Towards supporting elderly's orientation, mobility, and autonomy

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Abstract. In the context of the European-funded Ambient Assisted Living (AAL) Joint Programme, the project ALMA (*Ageing without Losing Mobility and Autonomy*) focuses on technologies for supporting the autonomous mobility, navigation, and orientation of the elder, and, more in general, of the person with reduced mobility. ALMA has developed modules for ambient monitoring, user interface and navigation, and automatic wheelchair control. All these modules are connected trough a central integration module that provides maps, planning, and scheduling services on demand. In this paper, we focus on the architecture of the central module and on its mapping and planning features.

1 Introduction

Aging brings limitations in the ability to effectively move and orient autonomously, both indoors and outdoors. Overall, this can have a strong negative impact on the quality of life and the psychological well-being of a person. Can technology help the elder to overcome these naturally arising limitations?

A concrete way of employing technology for this aim is illustrated by the following scenario, that is developed in a large facility of interest for the elder, such as a nursing home or a hospital. We assume that we can map the facility, and deploy sensors to monitor it and track the location of users inside of it. An elder woman, with orientation difficulties, needs directions, and asks for and receives them through a navigation interface tailored to her needs and (dis)abilities. An old man obtains assistance for traveling to a medical appointment using a motorized wheelchair that guarantees a safe navigation. In the meantime, the personnel is timely warned that a potentially dangerous situation is happening: a resident is escaping because of dementia issues. The AAL project *Ageing without Losing Mobility and Autonomy* (ALMA [1]) works in the direction of realizing the scenario vision, supporting the autonomous mobility, navigation, and orientation of the person with reduced mobility. The described example addresses a health-care facility, but project outcomes could be employed in more general scenarios, such as shopping malls or airports. The project includes 3 academic partners and 3 SMEs for technological development. In addition, a rehabilitation clinic and a nursing home provide real testbeds for on-field evaluation.

In this paper we briefly describe the components being developed in the ALMA project. We then focus on the aspects related to the *spatial representation* adopted to provide indoor services, to the use of this representation for two core planning problems: *finding good paths for wheelchairs*, and *extending path planning to include social and psycho-physical attributes of spaces and routes.* Similar to other works [12, 4, 7, 3], we use *Bézier curves* to define suitable paths for automatically controlled wheelchairs. To take into account for general spatial attributes in addition to the geometry of the curve, we use *multi-layered maps* [11, 2] with the new standard *IndoorGML* [8].

2 ALMA architecture

2.1 Component modules

The ALMA system is based on a set of modules that can work in isolation or together, exploiting each other's functionalities: (a) *A distributed, radio-based localization module* tracks the position of small RF transponders that can be attached to wheelchairs and users; (b) *An array of smart time-of-flight cameras* monitors people and wheelchairs and measures crowdedness of spaces; (c) *Personal navigation assistants (PNAs)* (tablet-like devices) offer specialized interfaces for query the system and for navigation to users with special needs and (dis)abilities; (d) *Personal mobility kits (PMKs)* interface with commercial motorized wheelchairs and enhance them with semi or fully autonomous navigation capabilities, making the wheelchair a *robotic agent*; (e) *An integration and planning module (IPM)* provides a central storage for users' and spatial information, and offer scheduling and path planning services.

In the following, we focus on the description of the integration and planning module, which acts as a central *server* for all other ALMA modules[1].

2.2 Knowledge modeling, acquisition, and sharing

The dynamic database hold by the IPM consists of *users' information*, like clinical profiles and preferences, and of *spatial information* stored into IndoorGML maps described in Section 3. Spatial information comes from three different sources: (a) available CAD floor maps that are elaborated, annotated with semantic information, and converted to IndoorGML maps trough a Sketchup [10] plugin that we have developed; (b) maps with additional semantic information on rules and uses of spaces, these maps are kept up-to-date by the personnel (e.g., nurse and doctors) as well as by the logistic managers of the facility; (c) data from ALMA localization and vision modules, that provide real-time ambient monitoring and location of users and wheelchairs.

