Housing Enabling: Detection of Imminent Risk Areas in Domestic Environments Using Mobile Service Robots

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Abstract Because of the greying society the need of user centred care concepts are raising. One big wish of older persons is to stay as long as possible in their own flat. Depending on the demographic change it won't be possible to realize complete care by formal or informal caregivers especially for people living alone. One possible way to cope this problem is to use ICT based solutions e.g. mobile service robots. The personal in-house mobility and its preservation it is one goal to enable staying as long as possible in her/his own flat. The concept of an automated housing enabling assessment which is presented here is an advanced solution for this problem. It is based on three main components: (1) Measurement and analysis of the cognitive and physical capabilities of the user, (2) Measurement and validation of the flat and (3) Computation of areas with a higher risk to fall and advice to remove such issues, e.g. restructuring of the furniture. The great benefit of a mobile robot platform is that all needed sensors are mounted on the robot and it can follow the user to make measurements at different places in the home. This will reduce the cost and installation effort in the flat to a minimum. Another benefit is the continuous assessment which helps to restructure the flat in a continuous way. This helps to reduce the probability of a fall event and raise the feeling of safety. All measurements could also be used by other assessment tools to preserve the indoor mobility not only by preventing a fall event but also by reacting on changes in the mobility level over time.

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1 Introduction

Industrial countries have to cope with different problems caused by the demographic change. Better medical care, health improvements and a healthier lifestyle increase the expected lifetime of the population. Another aspect is the decreasing birth-rate. This combination will lead to an aging society. The society has to cope with the problem that the number of recipients of care services is growing and the number of contributors is decreasing. An additional problem is the shrinking quantity of younger people which take the role as caretakers. This will lead to major economical and logistical challenges. One solution to handle these problems is to use assistive technologies [1]. Advanced Systems can support caretakers and assist elderly in an independent lifestyle and preserve their mobility up to a high age. These kinds of ICT solutions could also help to recognize and react on early signs of age-related diseases, which help to reduce the costs and manpower demands. There are different approaches to bring these technologies to the home of elderly people, one solution are the smart environments [2]. In this case all necessary components are integrated in the home to assist the elderly in the best possible way. Sensors and actuators will be used to provide different services to the user and to measure the current mobility/health level. A problem of smart environments is the high upgrade costs during the change from a "normal" flat into a smart environment. This reduces the user acceptance a lot. Service robots and the technological advancements in this sector are growing rapidly. A service robot has the advantage that it can support the elderly by the activities of the daily life continuously. This gives the caretakers the possibility to have more time e.g. for social interaction with the elderly. Another benefit is that all necessary sensors are mounted on the robot itself. So the sensors are not stationary and limited to one place. These aspects will reduce costs and installation demands and so it will help to increase the user acceptance and intend to play an important role helping to manage the demand of caretakers by assisting elderly in their daily life [3]. The fact that the mobile service robots are present the whole day enables long-term monitoring of residents. The major merit of technological monitoring is to enable early diagnosis and to identify and possibly prevent imminent dangerous situations [4]. Current applications are e.g. mobility assessments, activity detection and the autonomous exploration of the flat. By combining the approaches of these different services we think it is possible to deliver a new approach of a housing enabling service to increase the quality of life and the safety feeling of the inhabitants. The next chapter will give further medical motivation, followed by the state of the art in domestic robotics and assessments. Afterwards we will present our general approach to housing enabling assessments in domestic environments, give a short overview of already published work and outline a new concept on how housing enabling may be implemented on a mobile robot platform. Finally, we will conclude our paper.

2 Medical Motivation

The personal mobility is an important factor for the wellbeing of the user. Additionally, the ability to move around and to perform activities of daily life is a fundamental requirement for an independent lifestyle [5]. Impairments of mobility due to pathological reasons lead to more significant changes in parameters of gait than age-related changes [6]. One of the most frequent pathological reasons of mobility impairments are neurological diseases, especially dementia. Another important aspect is the raising risk of falls and need of assistance indicated by decreased self-selected gait velocity [7]. Fall-related costs are one of the major factors influencing the proportionally higher costs to the health care system caused by elderly people. From a clinical perspective long-term monitoring of changes in mobility has a high potential for early diagnosis of various diseases and for assessment of fall risk [4]. The relation between the average gait velocity and a local gait velocity in different areas of the flat is very helpful to find hot spots with a higher risk to fall. Additional other gait parameters like e.g. step size etc. are very helpful too. In combination with the housing enabling assessment it may help delaying need of care or imminent incidents like falls and thus may help saving costs. On a more personal level early detection of hot spots may help supporting an independent lifestyle by enabling early and purposeful prevention and may therefore increase quality of life for affected people [31], relatives, and carers. In today‘s health systems the potential of frequent housing enabling assessment is not exploited. Rather, housing enabling assessments are only applied infrequently or after an acute incident like a fall took place. This is mainly due to missing knowledge and technical capabilities.

