

Now I need help!

Passing doors and using elevators as an Assistance Requiring Robot [★]

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Abstract. The ability to handle closed doors and elevators would extend the applicability of Socially Assistive Robots (SAR) enormously. In this paper, we present a new approach which integrates uninstructed persons as helpers to open doors and to call and operate elevators. The current implementation status of these two abilities into a robotic application developed for real-world scenarios together with first experimental results obtained are presented below.

1 Introduction

Socially Assistive Robots (SAR) can already be found in lots of applications in everyday life, e.g. to fulfill transport or inspection tasks or to guide persons in shopping centers [1] or in rehabilitation centers [2]. But indeed, the amount of applications is restricted by the incapability of almost all robots to open closed doors and to operate elevators. This capability requires a technical upgrade of doors, elevators and robots as demonstrated in [3], or alternatively it requires the usage of a robot with integrated manipulator to be active by itself. Both approaches are barely practicable, because the upgrade is time and cost consuming and, moreover, the skills of cost-intensive manipulators to open doors are still underdeveloped.

An alternative approach is the integration of persons as helpers to open doors or to call and to operate elevators for our Assistance Requiring Robot (ARR). So the ARR has to find bystanders, to speak to and to motivate them for assistance. This approach is tracked in the ongoing research project FRAME („Elevator Usage and Room Access for Robots Assisted by Human Helpers“ running from 2017-2020), and investigated in different environments, an office, a production and a clinic building. So, in FRAME several challenges are investigated, e.g. the identification of situations demanding assistance, the robust detection and tracking of persons in everyday poses, the estimation of the willingness to support the ARR, the re-identification of helpers, an user-centered navigation in narrow environments as like elevators, and a human-robot-interaction to convey the concrete actions.

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In this paper, especially the identification of situations that demand an assistance, the handling of closed doors, and the use of elevators, together with a suitable user-centered navigation are to be introduced. The methods used for person tracking and for human-robot interaction are presented in [4], [5] and [6], respectively.

The remainder of this paper is organized as follows: Sec. 2 discusses related work in the field of human assisted robotic applications. In Sec. 3 typical procedures to drive through a door and to use an elevator assisted by a human helper will be introduced. Based on this, Sec. 4 presents the robot prototype that is used in FRAME with the used sensors, the essential human-robot interaction and navigation skills required to operate autonomously in challenging real-world environments, like an office building. Methods used for identification and handling of assistance demanding situations are introduced in Sec. 5. Using these functionalities in Sec. 6, the results of first functional tests with 20 non-instructed persons are discussed. Sec. 7 gives an outlook on pending long term user studies in an office building.

2 Related Work

SARs, explicitly using human assistance to fulfill a task that they can not do alone, are still rare to find. Similar to FRAME the group of Manuela Veloso already developed the Collaborative Robots (2009-2015) [7] to investigate human assisted SAR transport tasks in an office building. Different to FRAME they mainly investigated probabilistic planning mechanisms of where and when to look for help and integrated persons instructed to help.

[8] used the tasks of traversing doors and operating elevators, too, but in a simplified form to investigate social actions as subplans in motion control of a SAR. The explicit help from passers to reach a goal in downtown of Munich was used by the outdoor robot IURO of the Technical University Munich [9].

Also the FP-7 project HOBBIT [10] addressed the assistance of a SAR as mutual care in households with residents. Further, in 2015 it was demonstrated that the conversational but immobile robot hitchBOT can do hitch-hike tours, getting help by strangers. Children are needed in [11] to fill a sociable trash box (STB). The STB tries to receive attention by moving towards the trash or using intentional stance. The authors also evaluated the interaction distance which is an important metric for our AAR.

A main contribution of this paper in the context of FRAME is the **identification of need for assistance**. Especially closed doors and elevators have to be detected and to be integrated in motion planning. There are different approaches to detect doors and their features like the opening direction and the opening angle, e.g. by analyzing the local obstacle map [12], [13]. Further approaches take the geometric relations in image and depth data into account, e.g. [14]. [12] assumes that all objects (like doors or walls) have the same color, which is not suitable for our scenario. Therefore, [14] computes the vanishing point of the image based on line segments. Especially in the rooms of the production building of our project this approach would fail due to lots of shelves standing in front of

walls. Detecting doors by observing objects over time (like [13]) is only successful, if the robot would be able to observe every door open and closed which is not really promising in any building with lots of doors.

