ALMA: An Indoor Localization and Navigation System for the Elderly

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Abstract. ALMA is an integrated system to support autonomous mobility and orientation for the elderly and, more in general, for the person with cognitive and/or mobility impairments in indoor facilities. It is composed of a set of modules for navigation, localization, planning, and autonomous wheelchair mobility, interfacing with the user. In this paper, we describe in detail the localization and navigation modules that can guide the target user to a selected destination and report our experience in a large care- and assistance-giving facility.

Keywords: Elderly · Indoor localization · Indoor navigation

1 Introduction

The chance of moving through the environment autonomously is crucial for the physical and psychological well-being of a person. However, there are cases (e.g., among elderly people) for which this requires capabilities that the person does not possess, or does not possess anymore, due to ageing or illness. The ALMA project [2] has developed a system that supports users in safely moving in indoor environments, from their current location to other locations of interest, considering their particular needs and/or limitations, and taking into account the state of the environment (e.g., presence of local obstacles). Such personal navigation assistant (PNA) aims at supporting or enhancing the autonomous motion of people with different degrees of mobility and/or cognitive impairment. In this paper, we introduce the overall system and, in particular, we focus on two of its main modules: the indoor localization module that identifies the current position of the user in the environment and the user interface, consisting of a mobile application supporting the navigation of the user to reach the desired destination.

The design of effective user interfaces to present navigation guidance is one of the challenges of indoor navigation services. In the ALMA project we have designed and tested a possible solution targeted at persons with cognitive and/or mobility impairments. Given the current location of the user, provided by the localization service, the indoor map and the path to reach the destination, instructions supporting orientation of the user are provided. A pilot application, presenting different scenarios for both primary (elderly, rehabilitation patients) and secondary (caregivers) end-users has guided the whole project development from user requirements, to final testing.

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The paper describes the results of the ALMA project related to localization and navigation and is organized as follows: in Sect. 2 we describe the overall system and its architecture; in Sect. 3 we review works related to indoor localization and indoor navigation systems; Sects. 4 and 5 describe more in detail the localization module and the user interface; Sect. 6 presents experimental results of the pilot application; finally, Sect. 7 draws the conclusions and presents future works.

2 Overview and Architecture of the System

Figure 1 describes the overall architecture of the system. The ALMA project tackles the issue of not being able to move autonomously or efficiently by combining a set of advanced hardware and software technologies into an integrated and modular system composed by:

1. An indoor *Localization Module* based on a network of low-cost/low-power Radio Frequency (RF) emitters, to provide room level localization of people and objects; this module will be explained in detail in Sect. 4;
2. A system of networked smart cameras providing *video-based monitoring* for accurate indoor and outdoor localization, environment monitoring, and situation assessment;
3. An *Intelligent Module* for the online *planning and scheduling* of users' paths and activities, matching users' specific needs with the state of the environment (e.g., considering accessibility issues) and of available resources (e.g., a);
4. The *Personal Navigation Assistant*, a mobile application providing a user-friendly interface to all ALMA functionalities, tailored to the specific user requirements and physical limitations (e.g., with multimodal input/output modalities); this module will be explained in detail in Sect. 5;
5. The *Personal Mobility Kit* that, connected to a commercial electric wheelchair, allows users to perform automatic or assisted navigation and to interact with the surrounding environment.

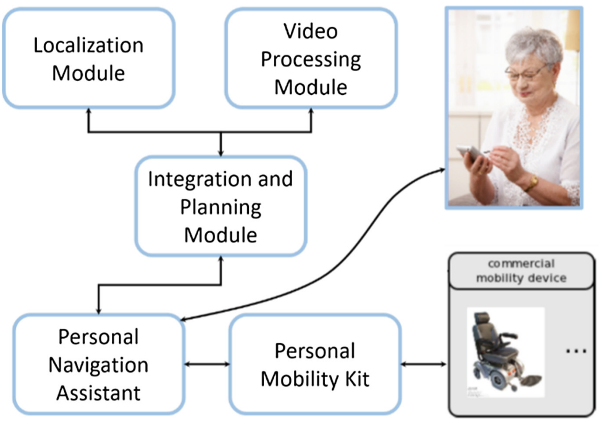

Fig. 1. Overview of the ALMA architecture

To support the different modules, a *Mapping Server* service collects and keeps updated a set of maps of the environment, providing information about

- physical obstacles, such as walls and fixed obstacles;
- terrain information, such as presence of steps/stairs or ease of accessibility for users with different needs and limitations, or for wheelchairs;
- passages connecting different areas, such as doors, and their current status (e.g., open/closed, unlocked/locked);
- possible destinations such as rooms, services or people, and their current status (e.g., if they are active/available);
- available services and their status (e.g., bathrooms, lifts).

