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MOVEMENT –Modular Versatile Mobility Enhancement System

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Abstract—**Although powered wheelchairs provide a well established solution for severely impaired persons they do not cover all needs regarding mobility of people with impairment. In the course of the EC funded research project MOVEMENT a novel approach for a highly adaptable and modular mobility enhancement system is targeted to cover additional user needs. A system consisting of a robotic platform and several dockable application modules is developed that additionally provides assistance for the driving process itself to the user or even takes over the complete driving autonomously. The project also includes development of new solutions for navigation of mobile robot systems including a "low-cost" sensor system as well as adaptable HMI components. This paper describes the concept and the first prototyping results.**

I. Introduction

Personal mobility is an indispensable factor of human freedom, dignity and quality of life. The European funded project MOVEMENT (Modular Versatile Mobility Enhancement Technology) aims at the development of a modular versatile mobility enhancement system. The system core is formed by an intelligent mobile (robotic) platform which can attach to a user definable selection of application modules (e.g. chair, manipulator, information terminal) [1].

MOVEMENT addresses the needs of persons that do not need or want to use a wheelchair permanently, but do benefit from motorization of various mobility related activities. This may concern shared incidental use in demanding circumstances or a versatile solution for different mobility tasks. Another possible user group includes persons who normally are not able to control a wheelchair (e.g. in case of spasm or athetosis) and thus also profit from the system developed within the MOVEMENT project. Given the broad range of potential users the MOVEMENT setup provides several possibilities to command/drive the system in a manual, an assisted or an autonomous mode.

Fig. 1: Typical combinations of MOVEMENT platform with various application modules for moving people and objects (early concept sketches)

The envisioned product comprises the following features:

A. *Transport of objects and persons*

The basis of the system is formed by a robotic platform which can carry a maximum load of 150 kilograms. Dedicated application modules (e.g. table or chair) can be automatically docked to this platform by a specially designed docking mechanism developed in the course of the project. This approach increases system flexibility as one platform can handle several application modules by delivering them (autonomously) to the desired location. A "chair" application module linked to the platform, for example, forms a powered wheelchair-like system with extended functionality.

B. *Autonomous navigation*

Among the different driving modes realized in the course of the project, autonomous navigation of the robot platform is used for certain use scenarios, i.e. for initiating a docking procedure or for moving the platform to the loading station on demand. By referring to a pre-programmed map and using the range data obtained from several sensors, the platform autonomously moves to a designated location while avoiding obstacles.

C. *Self charging and monitoring*

After duty the platform autonomously returns to its charging station for charging the batteries. It switches automatically into stand-by mode and awaits the next

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command. Connected to the system control center via wireless network the platform also offers self diagnostics and monitoring of status.

II. User involvement

For a successful development of such a device it is essential to consider the future use and users. In the domain of Assistive Technology it is even more important to consider the future users because the functional gain provided by the device will need to restore or compensate a functional loss of the user to some extent. The needs of the user, originating from his or her perceived problems at a functional level, must be taken as starting point in the development of such a device. This will guide the development towards a sensible solution, likely to be embraced by the projected user-population.

User involvement is applied throughout all main phases of the development of the MOVEMENT system [16][17]. Initially, user panels were formed in three countries representing distinguished target groups. The specified user target groups can be identified with a description of the need regarding mobility support:

A) users not able to make effective use of traditional power wheelchairs;

B) users needing a variety of motorized mobility support and benefit from a modular system

C) users needing occasional mobility support depending on temporary conditions.

The installed user panels (including 42 users) reflected their views and perceived needs in relation to the intended system. On the basis of this, use scenarios were formulated in nine clusters (see Table 1) formed by the 3 types of mobility services (for persons, objects, information) and the 3 user target groups exemplifying potential use of the system and steering the further development of the system. After assessment, user requirements have been translated into a set of concrete and measurable specifications in order to guide technical development. In addition to end user requirements additional external influences, like economical and market considerations, time frame considerations or acceptance by professional care givers and insurance companies, have been considered for system design.