There are less approaches to estimate the opening state of elevator doors like [15], which uses an approach based on opening states of doors or [16], which estimates the possibility to drive into the elevator. In FRAME, we need a fast way to classify the elevator door state as described in 5.

An **user-centered motion planning** is also important in environments where persons and a robot move close, as like at doors or for and in elevators. That's why based on the Dynamic Window Approach (DWA), which is the mostly used approach for motion planning, a personal space has to be considered [17]. Personal space also means, that to initiate an interaction a robot has to approach a person from the front [18] and has to choose appropriate movement parameters, like velocity or acceleration, which also will improve the person's acceptance [19]. The Evolutionary Motion Planner, developed in our group [20], a more versatile motion planner than the DWA, both enabling the optimization of motion command sequences under various combinations of criteria, is also used in FRAME.

3 Procedures to handle closed doors and elevators

In the following, the phases of door passing and elevator use of a typical ARR are outlined, implemented as a state-based training application (see Sec. 4), and tested in a series of functional tests with users (see Sec. 6).

The need for passing doors and use of elevators results from the task of the robot, e.g. a transport task in a multi-level building. This is also the context of FRAME, the transport of mail and material between rooms in the building, at first between secretariats in an office building and later in a production and a clinic building. The procedure is as follows: The mobile robot receives a concrete transport task in one secretariat to yield to another. For this task, it determines its best way [3], with the need to handle possible doors and evaluators.

In the following, the exemplarily described interactions integrate voice outputs, GUIs and LED-color representations at the robot's head described in [6].

3.1 Closed doors

When the robot approaches a door, closed or not enough open to pass, it recognizes its state and drives to a waiting position beside this door. This position has to be chosen allowing to recognize a changing of the opening state or opening angle of the door, caused by persons. Also the waiting position has to guarantee a good look for persons in the surroundings, which will be rated according their willingness to help and consequently asked for help, e.g. by „Could you help me to pass the door, please?“ together with a blinking of the head LEDs to enhance the peripheral attention (see Sec. 4.1). In the current implementation, persons in a distance of approx. 10m will be sensed but will be addressed not until an interaction distance of 3m is achieved (see Sec.5). In the next stage of expansion, an active search for helpers, instead of waiting alone, is supposed to be integrated.

If the person comes to the robot, it repeats its request when the person stands

in front of it and requests a confirmation to help by touching the display. By doing this the person becomes the short-term helper of the robot. Then the helper opens the door and as soon as the robot senses an opening angle enough to pass through, it says „I am starting to drive.“, changes its display and LED color and moves on. When the robot is passing the door threshold, it thanks for help, e.g. by „Thank you, have a nice day.“ while continuing its way to the goal without stopping. Should the helper open the door not wide enough to pass or blocks the passage by itself, the robot points out „The door is not wide enough open.“. Should the helper leave before ending the assistance, the robot waits at its waiting position for the next person to ask for help.

3.2 Elevator use

When the Assistance Requiring Robot (ARR) approaches an elevator, the same procedure to move to a waiting position as that from doors takes place. If the ARR has a helper, it says „Please call the elevator and keep the door open for me. When I'm in the elevator please press button for floor 2.“ So, the helper has to call the elevator and also has to ensure, that the door keeps open while the ARR drives into the elevator, e.g. by pressing the elevator call button repeatedly. Should the door close before the robot is at the threshold, it keeps outside and asks the helper to open the door again.

Depending on the goal of the helper, s/he can also use the elevator or leave it after assistance. Should the ARR be alone in the elevator, it moves in front of the door to realise a speedy leaving after reaching the desired floor level. Should the ARR be not alone in the elevator, shortly before reaching the desired level, it says to the bystanders „At the next stop I want to leave. Please make room in front of the door.“. After reaching the desired level, the SAR continues its way to the goal.