3 State of the Art

3.1 Mobility Trend Analysis in Domestic Environments

Environments equipped with various sensors especially from the home automation or security domain, are referred to as (health) smart homes [8]. Only some systems which use ambient sensors for detailed mobility analysis have been described so far. The research focus is on general mobility trend analysis instead. Various groups use home automation technologies like motion sensors, light barriers or reed contacts placed in door frames or on the ceiling. Cameron et al. [9] presented a solution with optical and ultrasonic sensors. These were placed in door frames to determine the walking speed and direction of a person passing. Pavel et al. [10] developed a system based on PIR sensors covering different rooms of a flat. The knowledge of the distances between the different PIR sensors and the measurement of the transit times is used to compute the gait velocity. Placing three passive motion sensors in a sufficient long corridor makes those computations more reliable

[11]. Within our own work [12] we have recently presented a new approach based on the definition of motion patterns by usage of available sensor events. By providing an abstracted definition of the environment, physically feasible walking paths can be computed and monitored automatically. The use of more precise sensors i.e. laser ranges scanners have been applied to implement very precise gait analysis in domestic environments. One approach has been presented by Pallejà et al. [13]. The advantage of this approach is the very detailed analysis, but it has some restrictions. The person has to walk straightly towards the scanner and on a predefined path. In our own work using laser range scanners [14] we do not restrict a person's walking path while measuring. So far we need only the computation of self-selected gait velocity in the different areas. This approach is highly precise and does not require any predefined knowledge but is more expensive to implement compared to the approach using home automation technology.

3.2 Mobility Assessments Using Service Robotics

Service robots combine ideas of different fields of robotic research into one system to target at a specific application. Most available platforms are still in (advanced) research states. Fields of interest in the community are acting autonomously in home environments [15], learning of environmental factors and user behavior [16] and as well as robot designs itself [17]. Within our own work [18] we have recently presented a new approach to enhance mobile robot navigation in domestic environments by the use of mobility assessment data. An application of the potential field method for mobility trend analysis and the precise measurements of human movement trajectories by a laser range scanner have been implemented (see Figs. 1 and 2). The advantage of a mobile robot is that it acts as a kind of mobile infrastructure. It can bring the needed sensor technology to the optimal place for monitoring, as introduced in [19]. The robot will start with an observation phase. During this phase the robot stands at a safe place in the initial room of the home environment and observes the human behavior and environment.

Collected data is used to compute the safety criteria. After that phase the Robot will travel to the different optimal observation slots and measure the different gait parameter. The gait velocity in different areas of the flat could be very helpful for the housing enabling assessment.

3.3 Housing Enabling

The housing enabling assessments is quite popular in the Scandinavian countries. The aim of this assessment is the rating of flats and their surroundings referring to the personal health status of the inhabitants [20]. This rating gives advice if the flat with its furniture etc. is not suitable for the resident. The housing enabling assessment is

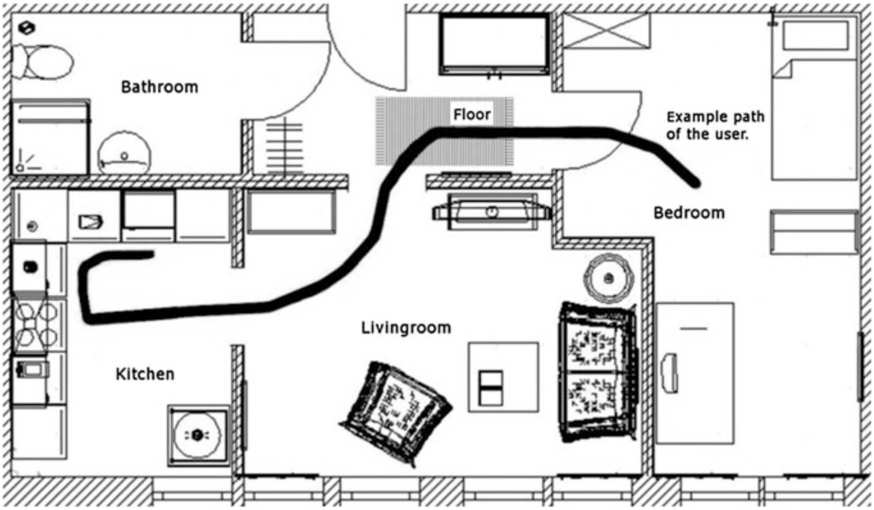

Fig. 1 An example path of the user from the bedroom to the kitchen which was recorded during a mobility assessment by the mobile robot