All ALMA modules act as clients that communicate with the IPM server trough a *RESTful HTTP interface* [5]. This design choice allows to: (a) keep the protocol simple; (b) serve heterogeneous clients (both ALMA modules and generic browsers); (c) keep the system modular with minimal dependencies; (d) follow the good practices that have contributed to the success of the world wide web. Each resource is exposed trough: (i) a lightweight json/xml interface designed for ALMA modules; (ii) an html/svg interface for the browsers used by the professionals using and managing the system. PMK modules interface with the wheelchair on-board control trough *ROS*: the PMK queries the IPM server for information and republish it to the ROS network, sending the received maps and plans in the appropriate ROS format.

3 Spatial information and IndoorGML maps

Spatial information is stored in *IndoorGML maps*, a recently approved OGC standard [9] that extends GML maps to describe the indoor navigation of heterogeneous agents. An IndoorGML map is a *multi-layered graph of cells*, where each layer can have a different scale and can contain geometric information.

[1] A public version of the server software, attached to simulated data sources, is available at `http://goo.gl/DOyOxU`

Inter-layer edges permit to move across layers. The maps used in ALMA contain at least *one geometric layer* – made of both non-navigable cells (like walls) and navigable cells, labeled by their role (like doors, corridors, etc.) – that serves for *navigation*. Additionally, each *sensing module* stores the information gathered from the ambient in its own map layer. Finally, *several semantic layers* are available to store names and other spatial attributes. Maps also contain information on *social norms*, like designed used of spaces, accessibility and privacy. Some layers are personalized to take into account the user's (dis)abilities.

The variety of spatial information contained in the IPM maps are made available to and used by different agents (i.e., humans and semi or fully autonomous wheelchairs) that require different granularity and semantic. The adopted representation has been primarily designed for humans, who require more high level data descriptions compared to robotic agents. This is the case of symbolic and topological space information that are needed for high level path planning and guiding directions for walking users. In addition, maps also store all the geometrical information necessary for robots/wheelchairs to perform lower level path planning. Figure 1a shows an example of a simple multi-layered map. Figure 1b–f show how a route is represented into the different map layers (see next section).

The vision behind IndoorGML is that in the near future, when entering a building, our smart phone will visualize the map and provide navigation instruction. The ALMA project, by complying with the same standard, ensures that its mapping an planning components could be integrated in this scenarios and address the special needs of elderly patients.

4 Mobility and path planning

Path planning in spaces populated by multiple human and robotic agents presents challenges, both for the pedestrians and the semi- or fully-autonomous wheelchairs. Wheelchairs/robots motion need to be predictable for the pedestrians, and in turn, wheelchairs' controllers need to be aware of the context and take into account social norms, in order to be perceived as friendly/safe [6]. These aspects are considered in the design of the IPM, that performs *path planning* both for pedestrians and wheelchair users. These latter can be on manual, semi-autonomous, or fully-autonomous driving control. Each user category has different needs but exploits the same information from the multi-layered maps of Section 3.

4.1 Geometrical path planning

In order to devise a path according to the requirements discussed above, the initial step is to look at the *geometrical layer* of the maps to define the *configuration space* for the agents. First, we compute the union of all the non-navigable cells in which the space has been partitioned. For wheelchairs, we further enlarge it according to the occupancy radius of the wheelchairs plus an additional safety margin. The resulting non-navigable space is subtracted from each navigable cell. Finally, the resulting navigable cells are partitioned into a set of convex cells. Large, mostly rectangular, convex cells, are obtained by cutting recursively along the *shortest* of the diagonals incident to reflex vertices. The final result is a *navigation layer* made of convex navigable cells. Its *adjacency graph* G serves as basic data structure for the path planner, whose plans consist of a list of cells borders to traverse. Because each cell is convex, the local planner (or the user itself), can easily navigate from border to border.

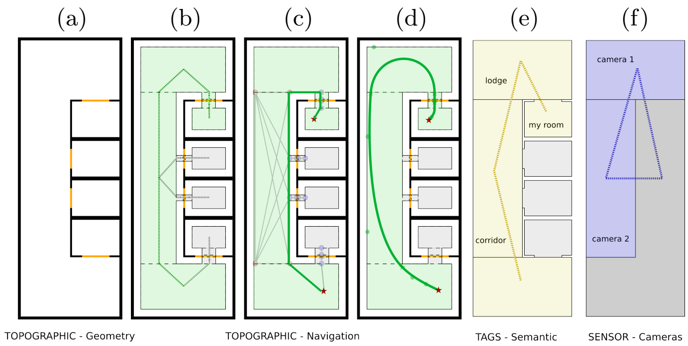

Fig. 1. (a) The geometric layer with walls and doors (colored in orange); (b–d) The navigation layer of a wheelchair with the steps needed to compute a path: path (green cells) on the topological graph → shortest polyline (green) on visibility graph (grey) → optimized polybézier; (e–f) The path offers directions (semantic layer), and predictions (cameras layer) about which sensor will support the user during the journey.

