with concurrency support. Built on Simple Concurrent Object-Oriented Programming (SCOOP) model, which provides simple and safe concurrency features, Roboscoop is a robotics library written in Eiffel [16] and has tools for integration with other frameworks and libraries via C/C++ external interface. The gesture and face recognition are implemented in C++ as nodes in Robot Operating System (ROS) [17]. ROS is a popular middleware in robotics and in addition to network communication, it provides libraries for image processing among others.

#### C. Modes of operation

The SMARTWALKER can function in two different modes: assistive mode and autonomous mode. In the assistive mode, the frame is driven by the user and it provides support to the user during the movement, as a

<sup>1</sup>Discontinued

<sup>2</sup><http://www.neatorobotics.com/>

<sup>3</sup><http://beagleboard.org/bone>

regular walker does. In the autonomous mode, the SMART-WALKER operates as an autonomous robot, without any physical exertion by the user. It navigates around its environment and executes the user’s commands given through gestures. Switching between the two modes requires just a touch of a button in the graphical touch interface on the tablet-PC. The user can also activate the autonomous mode by giving a gesture command.

#### IV. GESTURE-BASED INTERFACE

The gesture-based interface takes images from the RGBD camera as input and processes the information in three steps: gesture detection, face detection, and face recognition. The gesture detection accepts predefined gestures as commands and rejects unknown gestures. The face detection localizes the user’s position more accurately and ensures that the commands are processed only when the user intends to, i.e., when the user is looking at the walker. Finally, the face recognition ensures that the walker only responds to the commands given by its owner. The face detection and recognition modules are independent of the gesture detection module and can be individually deactivated through the graphical touch interface.

##### A. Commands

The gesture detector works with three different predefined gestures and interprets them as commands – “come here”, “go back”, and “stop”. In addition, the detector gives voice feedback to the user when a gesture is detected. The “come here” command requires the user to move a hand up and down, and when detected, the SMARTWALKER says “I am coming to you” and moves to the user with its handle bars towards the user. The “go back” gesture requires moving a hand sideways, either to left then right or to right then left, and the robot says “Going back to the charging station” and moves back to a predefined location. The “stop” command requires the hand to push forward, and it causes the robot to beep and stop. Figure 2 shows how the distance to the starting position of the hand changes during the execution of each gesture command.

##### B. Gesture detection

The gesture detector is built on hand tracking to handle various input data. Given that the walker is primarily for elderly people in need of walkers, the user would usually be sitting and could be partially occluded by a table, for instance, when they execute commands. The detector, thus, must impose minimal restrictions on the user’s pose. In addition, the detector must be able to cope with variability in the gesture execution that stems from different levels of cognitive and motor skills of the elderly and various distances between the user and the walker. As hand tracking requires only a hand to be visible, it imposes minimal restrictions.

Hand waving signals the system to start OpenNI’s hand tracking [18] and thus the gesture recognition. The hand tracker returns 3-D coordinates  $\mathbf{p}_h = \{p_x^h, p_y^h, p_z^h\}$  of the hand, and it marks the 3-D coordinates where the hand

tracking began as  $\mathbf{p}_s = \{p_x^s, p_y^s, p_z^s\}$ . From  $\mathbf{p}_h$  and  $\mathbf{p}_s$ , we compute the feature vector  $\mathbf{f}_h = \{f_x^h, f_y^h, f_z^h\}$  as the absolute distance between the two in each dimension, i.e.,

$$f_d^h = \|p_d^h - p_d^s\|, \quad (1)$$

where  $d$  indicates the three dimensions,  $x$ ,  $y$ , and  $z$ . We extract one feature vector per frame and represent a gesture  $g$  as a time series  $F_g$  of  $N \in \mathbb{N}$  feature vectors,

$$F_g = \{\mathbf{f}_1, \mathbf{f}_2, \dots, \mathbf{f}_N\}. \quad (2)$$

Once the time series  $F_g$  is extracted from the input gesture  $g$ , the gesture recognition system classifies it using a  $k$ -NN classifier. The classifier requires a training set, which is built by collecting gestures from seven people. Every person performed the three gesture commands 5 times per command, resulting in 105 gestures. Using this training set, the classifier computes the distance from a test time series  $F_g$  to the training data and selects  $k$  training data items  $F_{(t)}$ ,  $t = 1, \dots, k$  that are closest to  $F_g$ . It then assigns a class  $y_i$  to  $F_g$  that is most represented by the  $k$  neighbors. As  $F_g$  may be spurious, we introduce a threshold  $d_{\text{thresh}}$  such that no neighboring point in  $F_{(t)}$  lies farther than  $d_{\text{thresh}}$  away. For this work, we set  $k = 5$  and assign a class  $y_i$  to the gesture  $g$  if 3 or more points in  $F_{(t)}$  have the same class label  $y_i$ . Performing  $k$ -fold cross validation, with  $k = 7$  for the seven people, showed that the accuracy remains at 99.1% for  $k = 1$  to  $k = 12$  and drops to 98.5% for  $k = 20$  and to 96.4% for  $k = 30$ .