ALMA users are therefore supported in their mobility to acquire knowledge about interesting locations (e.g., services, people, facilities, etc.), and to select and follow an efficient and safe path to such destinations considering their needs and/or limitations or the status of the environment. Secondary end-users, e.g., residences and hospitals, can leverage on the information collected by the system on the movements of their guests to monitor their aging, to design personalized support services and rehabilitation paths.

3 Related Works

Indoor Localization. Identifying, locating and tracking a target object within a specific environment is nowadays quite a common task. Several indoor localization technologies and approaches have been proposed, e.g., based on Radio Frequency (RF), acoustic waves, magnetic fields, etc. Lateration approaches allow to compute the current position; Dead Reckoning techniques continuously update the position (sometimes accomplished by speed and acceleration) of the target, given a previous position. Surely one of the most interesting and populated category is the RF-based indoor localization system, typically composed by a fixed network of beacons and a mobile worn device.

Dian et al. [6] present a WSN and RFID based localization system for indoor humans tracking, based on 802.11 active RF tags. They leverage the change in RSSI and the clustering of reference devices to obtain an improved localization accuracy up to 0.7 m–0.45 m, requiring however a double grid of devices.

Ubisense (Ubisense, UK 2005) [15] is a commercial location estimation system based on Ultra WideBand: RF signals are exchanged between active devices fixed in known locations, and those to be tracked. It can cover large areas and can manage a high number of users at the same time. Though quite accurate, the system can be challenging to install, due to the deployment of a timing cable, necessary for each device, and it has a high cost.

Radar (Microsoft 2000) [4] is probably the first example of positioning system using Wi-Fi networks providing WLAN (Wireless Local Area Network) access; a mobile device collects RSSI (Received Signal Strength Indicator) measurements from Wi-Fi access points and a fingerprinting algorithm is used to reconstruct the user position. In particular, instantaneous data are compared with a radio map of the environment to search for the most likely position. However, environment changes (humidity, furniture placement, etc.) can significantly affect the estimation process. The reported accuracy is 4.3 m, while the precision is 50% within 3 m. Many other systems based on WLANs have been later proposed (for example, AeroScout Company 2011, RFTechnologies 2011, from Deak et al. [5]), but they have similar characteristics.

User Interfaces for the elderly. Different communication channels and impairments of the elderly have been considered in designing user interfaces [8, 14].

Among the elderly, loss of vision is a major health care problem; approximately one of three elderly persons has some form of vision-reducing eye disease by the age of 65. According to [8] the interface should help older users to find items easily and should keep their attention focused on them, i.e., with no overlapping windows or icons, and a simple layout based on clarity and consistency. Black and white interfaces are preferable as well as sans-serif fonts. Authors of [9, 11, 12] have also investigated the best button size on a touchscreen interface for older adults: a size of 16.51 mm^2 is acceptable; buttons should be separated by a space of 3.17 mm to 12.7 mm. The universal font used for the texts in their applications is Helvetica, a basic sans-serif font, which could benefit older adults. The font sizes used in the design vary from 26 to 72 points.

According to [11] touchscreen mobile interfaces are preferred and not too difficult to use by the elderly. They suggested that larger buttons, icons and links (at least 8 mm) should be used, the gap between intended and actual touch location should be addressed, drag and pinch gestures should be considered rather than taps, and that multi-mode/view interfaces should be avoided.

Dexterity limitations (the effect of age-related degenerative changes in the musculoskeletal, vascular, and nervous systems) may affect the person's ability to manipulate objects and/or use arms, hands, or fingers. These issues require simple interfaces, big buttons, simple gestures [14]. Also hearing loss has to considered [13].