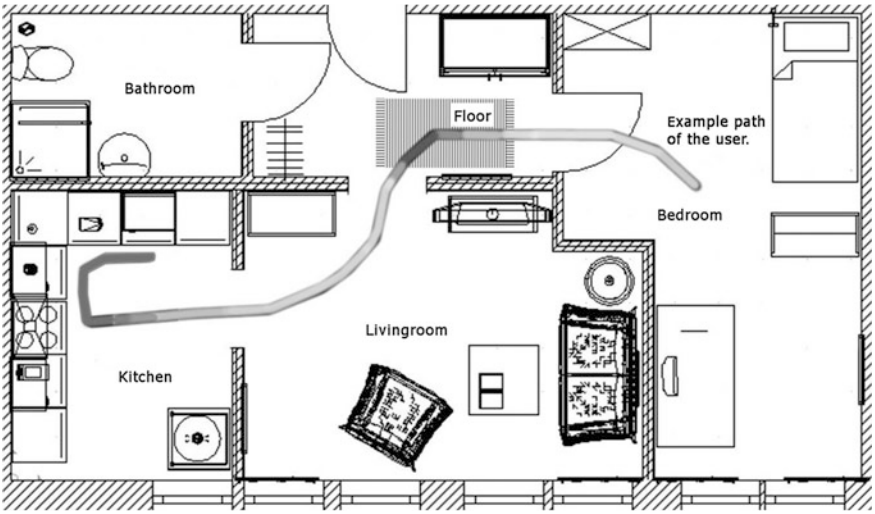

Fig. 2 The example path from Fig. 1 is highlighted with *grey* scale, *darker* slower gait velocity related to the average gait velocity, *brighter* near to the average gait velocity

split into three parts. The first part is the descriptive part to collect some general information about the flat and the condition of the user. The second part is the evaluation of functional limitations and dependence on mobility aids. Detailed information about medical condition of the user is collected e.g. severe loss of sight or limitation of stamina. The last part is based on different questionnaires which are related to the flat and the surroundings. Each question is weighted to the different diseases e.g. “Heavy doors without automatic opening” has high impact if the user has a problem with her/his upper extremity skills or has to cope with the loss of stamina. After completion of all questions it is possible to compute [21] the score of the flat in relation to the actual health status of the user [22]. It is also possible to adapt the flat related to the rating [23] in order to reduce the risk of falling.

3.4 Limitation of the State of the Art

As shown in Sect. 3.1 most of the systems use ambient sensors to observe the user not continuously. This means that only presence at specific known points is measured. The problem of this kind of monitoring is that it can only measure the mobility in an indirect way. The result could be only used for trend analysis instead of a precise assessment to determine the mobility of a person. For precise assessments of the mobility laboratory equipment is needed. But this is too large or complicated to install it in the domestic homes. Also the prices for such systems are too high to bring them to home environments as well. Within the domain of health care and rehabilitation service robotics there are quite few systems commercially available. Further, there is no robotic system that is capable of doing housing enabling assessments and tries to present advice to reduce the risk of falling. The current “offline” housing enabling tests suffer from some drawbacks. The estimation of the personal disorders and the investigated flat depends highly on the skill of the person executing the test. It is very difficult to rate the medical condition in its entirety for a person you see e.g. the first time. The adaption of the flat is a criterion which is also based on the experience of the supervisor. This could lead to different or insufficient results. Furthermore this assessment is mostly done after an accident has happened or to score new flats and not as a continuously assessment. In summary there is currently no system or approach available that is capable of doing precise and continuous housing enabling assessments in domestic environments and that is learning from the user’s behavior/mobility to get optimal assessment results.