4 Assistance Requiring Robot

4.1 Mobile Robot

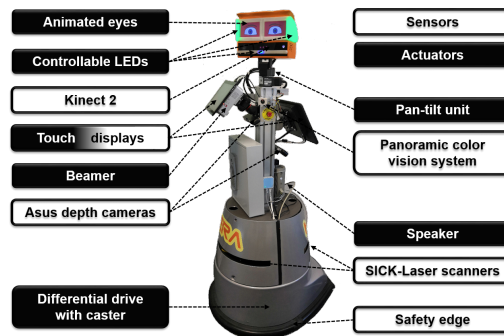


Fig. 1: Our mobile robot platform; grey: sensors, white: actuators

Using a differential drive, our mobile robot can reach a driving speed up to 1.4 m/s. To sense the environment two SICK laser range finders cover a 360°

field of view in addition to two ASUS depth cameras facing in front and reverse driving direction. Immediate contacts with obstacles can be detected with the safety edges which are directly connected to the robot's motor. A panoramic camera system and a Kinect2 (mounted in our robot head) are used for person perception. As we are challenged with the need of assistance by uninstructed persons, two touch displays are mounted for input of the person. For communication with people, we can use a speaker and our robot head with animated eyes and controllable LEDs to achieve a natural human robot interaction.

4.2 System Architecture

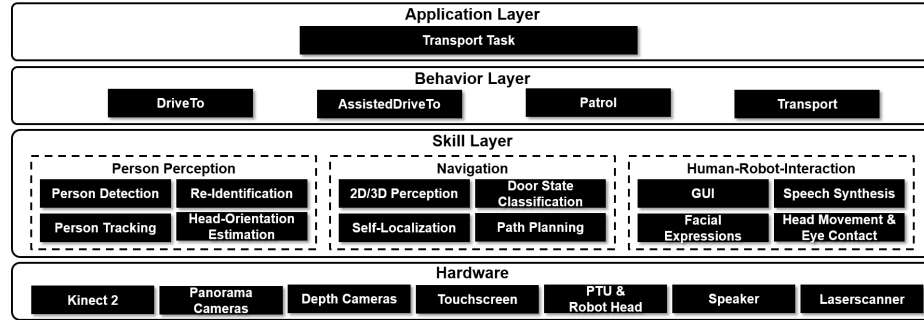


Fig. 2: Hierarchical system architecture; the intelligence to pass doors and elevators with assistance of humans is part of the AssistedDriveTo-Behavior

In our scenario described in Sec. 3 the mobile robot is facing multiple challenges in order to fulfill his tasks. Therefore we developed a complex system that can be separated in different layers (consisting of different modules) which are shown in Fig. 2.

1) Hardware Layer: Our mobile robot is equipped with different sensors and actuators for obstacle avoidance, human robot interaction or person perception which are mounted on a SCITOS platform (see Fig. 1). Details of the hardware layer are described in Sec. 4.

2) Skill Layer: The skill layer realizes the basic functions our mobile robot needs to fulfill our requirements for the door pass and elevator ride.

Person Perception: Obviously the person perception is a crucial skill for our application. Besides detecting legs in laser scans based on generic distance-invariant features [21] we use YOLOv3 [22] for detecting people on images of the panoramic camera system. Additionally, the point cloud based detector [23] is used for person perception. All information of the separate perception modules are fused in our Bayesian tracking framework [5] which is also able to track attributes like gender or orientation. In the current phase of the project we choose our helper out of all tracked people by estimating the interest in being assistive via their trajectories. A person walking towards the robot is probably more willing to assist our robot than a person going away. In future, we will classify if we should contact a person not only based on the trajectory by adding more information like head orientation. Furthermore, we want to classify if a person

is carrying only a handbag or maybe a huge box (like in [24]) or if the person is using a cellphone [25].

Navigation: In order to achieve a socially accepted and safe navigation in all of our scenarios, we use several algorithms. The robot localizes itself by means of the well known aMCL approach [20]. We use 3D information of the depth cameras and 2D laser scans for obstacle detection and generating maps of the environment. Using a multi-objective motion planner, the optimal motion command is computed. Our system ensures that we are always at the right position in the map. Small errors in the localized pose ($\geq 20\text{cm}$) can influence our door classification algorithm and should therefore be minimized. In future, we are planning to use door detection algorithms to update the local door pose in case of errors in localization.