Indoor Navigation. Among the systems for indoor navigation, different proposals assist visually impaired users [17]; general systems are surveyed in [7]. Accurate and/or safe navigation of users with impairments towards a given point of interest in large and complex environments has been considered in different works. In particular, [10] focuses on the elderly and provides a system without wearable modules that exploits recognizable aids and abstractions to ensure that the elderly users can feel comfortable with it. The work presented in [3] proposes an Android-based navigation system for elderly people in hospital, based on RSSI and Dead Reckoning, reaching an accuracy of 93.3% but few details about the technique and the experiment are described. The authors in [1] developed a robotic wheeled walker able to assist people with moderate cognitive problems to navigate in complex indoor environments.

4 Localization Module

The ALMA Localization Module (LM) is a radio-based localization system used to track people (and objects), providing low computation, continuous recalibrated localization with uncertainty estimation. It is used by the ALMA Integration Module (IM) as one of the key sources of information required to assist its users: in particular, localization data are used to match user requirements with available resources (e.g., a nearby lift) and to manage potential difficulties (such as areas where the terrain is difficult for some categories of users). It is also used by the Personal Navigation System to assist the user in the navigation. The LM communicates with the IM in order to receive maps to be stored locally (maps contain also the positions of the RF beacons) and communicates the results of the localization (position and expected error) to the IM every 1000 ms.

One especially challenging problem is that of localizing moving targets: as most of the targets considered by project belong to this category, this problem has been given special attention. To solve it, a wireless sensor network with dynamic association has been used in the LM to retrieve and exploit RF signals for localization.

The localization algorithm leverages the possibility to update adaptively the relation between log-distance and RSSI. This can be achieved transmitting anchor-to-anchor signals and collecting the related RSSI values. Once every 20 s these values, collected by the server contribute to the update of an anchor-to-anchor signal matrix, using an autoregressive update model. Such matrix enables to build relations between the power values received by the mobile device and their distances through such a zero-calibration method [16].

Multilateration is implemented based on a discrete method DISCS (DIscrete Search for Candidate Solutions), exploring a grid of candidates solution, searching the most fitting point given the distances estimation. This enables on one hand the reduction of computation times still achieving an error comparable to gradient descent or particle filtering methods, and on the other hand it avoids wall-crossing and stabilizes the person position in the space. These has been proved with tests on the field as displayed in Figs. 2 and 3.

The performance of the LM in localizing targets on the map is compatible with the requirement of ALMA room-level localization. Precisely, targets are localized with a

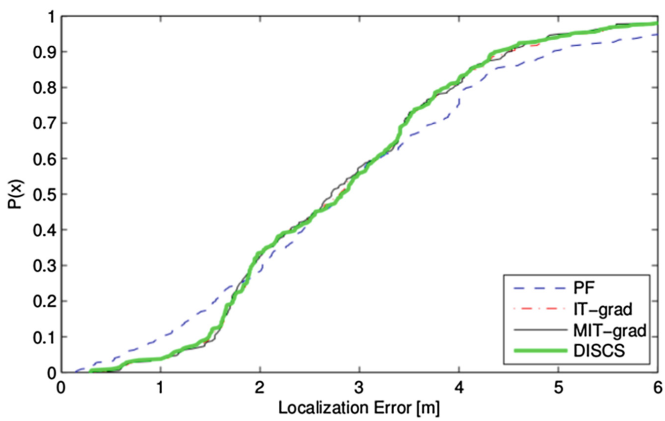

Fig. 2. Estimated Cumulative Density Function of Localization Error, comparison among DISCS, Iteration Terminated gradient descent (IT-grad), Magnitude of residual and Iteration Terminated gradient descent (MIT-grad), and Particle Filtering (PF)

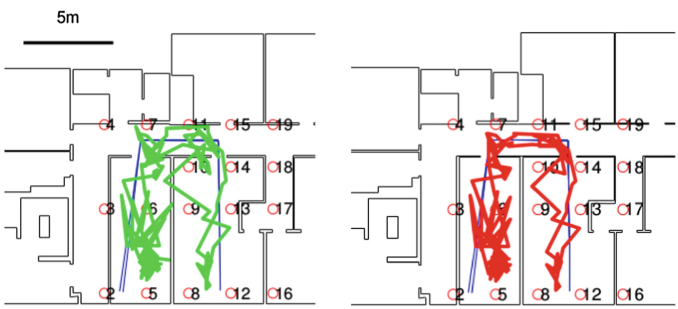

Fig. 3. Resulting localized path before (left, green) and after (right, red) the wall-crossing avoidance filtering. In blue the actual path. (Color figure online)

Circular Error Probable (CEP) of less than 4 m even with the lowest fixed devices density (0.04 m^{-2}) and this is compatible with the requirements of the specific application.