4 Approach

Our new approach to provide an automated and long-term housing enabling assessment will be a combination of mobility assessments, activity detection and autonomous exploration of the flat. By combining the approaches of these different services we think it is possible to deliver a new approach of the housing enabling service to increase the quality of life and the safety feeling of the inhabitants. A mobile robot will thereby act as a kind of mobile infrastructure bringing the needed sensor technology to the optimal place for monitoring, as introduced in [24]. Main goal of our approach is that the robot can be delivered via postal package and placed into the environment without any installation. To perform services and assessments without compromising the safety of the owner, we will use our approach as introduced in [25].

4.1 Mobile Robot Platform

As mobile robot, the current Florence platform [26] is used. It depended on a light modified Turtlebot Kit [27] from Willow Garage. Additional to the 3D Microsoft Kinect Sensor, a laser range scanner is mounted on the Robot. Two different models are used, a Hokuyo URG-04LX or a Sensorio LZR-U901 laser range scanner. The second one has four measure planes with a tilt angle shift between planes of approximately 2°. We will use these four measure planes to optimize the leg detection and the precision of our gait analysis approach [14]. For controlling the robot platform a Lenovo X130e a netbook is used with an AMD E-300 1.3 GHz dual-core CPU and 2 GB RAM. Ubuntu 11.04LTS is used as operation system with ROS Electric as a middleware software for controlling the robot hardware. To get more information about the user activities a HomeMatic bundle is used to communicate with the home automation devices e.g. from the OFFIS IDEAAL Living Lab. This additional information will be used to detect the activities of the user.

4.2 Identification and Clustering of Obstacles

During the automated exploration, we will update our 3D map of the flat and try to identify and cluster all obstacles into three categories: moveable, unmoveable and unknown. Moveable objects are for example chairs, tables etc. On the other side, a board will be classified as unmoveable. All Objects that could not be classified automatically will be clustered as unknown in the first iteration. There are different approaches to classify these objects. We will test an interactive method where the user is asked and an automated version which tries to learn from the user if she or he moves that object over the time or not. This information about an object together with the detailed information from the map will be used to compute the prescore of current environmental barriers and some other possible configurations as a part of the housing enabling assessment (Fig. 3).

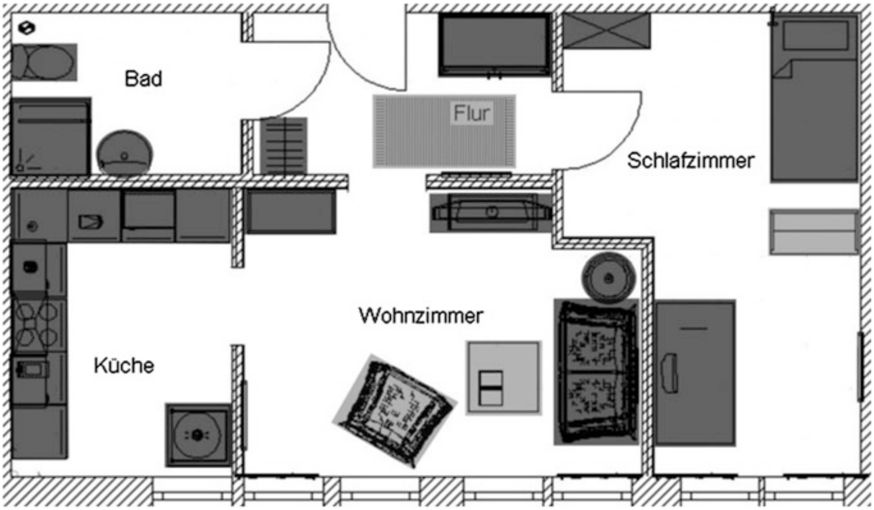

Fig. 3 The plan and the furniture of the flat after the obstacle identification. *Dark Grey* Static or unknown obstacles. *Light Grey* Moveable obstacles

4.3 Data Fusion of Different Assessments to Raise the Quality

To optimize and personalize the score we use the current health status of the user. We will combine these results with different results from the gait assessments e.g. the current gait velocity, step size and gait stability in the different areas of the flat. Related to the raising risk of falling if the resident is repeating to slowdown his or her self-selected gait velocity [7] potentially high-risk areas can be identified. Also the relation to different environment barriers [28] e.g. carpets or other soft surface and other gait parameters help to identify hotspots.

