Challenges for Indoor and Outdoor Mobility Assistance

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Kurzfassung

Der Stand der Technik für AAL Mobilitäts-Assistenz sowie die Herausforderungen für künftige Entwicklungen werden beschrieben. Intelligente Navigations-Assistenten für verschiedene Mobilitäts-Plattformen, wie Rollatoren, Rollstühle oder Dreiräder, sollen einen nahtlosen Übergang von drinnen nach draußen anbieten. Ziel ist es, altersbedingt geschwundene Fähigkeiten zu kompensieren, mit *physischer Mobilitäts-Assistenz* für schwindende Gehfertigkeit, *Sicherheits-Assistenz* durch Hindernisvermeidung, *kognitiver Assistenz* für schwindende Sehfähigkeit und mentale Fähigkeiten durch Hilfe bei der Orientierung und Navigation, ferner *Sicherheits-Assistenz* in Notfall-Situationen.

Abstract

The state of the art of AAL mobility assistance and challenges for future development are described. Smart navigation assistants for various mobility platforms, such as walkers, wheelchairs or tricycles, shall provide seamless transition from indoors to outdoors. The aim is to compensate for age-related decline of capabilities by *physical mobility assistance* for declining walking capabilities, *safety assistance* by obstacle avoidance, *cognitive assistance* for declining visual and mental capabilities by orientation and navigational aids, and *security assistance* in emergency situations.

Figure 1 Smart wheelchair, smart walker prototype, and smart tricycle design

1 Introduction

The physical and cognitive conditions of seniors still living at home, possibly with daily care support or in dedicated residential homes, vary considerably, ranging over mild versions of impaired gait or unstable balance, visual impairments, or cognitive indispositions such as spatial disorientation. Our aim is to compensate for declining physical and cognitive capabilities by user-centred development of modular navigation assistants for various mobility platforms, such as walkers, wheelchairs or tricycles, providing sustained everyday mobility and autonomy with seamless transition from indoor to outdoor environments; the common paradigm is to *only assist when necessary* and to permit the user to act independently otherwise:

- *Physical mobility assistance* for declining walking capabilities, but encouraging physical exercise;
- *Safety assistance* by obstacle avoidance;
- *Cognitive assistance* for declining visual and mental capabilities by orientation and navigational aids;
- *Security assistance* in emergency situations by a call centre connection.

This paper will present the state of the art and concentrate on the challenges for future development. The authors, together with other partners from academia, industry and end-user organisations, will participate in the upcoming ASSAM project [1] in the AAL Joint Programme, once the present contract negotiation phase has been concluded, where we hope to be able to develop solutions for these challenges, and to lead them to marketable products.

2 Physical Mobility Assistance

DFKI (German Research Center for Artificial Intelligence) has more than 15 years of experience in building smart assistive systems for electric wheelchairs [2,3,4,5], cf. several prototypes of *Rolland* in Figures 1, 2, 4. Based on the experience with Rolland, Universitat Politécnica de Catalunya (UPC) and DFKI developed the *iWalker* demonstrator in the EU-project SHARE-it [6], similarly equipped with sensors and motorised rear wheels; further development by UPC added energy management and effort assistance subsystems. The walker will brake safely when going down and assist the pushing effort on slopes going up; handlebars sense the grip, an inertial measurement unit (IMU) senses the inclination and 3D acceleration. While the pushing force is controlled to remain always constant, a medical prescription may specify a slight force to push against for controlled training exercises; imbalances in the arm or leg forces can be compensated to adapt to the user's needs, configured by caregivers or medical personnel, for:

- momentary help: only provided when the required user's effort exceeds a given threshold;
- fractional help: a certain fraction of the power needed;
- constant help: guarantees the user an approximately constant effort;
- complete help: completely substitutes the user's effort;
- adaptive help: adapted to the physical condition according to a medical prescription.

In analogy to the walker, a smart *tricycle* shall be developed that provides at least support on inclined paths as well as navigation and security assistance, cf. Figures 1, 3.

Safety Assistance

For Rolland and iWalker, a number of assistants for indoor environments have already been developed [7]. The *Safety Assistant* brakes automatically to avoid collisions with obstacles based on a local map of the surroundings with safety regions computed for given speeds and steering angles (cf. [8], Figure 2, DFKI patent [9]). The *Driving Assistant* for Rolland proactively corrects the driving direction to avoid obstacles by controlling the steering and speed accordingly. Similarly, the *Driving Assistant* for iWalker controls the driving direction by slightly breaking the appropriate wheel; the user is guided around obstacles.