Our mobile robot is challenged in various situations during the assistance of people as the distance between the robot and the person is very small. Usually the robot would not intrude the personal space of the people but due to the limited space in our scenario, we still need to ensure a socially acceptable navigation. The classification of door states is a major part of the navigation to empower our mobile robot to detect the need for assistance at closed doors.

Human-Robot-Interaction: Our robot is equipped with multiple devices to interact with humans. The two touch interfaces at the front and the back of the robot are used to show several information about the needed assistance and additionally to get touch inputs used as feedback. Furthermore, the robot head can show various emotions via animated eyes and generate attention with RGB-LEDs. It is mounted on a pan and tilt unit to be able to always look at the person that is supposed to assist the mobile robot. Every information will also be spoken by a speech synthesis software in realtime.

3) Behavior Layer: Each behavior uses several modules of the skill layer in order to achieve its task often realised as state machines which coordinate the use of all needed skills. In addition, each behavior is able to use the other behaviors of this layer. The main behaviors used in our application are the *AssistedDriveTo* (driving around with the assistance of people for closed door and elevator use) and the *Transport* (coordinating the route of the robot).

4) Application Layer: Our application is the interface for the users to send the robot to several offices. In each office the mailbox mounted on our mobile platform can be filled with additional post and be send to other offices in the building.

5 Functional Requirements

Requirements for door passes

In order to pass a door in any scenario, we labeled the position of doors in the environment of our mobile robot. On top of the knowledge about door positions, the door state needs to be classified. We analyze the door opening angle in order to decide if a door is sufficiently opened for our mobile robot to pass it. This classification needs to be very fast as the angle can change all over sudden. By applying a probabilistic hough transform as described in [26] on the local laser map, we are searching for the door line. In case we found the door segment, the

opening angle is computed and the door state is classified via a threshold (see Fig. 3). If the door is not visible in the laser map due to occlusions, the state will remain unknown.

During navigation, we check if there is a closed door in the next 5 meters around the robot that we need to pass. In case of an opened door we can just drive through, if it is closed or not wide open the robot needs to look for a person to assist it by opening the door. During the assistance of a helper, the door state classification is more difficult as the person will always partially (or fully!) occlude the door in the laser scan (see Fig. 3b) resulting in a failure if the door line cannot be detected anymore. As this will only happen when the helper blocks the path to the door center and therefore blocking our path to pass the door, the robot will ask the person to make more room.

In future, we are looking into utilize semantic segmentation to detect doors in color images and 3D point clouds instead of manual labeling. The big advantage of the semantic segmentation is that the robot will also be able to estimate the opening direction via the location of the segmented door hinges and therefore enable the robot to autonomously add all surrounding doors to its navigation map. The door state classification only needs around 5ms, and the tracking results are published with 5Hz, which allows the robot to react on all fast changes of the environment.

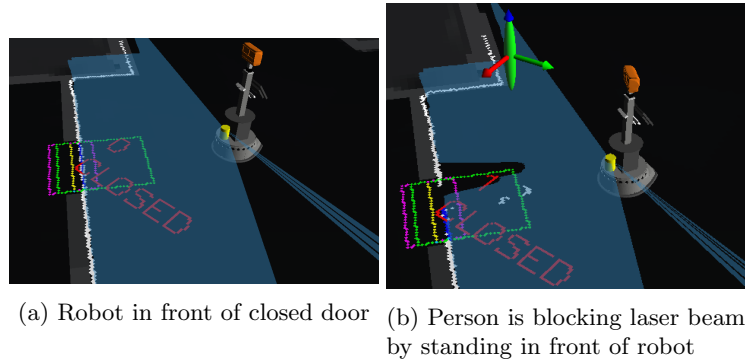


Fig. 3: Door state classification; yellow: labeled door line, blue: detected door line, green: detection area, red: classified state and opening angle

Requirements for elevator use

To identify the support need for elevator use the robot needs to use information of our topological path planning algorithm across multiple levels as presented in [27]. The different areas (so-called nodes) in each floor are connected via gateways and build a graph structure which is used for global path planning. The graph structure is handmade and needs to be created only once. At the moment, the position of all elevator doors is labeled manually, in future they will be automatically labeled using a classification algorithm for this task. The local path planning is based on the cost map containing local obstacles. Every time we are choosing a gateway to a different floor, we need to use an elevator

and, therefore, the mobile robot will start to search for a helper.