5 Personal Navigation Assistant

The Personal Navigation Assistant (PNA) is one of the key elements of the ALMA system: it a standard wireless device (a smartphone or a tablet) equipped with a software application, which enables the users to navigate through complex spaces and reach their destinations. The PNA has been designed for patients who need to autonomously move within a complex building (e.g., a hospital or a healthcare center): the PNA can guide them by constantly providing information about the direction to take, it can remind them the tasks of the day, and it can be a useful mean in case of help need. The user interface of the PNA is tailored to the target user and therefore it is easy-to-use, but together with the other modules of the ALMA system, it provides complex functionalities, such as: planning of routes that take into account the actual abilities and requirements of the user; monitoring of the progress of the user to detect possible deviations; possible re-planning of the routes to reach the desired destination. For instance, when local obstacles that require redirections are detected by the system.

The market already proposes several devices that can be turned into a PNA. However, the requirements of target users require simplified interfaces and the integration of specific functionalities that must be transparent to the user to enable patients/residents to reach their destinations independently and with safety. The proposed interface supports indoor navigation, manages a user's personalized agenda, and simple interactions in case of help request. The whole complexity is hidden to the final user, it is moved behind the interface and managed by the interaction between the PNA and the ALMA system.

To support navigation, the system exploits the map received from the ALMA server and gets a path computed by the integration module: the path is a sequence of points, which is processed to identify the doors to pass through, the turning points, and other elements such as lifts, stairs, etc. Figure 4 shows an example of a processed path. The

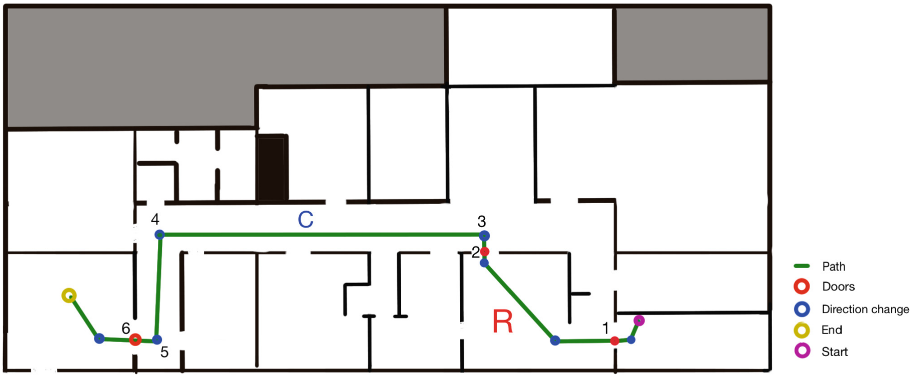

Fig. 4. Example of path segments

intermediate blue points indicate the direction change and the red points represent doors. They identify segments of the path. Depending on the type of the ending point of a segment, different instructions are provided.

Input/output multimodality is supported: users can use touch or voice input and receive information with text/images or audio. The modality may depend on the functionality that is used: e.g., to select a destination or browse the agenda, touch input is a feasible modality; instead, during navigation, audio output was requested to avoid the user focusing on the screen. Simple commands specifying the direction and exploiting landmarks such as doors, lifts, corridors etc. were used. For testing purposes a more advanced interface including also the map is available. Some snapshots of the PNA are shown in Fig. 5.

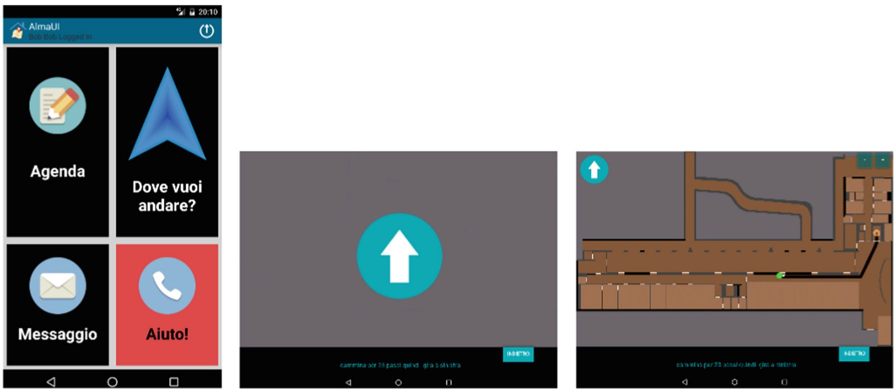

Fig. 5. (a) Main menu of the ALMA app with: agenda, navigation, messages, and help; (b) simplified navigation interface for target users; (c) advanced navigation interface used for testing.