As can be seen in the Fig. 4, two areas with a potential high risk to fall (hotspots) have been found. To rise to quality of detection of these regions, we try to combine also information from the activities of daily life [29]. In our example path we have found a potential dangerous area in the kitchen. If the ADL indicates that at the same time the user starts to prepare a meal, we could discard this area. The reason for the slower gait velocity was the preparation of the meal. After that step we have only high risk areas which should be related to obstacles. If moveable obstacles are in these areas, the user will be informed that she/he should remove this obstacle to reduce the risk of fall events in this area.

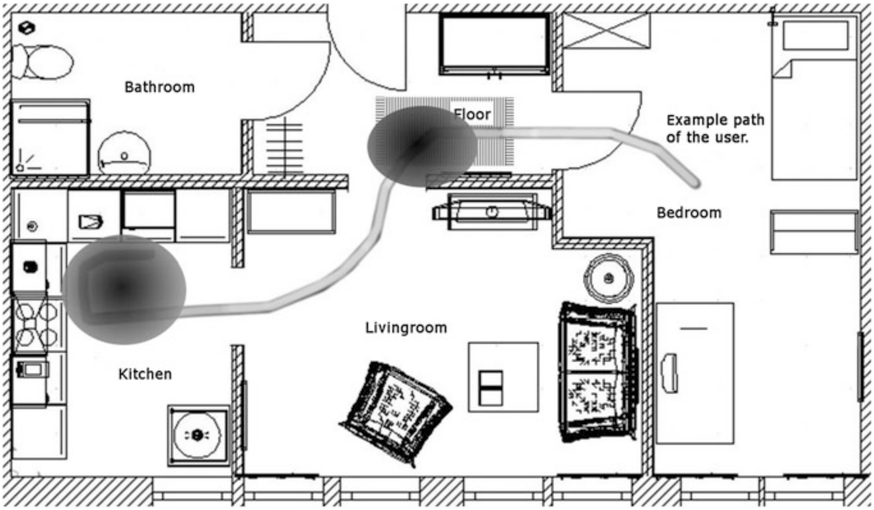

Fig. 4 The two red areas marked Hotspots, areas with a potential high risk of falling

5 Concept

As a first step towards realizing our new approach to housing enabling assessments in domestic environments utilizing a mobile robot we present a new concept for enhancing the prevention of fall events. Our main goal is to enable the robot to find hotspots and to find an optimal solution to remove these hotspots by adapting the flat. One quality criteria is the amount of removed hotspots, another quality criteria should be the necessary amount and kind of adaption. The concept combines our previous work [24], i.e. the precise measurements of human movement trajectories by a laser range scanner [25]. This concept enables the robot to learn from human behavior while assessing him or her at the same time. Currently the concept is based on the assumption that the robot is able to access a complete map of its environment. In the future, this map will be created while exploring the environment using 3D Simultaneous Localization and Mapping (3D SLAM) techniques. In short, the robot first measures the environment and localizes itself within the environmental map. Afterwards, the second step is to identify and cluster obstacles required for the following housing enabling assessment step. Then the human's gait velocity in general and at different areas in the flat is measured. Areas with slow gait velocity are analyzed and hotspots identified in the fourth step. Afterwards, the plausibility of hotspots is investigated by checking the obstacles in these areas and ADL at this time. Possible solutions to remove or reduce the hotspots are computed and advice is given to the user.

5.1 Environment Recognition

Within the first step the robot utilizes its laser range scanner and its 3D Scanner (Microsoft Kinect sensor) in order to measure the surface of its current surroundings. Ideally no moving objects are within the scan range during this step. Otherwise the robot has to distinguish between measurements belonging to static and moving objects utilizing one of various available approaches [30]. Measurements belonging to static objects are then transformed from the local coordinate system of the robot into the global coordinate system of the environmental map.

5.2 Obstacle Identification

The second step starts by identifying obstacles and barriers required by the next step of the housing enabling assessment. Identification e.g. carpets on the floor and clustering these obstacles in one of three categories (moveable, static and unknown). Also the general analysis of the flat, like measurement the width of doors or insufficient manoeuvring areas around white goods is part of this step and belongs to the indoor environment part of housing enabling. It based on a questionnaires with 100 different points to rate the suitability of the flat. We will try to implemented most of these questions in this part of our approach.

5.3 Movement Trajectory Measurement

As soon as a human enters the scan range of the robot its movement trajectory is measured. Again, the robot has to distinguish between trajectories belonging to the moving human and measured values of static objects. Measurements belonging to moving persons are transformed into the global coordinate system of the environmental map. These measurements are then used to compute the movement trajectory of the human. Additionally, the measurements are used to perform a mobility assessment of the human computing various spatio-temporal parameters of human gait. However, this enhanced assessment is not within the focus of this approach.