To compute the distance between the test time series  $F_g$  and the training time series  $F_{(t)}$ , we use DTW [19]. DTW is a well-known technique in signal processing and has also been successfully applied to gesture recognition [11], [12], [20]. Given  $F_g$  of length  $N$  and  $F_t$  of length  $M$ , DTW finds an optimal match  $p$  between  $F_g$  and  $F_t$  that aligns the two time series with the minimum cost under the following conditions:

- 1) The match starts at  $(1, 1)$  and ends at  $(N, M)$ .
- 2) The match can move one step in  $F_g$ ,  $F_t$ , or both but cannot go back in either.

Using these constraints and Euclidean distance as the distance metric between two feature vectors, we can find the minimum cost path using dynamic programming [21]. Dynamic programming constructs the  $N$  by  $M$  cost matrix that contains the lowest possible matching cost between the two time series  $F_g$  and  $F_t$  up to the time index  $i$  in  $F_g$  for the  $i^{\text{th}}$  row and up to the time index  $j$  in  $F_t$  for the  $j^{\text{th}}$  column. At position  $(N, M)$ ,  $F_g$  and  $F_t$  are completely matched with the minimal matching cost.

The length  $N$  of the test time series is based on the length  $M$  of the training set. On average, the gestures of the training set were performed in  $17 \pm 3.5$  frames. The gesture recognition uses the capture window of 50 frames to provide the user sufficient amount of time to execute a gesture. It matches the first 50 frames after the hand tracking starts to the time series stored in the training set.

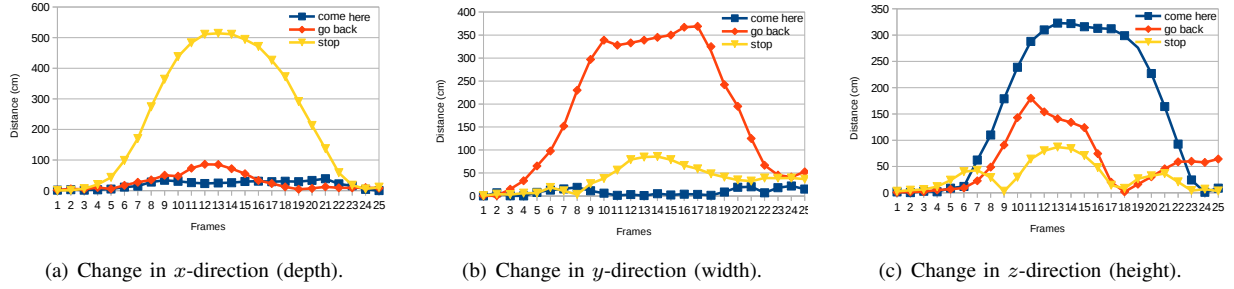


Figure 2. Change in distance with respect to the starting position for the three gestures – “come here” (blue), “go back” (red), “stop” (yellow).



Figure 3. Face detection and recognition. Only the frontal face and slightly turned faces are detected. The text below the green circle indicates recognition of the detected face.

### C. Face detection

The gestures defined as commands can also be performed and detected when the user does not intend to command the SMARTWALKER. To ignore unintentional gesture commands, the interface uses a face detector. Under the assumption that the user making a gesture to command the walker would look at the walker, the face detection finds frontal faces in the input stream. The system then processes the detected gesture command only if the frontal face detection is successful.

The face detector uses OpenCV’s Viola and Jones face detector [22]. The detector computes Haar features from the input image and trains the features on positive and negative images to select most distinctive features, i.e., features that have the highest variance between the positive and the negative ones. For fast detection, the detector uses a cascade of classifiers, where each stage uses one or few features to determine if the input image could contain a face. Only those images that pass all the stages are positively classified. For further speed improvement, our detector uses depth cues given by the RGBD camera to restrict the search area, as proposed by Burgin *et al.* [23]. In addition, the detector uses depth information to reduce false detection by creating a bounding box around the detected face and validating its size. Any face whose horizontal or vertical dimension is smaller than 8cm or greater than 23cm is deemed unlikely to be a face.