Table 1: use scenarios

Disability / Module	Severe	Moderate	Mild
Simple chair	1: “Smart wheelchair”: users who cannot use existing power wheelchairs	2: “Standard chair”, users who need a range of singular devices & opt for a modular system	3: covered by scenario class 6
Table/ container	4: “Electronic butler” Mobility of objects with manipulator	5: “Electronic tea table” Mobility of objects	6: “Trans-port cart” Supporting device on location
Multi-Functional Chair	7: Mobility for users who need multiple functionalities	8: Mobility for users who want multiple functionalities	
Walker/Lifter		11: Mobility of persons through lifting and or walking support.	
ICT applications	13: Mobile information, monitoring and/or control system		15: partly covered by scenario class 6

In a second series of user involvement, the same panels are being asked to evaluate prototype demonstrations in order to investigate usability and effectiveness of the developed prototypes. For this set of tests all relevant requirements according to GCP and other regulations/ standards (e.g. directive 93/42/EC, directive 2001/20/EC, directive 95/46/EC, ISO 14971, etc) are strictly adhered to.

III. The modular approach

A. Robotic Platform

The core of the MOVEMENT system is formed by the robotic mobile platform with its autonomous driving and docking. For the intended use the platform design is in conformity with the specifications defined in DIN EN 12184. Based on existing studies [8] a middle wheel concept is being used for the system – i.e. the drive wheels are in the middle while two spring loaded castor wheels are in the front and in the rear of the platform. The on-board control system is running the local navigation and is connected to the sensor systems located on the platform in order to provide with autonomous driving mode. For communication between the mobile platform and the global planner, the platform also contains a WLAN device.

For the envisaged concept of “Modular Mobility” the MOVEMENT platform is equipped with a dedicated mechanism for automatic (un)docking of application modules.

B. Application Modules

During the project the following application modules will be developed and evaluated:

- Chair for transporting persons (wheelchair functionality)
- Table for transporting goods
- Information, Control and Telecommunication terminal (ICT) including Environment Control

- Multi-Functional Chair adjustable from standing to sitting and lying positions
- Lifter/Walker module

Together with the platform these modules will be able to address most of the use scenarios conforming to the nine clusters of use.

C. Enhanced User Interface

An input-side User Interface has being developed consistent with power wheelchairs interfaces. It comprises mainly of a joystick - optionally head, mouth, sip/puff or chin operated controls and binary switches can be added. Output typically is provided via optical indicators or graphically on an LCD [2][3]. The interface system enables the user to perform the steering task with only little effort with varying degrees of assistance by the wheelchair system. When talking about a modular system with exchangeable modules it becomes even more important to address the individual abilities of single users. This cannot be achieved only by provision of the most suitable control devices (joysticks, special input devices etc.) but also needs careful activation of user specific individual adaptations to the user interface or the driving itself.

Input from the user, the overall system status, navigation information and additional sensor information is sent to a Shared Control Unit (SCU) [4][5][6] for further processing. This information provides the context in which the system is actually working.

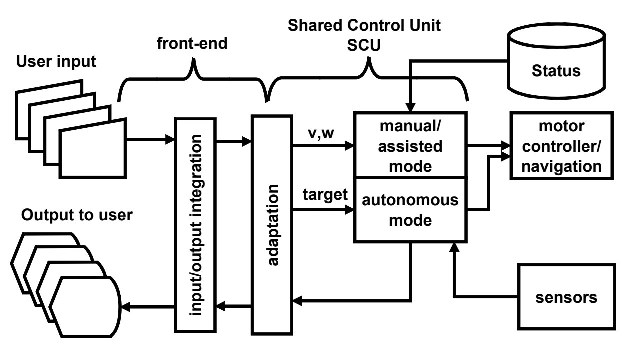

Fig. 2: User Interface and SCU and its interaction with the system

Due to different users abilities and the context of use (time, environment, state of system) MOVEMENT supports different assisted driving modes:

Manual mode:

Here only basic safety measures (e.g. collision detection) overlay the signals of the user who is manually controlling the system. This behavior is implemented by a safety layer and is active in all modes.

Assisted mode:

This mode interprets the input from the user in the following ways: it takes the input as indication for the user's intent and produces a smooth trajectory defined via the average speed and direction given by the user - also including the environmental situation acquired by the on-board sensor system.