5.4 Identification of Hotspots

After we have detailed information about the environment and the gait velocity in general and especially in different areas of the flat we can compute hotspots. Hotspots are areas with a high difference between average gait velocity and local gait velocity. These areas refer to points with a high risk of imminent fall events [9].

5.5 Plausibility Check

To increase the precision and use of these hotspots, we make a plausibility check for each point. Therefore we map the hotspots to the 3D map and analyze if any obstacles are in the common area. Also the activity of daily life will be included, e.g. in Fig. 4 we have found two hotspots, one located in the floor and one in the kitchen. During the plausibility check further information will be added e.g. that the user typically prepares meals at this place. So the gait velocity was not reduced by an obstacle but by preparing a meal. So this Hotspot is no longer valid and could be removed from further computation.

5.6 Compute and Show the Best Adaption

Now we are able to calculate advice for the adaption of the flat to remove these hotspots. Therefore we will look at obstacles in the surrounding of the hotspots and if they are moveable or not. If they are moveable the service will compute different scenarios e.g. remove the obstacle at all or relocate the obstacle. For all scenarios the algorithm will calculate the new housing enabling score for the flat. Probably the best score is always the solution when the obstacle is removed completely. But in the most cases this solution has the lowest user acceptance, because most elderly don't want to change their flat too much. To reach a higher acceptance of the test, we define quality criteria which rate the amount of adaption and the kind of adaption. But the main goal is to raise the safety for the user in their own flat by reducing imminent fall event caused by environmental obstacles (Fig. 5).

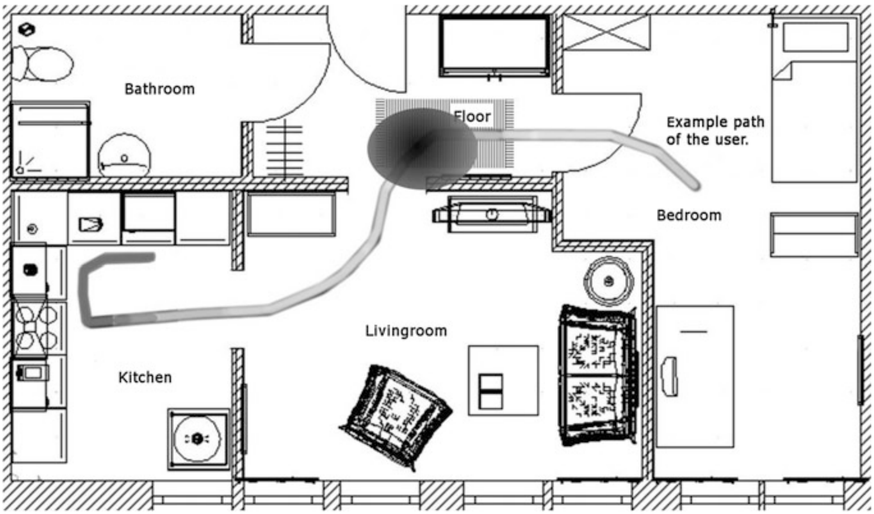

Fig. 5 Remaining hotspots after the plausibility check

6 Conclusion

A new concept for enhancing the housing enabling assessment by using a mobile robot and mobility assessments was presented. The concept is a first step towards realizing our approach to housing enabling assessment which utilizes a mobile robot as mobile software platform and its 3D scanner and laser range scanner as measurement devices. Our main aim is to enable the robot to find areas with a high risk of falls and giving solutions to remove or reduce these areas. Therefore we introduced the concept of hotspots which describe potential high risk areas near to the human‘s typical movement trajectories. The presented concept combines our previous work, i.e. the potential field method for determining movement patterns and the precise measurements of human movement trajectories by a laser range scanner. The overall flow of the concept has six steps:

– Measurement of the environment and self-localization within the environmental map,
– Identification and clustering of obstacles,
– Measurement of the human’s gait velocity in general and at different areas of the flat,
– Identification of hotspots and plausibility checking of hotspots,
– Computation of possible solutions to remove or reduce the hotspots,
– Presenting the best solutions to the user related to the quality criteria.

We already implemented first parts of the algorithm; the next step will be a complete implementation on a mobile robot platform (‘TurtleBot’by Willow Garage) and an evaluation of the system with test persons in real flats.

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