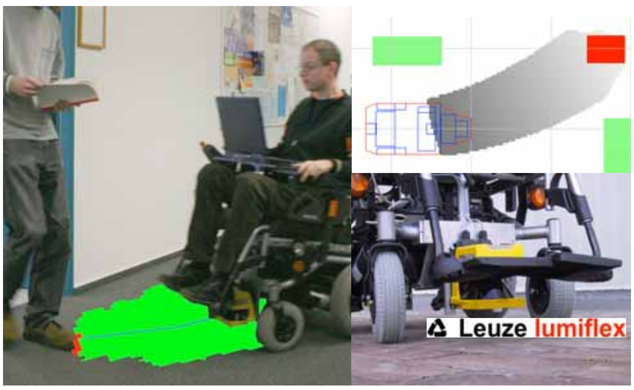

Figure 2 Safety region

Rolland, iWalker, and the future tricycle (cf. Figure 3) are equipped with wheel encoders on the back wheels for odometry, controller hardware, a netbook PC, tablet computer or cell phone for interaction with the user, and laser scanners. The cost of the laser scanners has so far been prohibitive for market introduction; the challenge is to use affordable novel sensors and to re-develop the software for outdoor deployment and 3D recognition of the environment to avoid obstacles at various heights, such as poles or crossbars, stairs or changing pavement heights (Figure 4). Figure 5 shows a sample configuration with 2 scanners; we will investigate, what configurations are admissible for indoor and outdoor usage to achieve adequate safety.

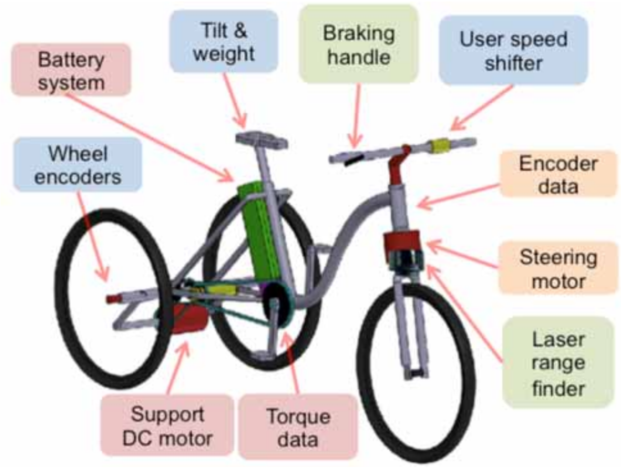

Figure 3 Tricycle subsystems

Figure 4 Problem zones

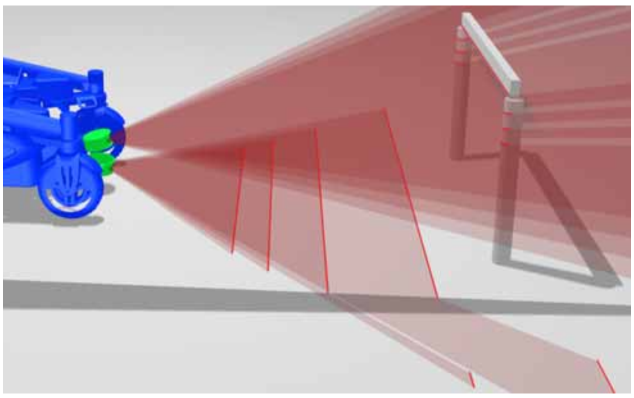

Figure 5 Scanner configuration for wheelchair platform

3 Navigation Assistance

The *Navigation Assistant* allows automated driving (without manual steering) to a specified target location in a charted indoor environment. Route graphs are constructed using SLAM; path planning uses a Hybrid State A* algorithm [10]. For outdoor navigation, additional sensors such as a differential GPS receiver (which cannot be used indoors) will have to be added, and the indoor software adapted accordingly.

Existing map support for navigation, e.g. the Open Street Map (OSM) standard [11] [12], allows the annotation of outdoor path properties such as the accessibility of a sloped curb for a wheelchair, ramps, obstructions, or the availability of toilets nearby. Everyone can freely use and contribute to geographical data in a collaborative way, as in WIKIPEDIA, based on a Creative Commons License. More than 100,000 volunteers, and some civic authorities, support OSM. However, annotations for specific requirements of walkers or users with declining vision, etc., are not available, and are totally lacking for indoor environments; compatible extensions to the standard are necessary responding to the challenge of *seamless transition from indoor to outdoor environments*. Under the assumption that the mobility assistant is always located on a navigable path or area (i.e. no cross-country driving), GPS sensor information shall be fused with odometry and Inertial Measurement Unit (IMU) data by a highly specialised augmented particle filter [13]. When obstacles and stairs or ramps are detected (to avoid toppling over), safety and self-localization for security will be considerably increased.