Autonomous mode:

Here the user pre-selects a target location; the system autonomously plans a path and performs the driving. The user stays in control of the process because at any time he/she has the possibility to interrupt the process by overlaid input and the implemented safety mechanisms (dead-man switch functionality).

D. Sensor System

The core of the MOVEMENT system is the robotic platform with its (semi)autonomous driving and docking. The platform has the task of moving to any destination within the map while avoiding obstacles. It should either navigate the user in the chair or the platform itself to execute fetch-and-carry tasks. An appropriate sensor system for perception of the environment and for safe operation of the mobile system thus defines one of the main components for such a robotic setup.

A detailed analysis of existing sensor systems and of their applicability in the context of MOVEMENT built the fundaments for the development of a "low-cost" sensor system which provides with the grade of robustness, reliability and practicability (under realistic conditions) required for MOVEMENT. Criteria for sensor evaluation/selection have included performance parameters (e.g. field of view, range, resolution/accuracy), safety issues (safety to user or environment, redundancy, cross interference with other sensors, robustness to certain situations during use) as well as certain requirements from the intended use ("low-cost" aspect, mounting conditions, power consumption, ethical and design issues). The evaluation includes 7 sensing principles for "Near field Sensors" and 5 possible setups for "Wide Range Sensors".

Resulting from the above described evaluation process a combination of three different sensor types was finally chosen for MOVEMENT. Six reflex light switches on IR basis are placed around the platform and are used for short range measurements during certain scenarios (e.g. docking phase, passing a doorway, etc.). For the necessary wide range measurements 3D vision shows the highest potential for an acceptable compromise between user compatibility, technical features and economical constraints. Based on the experiences and results obtained from several test setups a combined sensor configuration - consisting of a binocular stereo vision system on one side of the platform and a 3D TOF sensor system on the other side – was finally selected for the MOVEMENT prototypes.

One major step in sensor development has been the evaluation of different stereo algorithms (with special focus on the particular requirements from the MOVEMENT use cases) based on available hard- and software environment (e.g. VidereDesign SVS stereo system as presented in [12], ARC Embedded Stereo Vision System, and others). As final development of the MOVEMENT stereo vision system is still an ongoing process no further results can be described at this stage.

As mentioned above a 3D TOF (time-of-flight) sensor system (SwissRanger II, CSEM) is being used as redundant sensor system as well. One of the advantages of this 3D TOF sensor is that depth data can be obtained directly. Figure 3 shows an example of an office scene (bottom left). The depth image acquired by the TOF camera (top) is used in different ways. First the floor and the main vertical surfaces are found. In this case a sample-based strategy [15] is being used, which again delivers dominating planes first. In this way the floor and particularly the larger sidewalls are rapidly detected and can be used as features for navigation. In a second step the data is treated in layers at increasing heights. Single or selections of layer(s) are projected to the ground floor and line segments are extracted. Finally, line segments can be used for navigation and localization while remaining data fills an occupancy grid (bottom right) used for obstacle avoidance.

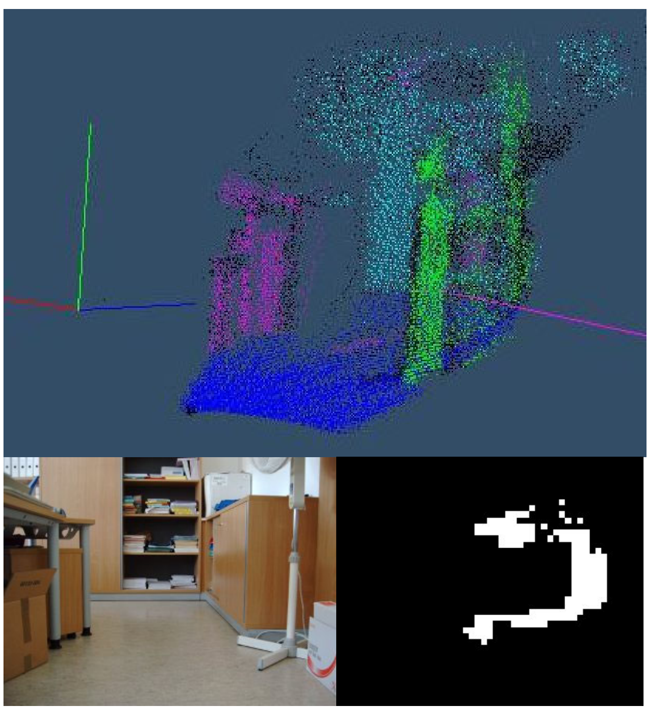

Fig. 3: Top: depth image from the CSEM camera corresponding to the image bottom left. The floor and the surfaces of desk and the cupboards have been detected and can be used for navigation. Smaller structures such as the box and the fan are treated as obstacles and marked in the occupancy grid (bottom right).