To determine if the user is looking at the walker, we train the aforementioned classifier only on frontal faces. The detector puts a bounding box around every plausible frontal face. In turn, a higher number of bounding boxes indicates a higher probability of a frontal face. Similar to the approach of Monajjemi *et al.* [13], which selects the most attentive face from many faces using a face score, the detector uses the number of bounding boxes as the face score; however, as there is only one face, it introduces a threshold and accepts only those faces whose face scores are higher than the threshold as frontal faces. Figure 3

shows how turning of a face affects the detection.

### D. Face recognition

The face recognition ensures that the SMARTWALKER only responds to the commands of its owner. Once a face is detected, the face recognition is activated to determine if the detected face is the owner. The face recognition system is based on the LBPH Face Recognizer [14], provided by the OpenCV library. LBPH takes a detected face – a cropped image of a face from the face detector – as input and constructs histograms of local binary pattern operators. The operators capture fine grained details such as spots, lines, edges and corners in an image and are invariant to different lighting conditions. LBPH recognizes the input face by comparing its histograms to those of the face training set. It ensures scale invariance by applying local binary patterns operators of different sizes.

## V. METHOD

Our study had three research questions related to the appropriateness and usefulness of the SMARTWALKER. To answer these questions, we conducted interviews with residents and staff at retirement homes.

### A. Research questions

- 1) Is a robotic walker an attractive alternative to a traditional walker?
- 2) Is gesture-based interface an acceptable form of user interface for the elderly?
- 3) Is the ability to move autonomously a useful functionality?

### B. Study setup

The study was conducted with residents of retirement homes. The experiment required a room with about 5m by 5m of free space and was conducted either in an activity room or a dining room of the homes. Each experiment, which consisted of one participant filling out a questionnaire (Section V-C) and testing the SMARTWALKER and its interface, lasted about 30 minutes. To ease the experimental process, an interviewer read out every question and possible answers to each participant and marked the responses on the participant’s behalf; reading out the questions was especially important for the elderly with limited or no vision.

Each experiment began with a brief introduction to the SMARTWALKER and the study. We then collected

each participant’s background information such as the age and usage of mobility aid. Each participant then walked around the testing room with the walker and answered the questions about its functionality as a regular mobility aid. After the first evaluation, each participant tested the walker’s gesture-based interface by calling it to them and sending it back to a predefined location. They then evaluated the walker as an autonomous robot.

We also had discussions with the staff of the retirement homes. The staff were present for part or all of the experiments, and after the experiments, they shared their opinion with us. Their responses varied from general comments about the visit to specific suggestions for improvement of the walker. There was no particular format to the discussion; the authors simply noted their remarks.

### C. Questionnaire

The questionnaire had 23 questions, divided into three groups. The first group was about gender, age, usage of mobility aids, activity level, and familiarity with technology. The second part contained questions about their impression of the SMARTWALKER’s assistive mode such as how they like the walker and how big, heavy, and maneuverable the walker is. The last section had questions related to the SMARTWALKER as an autonomous robot. The questions included the usefulness of the SMARTWALKER’s autonomy, the easiness and appropriateness of its gesture-based interface, and their general impression and opinion of autonomous robotic walkers. The questionnaire ended with a free response question about desired functionality of the SMARTWALKER. Appendix A shows a subset of the interview questions.

## VI. RESULTS

We contacted 28 retirement homes via e-mail and received five positive responses. The homes included one male-only place and one for visually-impaired and blind people. Three of the five places made an announcement of our visit to their residents on bulletin boards and allowed people to join the experiment freely. The other two places had contacted individual residents in advance and brought the interested people one by one. In total, 23 residents (14 men and 9 women) and eight members of the staff participated in our study. Four of the residents were visually-impaired or blind.

Table I shows the background information of the study participants. The majority of the participants were 80 and above. Most used a rollator or a cane, with three using both. Many stated that they use their mobility aids regularly, both inside and outside, though outside is often limited to the garden area of the retirement homes. Most were unfamiliar with technology, never using a computer or a smart phone.