The next step in path definition, is to refine the obtained topological plans by adding the precise geometrical trajectory to be followed inside each cell. For pedestrians, this is obtained from computing the visibility graph of the navigation layer. More precisely, the dual of graph G (i.e., the graph with borders as nodes and cells as edges) is extended with nodes that lie on the intersection of a border with a line between border vertices. This operation is performed for all cell borders, except for those representing doors and for those cutting perpendicularly narrow corridors, where we force the trajectories to pass in the middle. Pedestrians' paths are computed as *shortest polylines* on this graph.

For wheelchairs, a further refinement is needed to compute paths that would turn gently. In fact, on those paths, the wheelchair can be controlled smoothly and would not suffer from significant accelerations, that would cause discomfort to the user sitting on it. At this aim, pedestrians' polyline paths are transformed into *polybézier paths*, whose segments – one per cell – are Bézier curve of order 5, with endpoints on the cell borders and the other control points constrained to be inside the cell. Such paths are *collision free*, because the curves are contained in the convex hull of the controls points, which is itself contained in the cell. The path trajectory is constrained to pass *perpendicularly* by the middle of fixed borders. Instead, on non-fixed borders, end control points are free to move along. The segments are glued together to form a C^2 curve γ, which provides, to a differential driven wheelchair, a reference trajectory with continuous angular speed given by a curvature k and linear speed. The values of the remaining control points are selected so that γ minimizes a version of the bend energy $\int_\gamma k^2(s) + k'(s)^2 ds$, as appropriate to maximize user comfort [3], where γ is parametrized by path length s. Figure 1b–d summarizes the described process.

When multiple topological routes between two locations are possible, like in Figure 2, the choice is to select those trajectories that have both low bend energy and short length. This problem extends to the larger multi-objective problem detailed in the next section.

4.2 Multi-objective path planning

People, while moving, take into account extra spatial aspects in addition to the geometry of the trajectory. Desired routes are *direct, safe, avoid difficulties,*

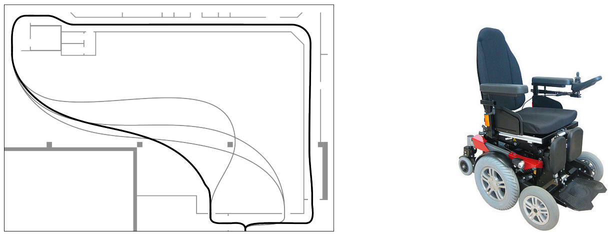

Fig. 2. (Left) Multiple paths may be possibles: in bold face the Pareto optimal solutions with respect to path length and path bend energy, in gray the dominated solutions. (Right) Commercial electric wheelchair (Degonda T3) used in ALMA with a PMK.

pass trough pleasant areas and conform to social rules, like privacy. In general, individuals may select different routes to the same destination by relying on different knowledge of the environment and by weighting differently the various spatial properties. In ALMA, we aim to address both these aspects.

On the one hand, the IPM leverages ambient monitoring to enhance the perception of the environment provided to the users (and used for planning). For instance, ALMA let the users know if some areas are better to be avoided because currently overcrowded. Moreover, maps contains semantic information, like data about the designed use of the spaces (e.g., a hall, a bar, a gym). This information, when properly presented to the user, can greatly help the user to get oriented and navigate throughout the environment.

On the other hand, we want to help the user to select the best route, when multiple valid alternatives exist. The approach followed in ALMA is that we always let the user remain in charge of the strategic decision to pick one among multiple choices. This way of proceeding partially addresses the difficulty of robustly modeling user preferences, that may also change day-by-day. Yet, some users may prefer not to be presented with multiple choices, or may prefer just to choose among at most two possibilities. This gives rise to a series of interesting scientific challenges on how and how many choices to present to elder users and how to gather their feedback to improve the planner.