With stereo vision and the time-of-flight sensing, two sensing modalities are used that provide all the information needed to cope with cluttered office and home environments. The example given in Figure 3 shows, that the necessary information can be extracted in a sufficient manner. Future extensions are to better cope with smaller features which enable better modelling of the environment and to also navigate in areas where the open corridor for navigation is narrow.

Risk analysis also came up with the importance of a reliable and fast detection of (especially descending) steps. Results obtained with classical stereo vision and with the 3D TOF sensor system show the usefulness (and maybe even necessity) of an additional sensor for detection of this particular type of obstacles. A first prototype of such a sensor system – based on light-section principle – has been developed in order to complete the sensor setup of the MOVEMENT platform. The step-detection sensor in its current configuration is able to detect climbing and descending obstacles (like steps) in a 1.5m distance ahead with a “detection delay” of about 100ms. The minimum step-size detected by the sensor is 2cm (which is about 50% of the obstacle climbing ability of the platform). Further tests about the sensitivity of the sensor system against variation of lighting conditions are currently in progress.

E. Navigation

The Navigation Framework established in MOVEMENT mainly consists of two main parts. *Global Navigation* is based on ARC Robot Navigation System ARONA [18] and aims to maintain the status of dockable application modules as well as path planning based on a hybrid map system – i.e. a combination of a set of topological and metric maps. The metric maps are consisting of different layers, where symbolic terms for objects in the environment can be added, e.g. specifying a table or door and possibly adding affordances such as what can be done with these objects. Global path planning in ARONA is based on an adapted version of a “Visibility Graph” [19]. ARONA is running on the “Base Station” of MOVEMENT setup.

Local Navigation and Self-Localisation of the mobile platform is based on functionality of the existing Autonomous Navigation Technology ANT provided by MOVEMENT partner BlueBotics. For localisation, data from the wide range sensor system(s) together with map data (lines, segments) extracted by ARONA are used in order to periodically calculate a pose correction. For local navigation NF1 navigation function [20] combined with elastic band method [13] is used to transfer the path calculated by ARONA into an executable path also considering sensor readings. Both services – local navigation as well as self-localisation – are running on the on-board controller of the mobile platform due to the real-time character of the tasks and for safety reasons.

F. Communication Infrastructure

As the MOVEMENT system effectively forms a distributed system, communication between the system parts is of paramount importance. During development phase several possible communication architectures and technologies have been studied in detail. The finally chosen approach uses SOAP messages transported over 802.11b/g respectively 802.3 compatible layers.

The necessary infrastructure for communication between mobile modules is enabled by a WLAN network, which is managed by the “Base Station”. This particular module is a fixed located PC which provides the network and communication infrastructure for the MOVEMENT system. It also acts as gateway to the internet and therefore supports user communication like web browsing and VOIP telephone from the ICT.

Dynamic management of active modules is achieved by recognizing powered-on modules and accomplishing the necessary steps to integrate them into the MOVEMENT system. Every MOVEMENT module can request information about modules and system status from system control by means of a SOAP-interface.

The “Base Station” finally also forms the gateway to a home automation system and therefore provides the infrastructure to connect people to their environment. Users can control environmental devices like lamps, TV-sets or various other devices from the user interface. The environment controler on the “Base Station” converts and relays the instruction to surrounding sensors and actuators.

IV. First MOVEMENT Prototype

According to the evaluation concept of MOVEMENT there will be three different prototypes realized during the project. The first prototyping stage (PT1) includes the robot platform (including global/local navigation features) as well as three different versions of “chair” modules (one standard chair, two chairs with adapted seat - Fig. 4) and an environmental control terminal module (ICT terminal) as application modules.