### A. Responses of the elderly

Twenty-one participants evaluated the SMARTWALKER’s potential as a mobility aid by walking around with it; two of the wheelchair users could not participate in this portion of the test. Figure 4 shows the responses

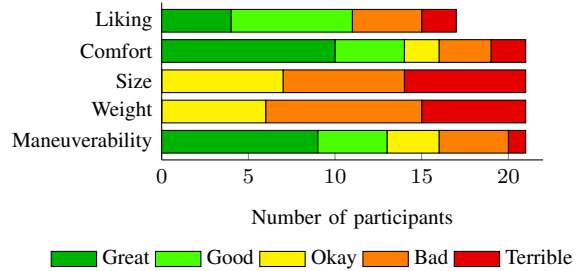


Figure 4. Evaluation of the SMARTWALKER as a mobility aid device.

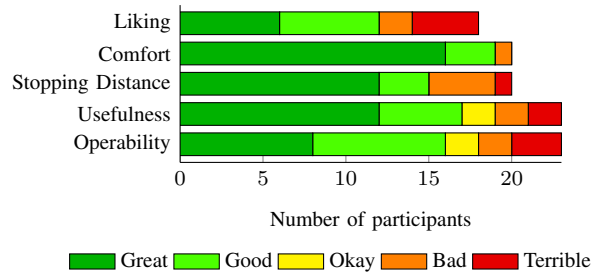


Figure 5. Evaluation of the SMARTWALKER as an autonomous robot.

of the participants after testing the device. Eleven of the 17 who were asked how much they like the walker<sup>4</sup> stated that they like the SMARTWALKER. Fourteen out of the 21 found the walker comfortable to use and 13 found it easy to control. Many, however, found it big (14) and heavy (15).

All 23 participants tested the SMARTWALKER’s gesture-based interface by calling it towards them and sending it back to a predefined location. The results are shown in Figure 5. The interface failed to recognize gestures of three of the participants because they performed the gestures too slowly, and we omitted some questions for those participants. After testing the interface, 12 out of 18 stated that they like the walker. Nineteen out of 20 said that they were comfortable with the SMARTWALKER coming towards them, and 15 said that its stopping location, set at 40cm from the user, is a good distance. Seventeen out of the 23 found the SMARTWALKER’s ability to move by itself useful, and sixteen people said that the walker’s gesture-based interface is easy to operate.

In terms of the interface, 21 out of the 23 said that the gestures are easy to execute, and 16 said that their commands were well-understood (Figure 6). The recognition rate was 0.41, i.e., the participants had to execute the same command on average 2.4 times before the interface recognized the command (Figure 7). The low recognition rate is partially due to the mismatch between the training set and the test set; the training set was built using healthy adults in their 20’s and 30’s while the test was performed by elderly people. Lastly, eleven participants said that the voice feedback that the robot gives when it recognizes a gesture is sufficient whereas eleven said that the voice feedback is insufficient.

<sup>4</sup>The four visually-impaired people were not asked this question.

Table I  
USAGE OF MOBILITY AID AND COMPUTING DEVICES.

Categories	Responses				
Age group	Under 70 (1)	70 – 79 (3)	<b>80 – 89 (11)</b>	90 and over (6)	
Mobility aid usage	None (3)	Cane (9)	<b>Rollator (11)</b>	Wheelchair (3)	
Years of usage	Zero (3)	< 1 year (5)	1 – 2 years (3)	<b>3 – 5 years (8)</b>	> 5 years (4)
Frequency of usage	Never (3)	Rarely (2)	Sometimes (3)	Often (1)	<b>Always (14)</b>
Outside usage	Never (4)	Rarely (0)	Sometimes (1)	Often (4)	<b>Always (14)</b>
Usage of computing devices	<b>Never (16)</b>	Rarely (1)	Sometimes (3)	Often (2)	Always (1)

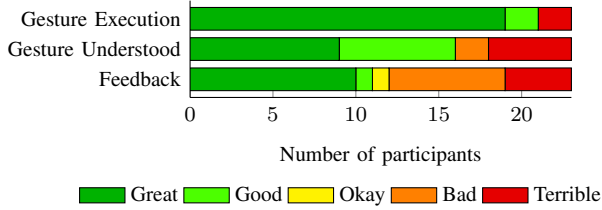


Figure 6. Evaluation of the gesture-based interface.