In order to select the set of routes to be presented to the user, our planner makes use of the information contained in the multi-layered map (see Section 3). First, the geometrical paths obtained as described in the previous section, are scored based on: (a) *safety*, (b) *social conformance*, and (c) *psycho-physical comfort*. For a route, each of the three scores is the sum of one term that depends on the geometry of the route and one term that depends on the cells that the route traverses. Each cell has associated a weight attribute that depends on the user profile. During the project evaluation phase, user feed-backs will be gathered and employed to adapt user profiles. At the moment, safety, social conformance, and psycho-physical comfort are derived as follows. (a) The distance from helping personnel, the illumination of the rooms, the sleepiness of the floor, and the steepness of the route, assess the risk of a user falling down, which is related to a measure of *safety*. (b) The privacy requests and the assigned use of the spaces assess the *social conformance* of the routes. (c) The crowdedness of spaces, the amount of effort required to travel the route (length, amount of descending/climbing), and the amount of different spaces and turnings required, which could make the user loose orientation, estimate *psycho-physical comfort*.

The use of three numerical values to score a route sets the route selection problem as a *multi-objective* one. In case of pedestrians, all Pareto dominated routes are discharged. Only the *Pareto optimal routes* are presented to the user (in graphical or linguistic form) for selection.

For the routes to be traveled by a user on a wheelchair, the planner considers the same criteria as above, but with different weights. Similarly, for autonomous wheelchairs traveling without a sitting person (e.g., for going back to a parking space), as well as for any other mobile robots that might be used for logistics, for instance, the planner takes into account aspects like social conformance and the geometry of the route, while other aspects are weighted only from the point of view of the people occupying the spaces that the route will traverse (e.g., the planner could avoid that the wheelchair pass trough a group of people) in order to be perceived as friendly and navigate efficiently.

5 Ongoing work

In the forthcoming months, the installation of the ALMA technologies and an intensive evaluation campaign is scheduled at the consortium pilot sites, the nursing home and the rehabilitation clinic. In particular, the efficiency of the ambient monitoring system will be evaluated and put to test in different scenarios where the users need to be guided in their daily routine and mobility, and in scenarios where ALMA helps the facility personnel to promptly react to dangerous events. Both autonomous and semi-autonomous wheelchair navigation will be also tested, with a number of selected residents that will provide useful feedback. We will also test the application of the ALMA mapping and planning tools for indoor logistics, using a fleet mobile autonomous robots.

References

1. ALMA. `http://www.alma-aal.org`.
2. T. Becker, C. Nagel, and T. Kolbe. A multilayered space-event model for navigation in indoor spaces. In *3D Geo-Information Sciences*, pages 61–77. Springer, 2009.
3. L. Chen, S. Wang, H. Hu, and K. McDonald-Maier. Bézier curve based trajectory planning for an intelligent wheelchair to pass a doorway. In *UKACC International Conference on Control (CONTROL)*, pages 339–344, 2012.
4. J.-W. Choi, R. Curry, and G. Elkaim. Curvature-continuous trajectory generation with corridor constraint for autonomous ground vehicles. In *Decision and Control (CDC), 2010 49th IEEE Conference on*, pages 7166–7171, Dec 2010.
5. R. T. Fielding. *Architectural styles and the design of network-based software architectures*. PhD thesis, University of California, 2000.
6. J. Guzzi, A. Giusti, L. Gambardella, G. Theraulaz, and G. Di Caro. Human-friendly robot navigation in dynamic environments. In *IEEE International Conference on Robotics and Automation (ICRA)*, pages 423–430, 2013.
7. B. Lau, C. Sprunk, and W. Burgard. Kinodynamic motion planning for mobile robots using splines. In *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 2427–2433, Oct 2009.
8. K.-J. Li and J. Lee. Indoor spatial awareness initiative and standard for indoor spatial data. In *IROS Workshop on Standardization for Service Robot*, 2010.
9. Open Geospatial Consortium. OGC IndoorGML v.1. `http://www.opengeospatial.org/standards/indoorgml`, 2014.
10. Trimble. Sketchup. `http://www.sketchup.com`.
11. H. Zender, O. M. Mozos, P. Jensfelt, G.-J. Kruijff, and W. Burgard. Conceptual spatial representations for indoor mobile robots. *Robotics and Autonomous Systems*, 56(6):493–502, 2008.
12. F. Zhou, B. Song, and G. Tian. Bézier curve based smooth path planning for mobile robot. *J. of Information & Computational Science*, 8(12):2441–2450, 2011.