The completeness of available annotations for all platform and user requirements is essential; *safety levels* of accessibility and the constraints required for variants of the mobility assistants shall be defined. Relevant environments such as a user's home, enclosed residence complex, courtyards, nearby parks, the local city quarter or shops, even areas outside the local walking distance like shopping malls, pedestrian city centres, public recreation sites, railway stations, airports, or touristic regions, should be *certified* to be consistent and complete for a specific safety level such that public or hired transportation can safely deliver a senior to be on her/his own at the destination. This will help cities to attract tourists and enterprises to attract clients, and to advertise specialised facilities for senior citizens.

4 Assistance for Declining Vision

In contrast to young persons, elderly persons with declining vision are less likely to learn the usage of standard aids for the blind. For these, the walker platform, in particular, should provide excellent obstacle avoidance and guidance with the Driving and Navigation Assistants, in particular when equipped with a natural language interface (see Section 7). The challenge is to support seamless mobility support from indoor to selected outdoor environments; the precise limitations will have to be defined by careful field trials with end-users.

5 Security Assistance in Emergencies

Users of navigation services such as the Navigation Assistant will be safely guided back home; localisation and positioning allows orientation in unfamiliar surroundings, and gives the secure feeling of never getting lost. However, some users will additionally wish to be cared for by a real person upon request, in particular in unfamiliar environments, when having difficulties dealing with a map or automated computer support (e.g. due to stress or cognitive overload), or in case of slight dementia. In emergency situations, the user may raise an alarm and will automatically be connected to caregivers at the call centre of a care organisation such as Johanniter-Unfall-Hilfe (cf. an analogous service for cars [14]).

A caregiver will be able to interact with the user to assess the situation, access the personal medical profile, even inspect a person by an on-board camera when permitted to do so, and provide online navigation assistance. With the sensors of the mobility assistant, not only the position is known, but also the cardinal direction of the platform (and thus the user) in the environment. Thus a first question by the caregiver (looking at a map in an appropriate 2D or 3D representation) "do you see the landmark X in front of you?" will establish contact and provide assurance.

This way, secure orientation can be assured in daily life, but also on trips, even abroad, preserving the social environment and increasing mobility, with a seamless transition in the mobility chain from home via the local environment to mobile activities on vacation.

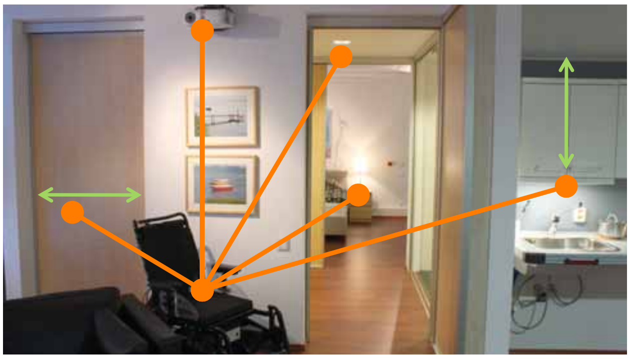

Figure 6 Seamless environment control in BAALL

Figure 7 Environment control at door, lift

6 Environment Control

In the future, the user should be able to remotely direct the smart walker from the bed, sofa or shower to a parking position out of the way, and call it to return on demand.
The vision of a *personal service* or *companion robot* becomes even more prominent, when interaction with an intelligent environment is added. This is demonstrated in BAALL, DFKI's *Bremen Ambient Assisted Living Lab* [15] (cf. Figure 6), a $60m^2$ apartment fully equipped for trial living of two seniors: sliding doors are opened, light is switched on, the kitchenette (or cupboard, microwave) is moved to an appropriate height; a higher service such as "reading in bed" adjusts the bed to a comfortable reading position, dims the lights, closes the doors, etc. Uttering an intention such as "I want to eat a pizza" triggers proactive actions in the environment, affecting doors, lights, kitchenette, fridge, and corresponding routes.
Services should be extended to building and outdoor environment control, such as remote door and lift controls, cf. Figure 7, or activation of traffic lights at street crossings.