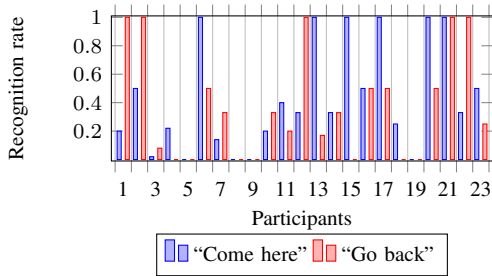


Figure 7. Recognition rate of the two gesture commands. The participants gave the same gesture command until it was recognized or until they no longer wished to try.

Nineteen of the 23 participants found the idea of a robotic walker very exciting (11) or exciting (8); however, eleven said that they would rather not (4) or definitely not (7) replace their traditional mobility aids with robotic walkers. Only a small portion said that they would definitely (6) or likely (1) replace their traditional aids. The low acceptance may be due to the walker’s size and weight and the elderly’s unfamiliarity with technology.

The elderly suggested several additional features for the walker. They include a seat, the ability to identify its owner, which was implemented but not tested with them as it required collecting their face data first, a better feedback system, a reduction in size and weight, assistance for uphill and stair climbing, and safety assurance.

#### B. Comments from retirement home employees

All eight personnel (5 women, 3 men) from the five retirement homes had a positive impression of the SMARTWALKER and our visit. They shared their comments about the device, recommending new features for the walker. Their suggestions were uphill/downhill support, a parking brake for safety, and an ergonomically designed tiltable hand grip. The retirement home for visually-impaired and blind additionally wanted obstacle and stair recognition for warning, more audible warnings when the walker is in action, a physical interface (e.g. buttons) rather than a touch screen or a gesture-based one, and an emergency alarm.

Table II  
EVALUATION OF THE SMARTWALKER’S SIZE AND WEIGHT AND WILLINGNESS TO REPLACE TRADITIONAL WALKER TO THE SMARTWALKER.

Would replace	Too big			Too heavy		
	Too big	Big	Perfect	Too heavy	Heavy	Perfect
Definitely (6)	0	4	2	0	3	3
Probably (1)	0	1	0	0	1	0
Not sure (2)	0	1	1	0	1	1
Probably not (4)	2	0	2	1	3	0
Definitely not (7)	4	1	2	5	0	2

Everyone said that an autonomously-moving robotic walker would be particularly useful at mealtimes. Moving walkers in and out of a dining room is a laborious process, requiring a lot of resources. Currently, the staff parks the walkers outside of the dining room at the beginning of each meal and brings them back to the residents one by one when the mealtime is over. A robotic walker would eliminate this laborious process. Moreover, a robotic walker would enable the residents to have a meal and leave the room when they wish, and this prospect was particularly well-received by the residents.

## VII. DISCUSSION

The overall impression of the SMARTWALKER by the residents and the staff was positive. Most residents found the walker exciting, and the staff showed their interest in the device. As a prototype, the SMARTWALKER, however, was not yet deemed an acceptable replacement of a traditional walker. This may be because the walker is too big and heavy and the elderly are unfamiliar with technology.

#### A. Acceptance of robotic walker

More than half of the participants said that they would rather stay with a traditional walker. This was especially true for current walker users, with nine out of the 11 stating that they would definitely not (6) or probably not (3) change to a robotic walker. This is surprising given that five of the 11 liked the walker and eight found it exciting. Unfortunately, their positive review did not translate into their willingness to switch to the SMARTWALKER.

A possible cause is the SMARTWALKER’s size and weight. Equipped with extra hardware, the walker is bigger and heavier than normal walkers. While none of the seven people who would consider changing found the SMARTWALKER too heavy and three even found the weight just right, only two of the 11 who would not change found the weight acceptable; six of the 11 found the walker too heavy (Table II). We were told that many have trouble

going over a curb using a traditional walker and thus stay within the perimeter of the retirement homes. The residents may have felt that the SMARTWALKER would hinder their autonomy even further.

Another cause may be the unfamiliarity with technology. As most participants did not use any computing devices, they could have found the SMARTWALKER overwhelming to use. Indeed, those who use technology regularly were more willing to switch to a robotic walker than those who do not (Table III).

### B. Appropriateness of gesture-based user interface

The evaluation of the gestured-based interface was positive despite the low recognition rate. In contrary to their positive feedback that the gestures were easy to perform, we noticed that the participants had a hard time executing gesture commands to the walker. Many participants had limited fine-motor skills due to old age, and some participants even suffered from movement disorders such as Parkinson’s disease. The visually-impaired and blind people had extra difficulty with the gesture commands as they had to conceptually translate our verbal explanation of the gestures to physical movements.