Fig. 4: Off the shelf chairs adapted with MOVEMENT docking system in order to be moved by the robotic platform. In addition to the sensor systems used in MOVEMENT (binocular stereo vision and 3D TOF sensor) and for the first test phase an additional laser scanner (LMS200, SICK) is mounted to the mobile platform in order to serve as a reference system (left image).

All modules use the same mechanical construction for connecting to the robotic platform. Electrical connection of the application modules to the platform (e.g. for data transmission between module and platform) is done via a defined multi purpose connector, identical on each module.

For the first prototype the chair modules were equipped with a User Interface consisting of a standard wheelchair joystick (CAN bus based) as well as with an PC compatible processor running a dedicated User Interface (UI) software.

Since the UI and the ICT terminal in their core use the same software it is ensured, that the user will find preferred settings and functionality as well as a familiar look on both of the modules. Figure 5 shows in comparison both the screen of the ICT and the smaller UI on the chair.

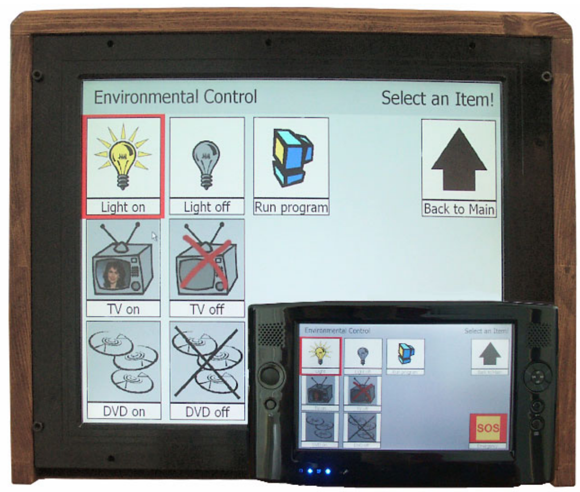

Fig. 5: User Interface presented on two different touch screens

A. *Evaluation Concept and Results*

Four types of evaluations will be performed in MOVEMENT:

- Technical evaluation
- Functional application evaluation
- Expert evaluation
- User evaluation

Main aspects for the first two evaluation phases can be described with

- technical analysis of existing functionalities against technical specifications,
- reliability analysis of existing functionalities,
- analysis of MOVEMENT modules according to standards (European standards).

The evaluations will be conducted at the different sites by the partners who have developed the prototypes

The final project phase is mainly dedicated to system evaluation by end users, with special attention to:

- the practical use of the movement use cases,
- the user system interactions in practical situations.

Modules for PT1 (description see above) are available since fall 2006 and are extensively used for testing of basic project outcomes, like user interface design, autonomous operation of the platform, automatic docking/undocking of application modules, and system communication. Beside of this "Technical/Functional evaluation" phase, the functionalities of prototype PT1 are also been used for a first feedback round together with the user panels.

Results from technical evaluation of PT1 components/ modules – like communication, navigation, platform, docking – are very promising. Results from user panel interviews allow concluding that both the MOVEMENT concept and the UI concept were accepted well by the target users. Inconspicuous look of the modules and particular features from autonomous mode – e.g. the possibility to automatically send away the platform if not used - were highly appreciated.

V. Conclusion

Mobility is a challenging key factor for personal independence and self determination and it is inseparably linked to our quality of life. The MOVEMENT project stands for the transfer from the existing state of the art to a user oriented, modular as well as market compatible system approach to enhance societal mobility. In this paper the concept and first prototyping results from MOVEMENT were presented. The prototypes of the robot platform and of the application modules "chair" and "ICT" as well as the underlying communication and navigation software already proved their suitability under laboratory settings. During the "User evaluation" round started in spring 2007 the feedback of the user panel will be collected and used as a feedback for further development.

The modular concept together with the autonomous features is expected to offer a new degree of assistance to potential users, touching areas where current mobility aids are presently not applicable. The prototypes developed so far will be further enhanced during the following project stages and, together with the currently developed Shared Control Unit (SCU) and the further improved sensor framework, result in a final set of prototypes that are able to demonstrate the intended use in a series of user trials.

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