The navigation system takes into account also possible *deviations*: they occur when the user during path progression is in an unwanted status or direction. Therefore, a proper reaction is anticipated in order to avoid her getting lost in the path. This is really important, especially for people with mobility or cognitive limitations. We have defined three different categories of deviations:

- **Positional Deviation:** when the user is in a place outside of the current path. For example, a user is inside the wrong room or takes a different corridor with respect to the planned one. In such a case the reaction consists in regenerating a new path by asking it to the server.
- **Temporal Deviation:** if there is a predefined maximum time to reach the destination (e.g., in case of a visit with a doctor at a given time) and the user may not be on time to reach the scheduled place, in this case s/he (as well as the staff) is notified about the delay.
- **Orientational Deviation:** when the user is located in the proper place, but he or she goes towards a wrong direction, which may lead her to go outside of the path or waste his/her time in the path progression. This may lead to the other two types of deviations, and the reaction toward consists in bringing the user back to the correct orientation.

6 Experimental Session

We performed some experiments in a care-giving facility. The Elderly Group consisted of n = 5 participants, who were in average 86.3 years old (SD 2.045), four females and one male. The included participants have similar physical and cognitive impairments, but they do not have strong visual or hearing impairments. The residents are at the facility on average since approximately 5 years, because of mild cognitive deficit (dementia) with memory disturbances. The level of autonomy in the activities of daily living is quite low and they need nursing assistance for simple activities, like washing. Most of the participant uses walking aids for displacements and walking (rollators, crunches). Regarding technology, they never use smartphones or tablets.

The path that the users had to follow included some turns and an unknown final destination (the kitchen elevator used only by cooking personnel).

Navigation commands were given using audio output. Because of the particularly noisy environment, the audio was enforced with a Bluetooth external speaker. We annotated comments made by the participants during the walk.

Most of the feedbacks were associated with the volume of the vocal commands, considered too low, despite the use of the external speaker. The interface was considered intuitive and the directions for the navigation were clear and easy to understand. The acceptance and the interest towards new technologies were rather high. During the displacement, the information given by the device did not affect the concentration and the stability of the participants.

All the users understood the commands and could press the correct buttons on the interface, with some problems with a left-handed user. The way they press the button depends on the person: in some cases, pressure was high and for an extended time; in other cases normal pressure was used; selection worked correctly in all the cases.

At the beginning of the navigation, they gave the impression to feel a little bit unsure, but immediately after, they continued on the path showing more confidence. The end of the path in front of a lift they have never used created some surprise to the participants since it was an unexpected destination: however, all of them could reach the selected destination.

7 Conclusions and Future Work

In this paper we have described the ALMA system targeted at elderly and, more in general, persons with cognitive and mobility impairments, to support indoor navigation. In particular, the system comprises a localization module and a personal navigation assistant application to guide the user to a selected destination.

Experimental results are promising for using the PNA as an aid in the rehabilitation process: the staff of the care facility believes that the PNA can be a useful auxiliary means to compensate for the cognitive deficits, but during the move the caregiver should be present anyway. More specific studies in this direction should be conducted.

Also the PNA may be further improved and include also user's adaptation of the navigation: by analyzing the path (e.g., in terms of speed, deviations, etc.) in relation with the characteristics of the user's profile, it should be possible to improve the whole system, as well as the PNA. For example, if by looking through the history or logging data of the user's paths we understand that following a specific part of a path is much harder for specific users or users with special restrictions, this should be considered.

Moreover, the LM can be improved by implementing more advanced power saving features, to reduce the maintenance costs and the user effort to keep the personal device recharged and operative. Finally, it would be interesting to implement dependability features among the different ALMA submodules, implementing methodologies based on redundant or correlated information [18].

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