7 User Interaction

The usual mode to operate the Rolland wheelchair with Safety and Driving Assistant is the hand-operated joystick; alternatively, a head-joystick can be used (an Inertial Measurement Unit with Bluetooth®, integrated into the drivers cap), a replacement that interprets head motions as driving requests, originally developed by DFKI for patients with severe physical impairments such as tetraplegia but also useful in the home when the hands are engaged, e.g. while cooking.
On iWalker, the hands should remain on the handlebars for safety; thus a target for an intended route is selected by moving iWalker itself, scrolling through an on-screen menu (RollScroll, DFKI patent [16]).
One generic mode is by pointing to symbols for services or visualised route graphs on the touch screen of a PDA (such as iPhone, iPad). However, visual faculties decline; the size and number of symbols and options may become hard to manage.
Every-day usability particularly regards the design of individualised user interfaces. In general, interaction of the user with the mobility assistants and the intelligent environment should be multi-modal, adapted to the individual user's needs. It shall use a standard such as URC, ISO/IEC 24752 Universal Remote Console, an open scalable platform for interoperability and personalised – thus accessible – user interfaces (cf. Figure 8, [15, 16]). URC interface controllers, target device descriptors, service software (controllers for higher services, synchronisation, etc.), environment profiles, etc., live on resource servers in the Cloud; as more and more become available, the mobility assistants will increasingly benefit.
One generic mode is by pointing to symbols for services or visualised route graphs on the touch screen of a PDA (such as iPhone, iPad). However, visual faculties decline; the number of options and symbols may become hard to manage. Thus an important alternative is spoken dialogue. Although the general case of *natural language interaction* (initiation of clarification dialogues, understanding of dialects, adaptation to individual language deficiencies, etc.) is a research issue, interaction in well-designed restricted dialogues is fairly well developed and can be deployed for goal-oriented navigation.

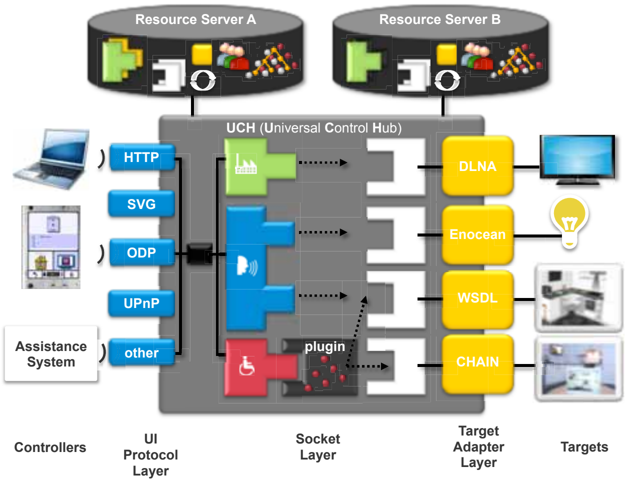

Figure 8 Universal Remote Console URC

8 End-User Perspective

As in any AAL project, addressing the user's needs shall be a primary concern in the upcoming ASSAM project [1] [17]. End-users will be involved from the beginning in the design of new features and evaluation of the mobility assistants; initial prototypes will be adapted according to the users' feedback.
Primary end-users are seniors still living at home with daily care support or in dedicated residential homes. Their physical and cognitive conditions vary considerably. Volunteers for the testing of walker variants will primarily be selected by sample characteristics involving mild versions of impaired gait or unstable balance, and cognitive indispositions such as visual impairments or spatial disorientation for the Driving and Navigation Assistants. Candidates for the testing of wheelchair variants are characterized by physical health conditions that prohibit them to walk for extended periods of time; for the tricycle, as for the walker, moderate physical exercise is encouraged. Mental impairments influencing situational awareness call for the testing of the Navigation Assistant. Moreover, longer term *every-day usability* assessment particularly regards the design of individualised user interfaces.
One of the main concerns when developing assistive devices is the need for respectful interaction with the end-user. The common paradigm for all mobility assistants to be developed, evaluated and launched to the market is to *only assist when necessary* and to permit the user to *act independently otherwise*. This approach is also pursued during field trials. Primary end-users will be carefully introduced to the assistants and accompanied by dedicated

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trained personnel; they will always have the option to abort single test sessions or even their whole participation. With regard to privacy concerns, informed consent will be acquired beforehand. Thus primary end-users can feel assured about anonymity of personal data and confidentiality of recorded data.

9 Conclusion

With the significant rise of the number elderly people, the market for mobility assistants increases as well; the market for navigation and security add-on components for non-electric wheelchairs or walkers, and for smart electric platforms, is new. So far, elderly people with declining visibility receive very little support in Germany.
The advanced components *Driving Assistant*, *Navigation Assistant*, and *Autonomous Helper* require powered wheels and at least one laser scanner. The cost of a *safety* laser scanner for *Rolland* has so far been prohibitive for market introduction. In the ASSAM project we will use affordable novel sensors; thus the development of an industry prototype for *Rolland* is within reach. Similarly, affordable laser sensors for the walker will support indoor navigation support as well as obstacle recognition.
An even larger market can be reached with a hardware and software add-on navigation component for existing *non-electric* wheelchairs, walkers, tricycles, etc., where the navigation precision profits from additional odometry sensors. Moreover, such extension components would also comprise emergency and security facilities (see Section 5), connecting with a call-centre, as an option.

10 Literature

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