As an alternative to gesture, several staff members suggested using a button and integrating it into the medical alert system. As most residents have alarm buttons, integrating the interface into the system would make it easier for the residents to use the interface. Interestingly, they also pointed out that many residents do not wear their alarm button despite owning one. They generally prefer simple and physical interface, but determining the most appropriate interface requires a further study.

### C. Usefulness of autonomous walker

Most residents found the walker’s autonomy useful, but many were initially unsure of its actual use case. The staff at the retirement homes saw its usefulness more readily, stating mealtimes as the main use case. An autonomous walker would eliminate the laborious process of parking and fetching walkers. The elderly, once told of the scenario, were also excited about it. In a longer term, several imagined the walker developing into a butler.

### D. Factors influencing the evaluation

Flandorfer’s meta study [24] showed that different sociodemographic factors influence the elderly’s acceptance of socially-assistive robots. We analyzed the influence of the walker’s performance and the elderly’s gender and experience with technology on their willingness to switch to the SMARTWALKER (Table III). In terms of the gesture interface’s recognition rate, we noticed no significant difference between those who are willing to replace and those who are reluctant. In terms of gender, about half of men were interested in switching while no women were interested. Similarly, more than half of the technology users were willing to replace to the SMARTWALKER whereas many non-technology users were unwilling to change. Although the small sample size makes it difficult to draw any statistically significant conclusions, our results

Table III  
FACTORS INFLUENCING THE EVALUATION.

	Average recognition rate	Male (14)	Female (9)	Technology user (7)	Non-tech. user (16)
Replace (7)	0.31 ± 0.27	7	0	4	3
Not replace (11)	0.40 ± 0.36	4	7	2	9

show that gender and technology may have some influence on the participants’ acceptance of the SMARTWALKER.

### E. Limitations

This study was conducted with residents of retirement homes and would thus reflect the preference of those who live in community-living environments. No participant carried out outside activities such as grocery shopping regularly, if at all; in fact, although most participants went outside regularly, they mostly stayed in the garden area and rarely left the perimeter of the retirement homes. Given that many walker users do live independently, the findings of this study may not be applicable to the general population of current and potential walker users.

## VIII. CONCLUSION

This paper introduced the SMARTWALKER, an autonomous robotic walker for the elderly, and its gesture-based user interface. Equipped with low-cost, off-the-shelf sensors and actuators, the SMARTWALKER’s can autonomously and intelligently interact with its environment. Twenty-three residents and eight staff members at five different retirement homes evaluated the device. In general, the residents liked the SMARTWALKER and found its interface easy to use. They also found the walker exciting and useful; however, they were reluctant to replace their walker with a robotic one, possibly because the SMARTWALKER is bulkier and heavier than traditional walkers and many elderly are unfamiliar with technology.

Next steps of this research include evaluating the face detection/recognition module, providing more physical support for the elderly, and investigating different user interfaces such as a button or voice for remote interaction. In general, we are interested in understanding the demand for an autonomous robotic walker among a wider group of people, in particular, walker users who live independently.

## APPENDIX

### A. Sample questions from the questionnaire

#### Part one (1–7):

- 4) Do you use?
  - nothing  cane  walker/rollator  wheelchair
- 5) How often do you use the device?
  - never  seldom  sometimes  often  always
- 7) How often do you use a smartphone, a computer, ...?
  - never  seldom  sometimes  often  always

### Part two (8–12):

- 8) Do you like the rollator?  
( ) a lot ( ) somewhat ( ) neutral ( ) not really ( ) not at all
- 11) How comfortable was it to walk with the rollator?  
( ) very comfortable ( ) comfortable ( ) neutral  
( ) uncomfortable ( ) very uncomfortable

### Part three (13–23):

- 14) Is it useful that the rollator can come and go away?  
( ) very ( ) somewhat ( ) neutral ( ) not really ( ) not at all
- 18) Were the hand gestures difficult for you to execute?  
( ) very difficult ( ) difficult ( ) neutral ( ) easy ( ) very easy
- 19) Did the robot understand your hand gestures well?  
( ) always ( ) mostly ( ) neutral ( ) sometimes not ( ) never
- 22) Would you change to a robotic walker, or would you rather stay with a traditional one?  
( ) definitely change ( ) probably change ( ) neutral  
( ) probably not change ( ) definitely not change

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