As the complexity of assistance is higher during an elevator ride than a door pass, our mobile robot needs to adapt to a lot more of possible actions of the selected helper. For example it is crucial in some elevators that the robot enters first due to the limited space in the elevator. Therefore, we do not only observe if the door is held open but also continuously check the position of all tracked people around the robot and within the elevator. If anyone enters the elevator before the robot, it will immediately stop and ask the person to leave the elevator. An instruction repetition will be done when the elevator door closes again (e.g. because the helper did not hold it open the entire time).

As our robot can ride the elevator alone as soon as the helper chose the right floor, we are always observing the current floor by evaluating the acceleration sensors. If the helper leaves the elevator in a different floor than our target floor, we just wait for another person to enter the elevator (or check if there is someone else in the elevator) and then ask the new person to assist our mobile robot. If the elevator is moving and no person is present in the elevator, the robot knows it is riding alone and can already drive in front of the door. If the elevator is starting to brake for another floor (which is not our target floor), it leaves its position in front of the door to enable people to enter the elevator. Evaluating the acceleration sensors enables the mobile robot to react fast to changes in the environment.

6 User Tests with Technical Benchmarking

To assure that all our skills and behaviors are working as planned, we performed functional tests with 20 non-instructed persons in January 2019. The half of them had to assist our mobile robot during a door pass and the other half during an elevator ride. They were sent to a specific secretariat on a way passing our robot waiting at a closed door or in front of an elevator. After being contacted by the robot, the people assisted it based on the instructions given by our system. This functional test proved that our system is able to pass doors and ride elevators with the assistance of people. On the one hand, this was evaluated from a social sciences perspective, and on the other hand we performed a technical benchmark to determine the performance of our system.

For the evaluation, we chose a bunch of performance measures including:

- Mileage (How far did the robot drive autonomously?)
- Duration of assistance (How long did people assist our mobile robot?)
- Interaction count (With how many people did the robot interact?)
- Success rate (How many approached people are helping?)
- Termination rate (How many people aborted the assistance?)
- Fail rate (How often did our system fail to pass a door or ride an elevator?)
- Waiting time (How long did the robot wait until he could pass the barrier?)
- Instruction count (How many instructions were needed for a successful pass?)
- Ignorance count (Did people ignore the robot? How did they ignore it?)
- Non-intended helper behavior (Did people behave in a non-intended way?)
- Trajectories of selected helper (How often did the tracker lose the helper?)
- Human-Robot-Interaction (What are typical trajectories close to the robot?)

As some performance measures are not suitable for the fixed setup of the functional test (like waiting time or interaction count), we only evaluated a subset of them. The average assistance duration for an elevator ride was 92 seconds, for passing a door 27 seconds. During those functional tests, our mobile robot was not ready to ride the elevator alone. Therefore, the needed assistance duration is now lower, and we expect more people to be willing to assist if the duration is as low as possible.

As already described in section 5, our mobile robot is challenged with a very small interaction distance to the selected helper. During the functional test, the average distance between the helper and the robot was around 1m only. Despite this small distance and the need of disturbing the personal space of the helper, no person felt uncomfortable during the assistance.

In ongoing tests we are comparing how the robot is able to obtain help in the all scenarios. We already determined the need of different approach behaviors based on the target audience. In an office building of a technical university the potential helpers are trying to test the limitations of our system while in other scenarios the people might be more willing to just follow the instructions of the AAR.

7 Conclusion and Outlook

In this paper, we presented a new approach integrating uninstructed persons as helpers to open doors and to call and operate elevators. This allows our mobile robot to operate in entire buildings consisting of multiple floors and aisles with doors without the need of any technical change of the building. Using a fast door state classification and person tracker, we obtained a real-time application which is able to react to fast changes in the environment. This will be proven in long term tests in different scenarios of FRAME.

Besides detecting doors autonomously, our mobile robot will also start to actively search for people to assist in future. This will result in a huge decrease of the waiting time in less frequented areas of the building.

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