Development of a general purpose robot arm for use by
disabled and elderly at home

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ABSTRACT
Robots to assist disabled persons is a challenging area
that include most aspects as demanding tasks, partly un-
structured environment and to some extent autonomous
behavior. The on-going MATS project focuses on a
robot system that meet requirements on performing do-
mestic tasks within environments as kitchen, bathroom
and living room. The system has mobility within a
home environment by moving along walls to different
fixed locations by using a docking system. The mobility
is further improved by a docking station that attach the
arm to a wheelchair allowing freedom to use the robot
in a more flexible way than most other robot systems.
Within the development process, the usefulness is in the
center and user scenarios produced using robot simula-
tion tools is used as a communication tool to functional
and technical specifications. Such simulations have
provided invaluable information in a conceptual phase
to set early specifications on dimensions and tasks to
perform.
This paper will present the on-going development of the
robot system that during the first phase has been based
on simulation studies together with prototype mock-ups
of sub-systems. Results from this work indicate a suc-
cessful continuation and final completion of the robot
system.

Keywords: robotics, disabled, service

1 INTRODUCTION
Robotics for use by the disabled is an application area
where robots, from a home based perspective, integrate
robots and humans both in a common workspace and
in the execution of the same work task. Examples of
such tasks include a direct interaction with humans as
well as control of different equipment through push but-
tons, such as, computers, copy machines, turn on/turn
off lights, functions in the kitchen, etc.
Therefore, the mechanical design of robots for rehabil-
itation must consider different specifications compared
to those used in industrial applications. Examples of
differences are: payload in the lower range, low total
weight of the robot and high payload/weight ratio, low
life duty cycle and low acceleration and velocity perfor-
manence. However, the system must have a high robust-
ness and be able to be operated by a disabled user which
means a semi-automatic operation using different types
of user interface devices for operation in unstructured
environment.
Nevertheless, most robots used in rehabilitation today
have similarities with industrial robots, such as the RT-
series robots and SCORBOT which originally were de-
veloped for educational purposes and have been used
within projects for disabled people [1, 2]. An example
of an adaptation of a robot for rehabilitation purposes
is Handy-1 which is used to assist in eating [3] and De-
Var which uses a PUMA robot for assisting disabled at
home or vocational workplaces [4]. The Handy-1 robot
is further developed through improvements in the con-
troller and attachments adapted to the user for specific
purposes (shaving, tooth brushing, make up) within the
RAIL project [5]. An example of a commercial robot
designed to be mounted on a wheelchair is the Manus
robot with a relatively advanced design which can be
considered to be one of the most successful robots for
disabled people of its kind [6].
An example of a mobile robot system with autonomous
functionality within the area of health care is the
MOVAID project [7] which is a modular robotic sys-
tem, including both the mobile unit and the robotic arm.
The issue of modularity and specific developments re-
lated to robotics for disabled people has also been in-
vestigated within the MOBINET project [8].
This paper will describe the development process and
ongoing results of a new robot arm for use by disabled
and elderly people at home. Based on experiences from
earlier robots in the field as described in this section a
new concept was developed that addressed the issues of
modularity and mobility [9]. In addition, a devel-
opment process should be followed that from a holistic
view integrate not only technical aspects but users in the
development phases.

2 THE MATS ROBOT CONCEPT
The MATS robot is designed to be modular and capa-
ble of operating in a structured as well as unstructured
environment. It will possess high levels of autonomy being capable of travelling on walls, ceilings or floors and moving accurately and reliably between rooms and between floors. It will have the ability to transfer itself accurately from being wheelchair mounted or attached to sockets enabling it to carry out a great number of activities.

This degree of flexibility will have significant implications to the general public and for the care of the disabled and elderly with special needs. For example, the modularity of the system would make it possible for the system to grow as the level of disability of the user worsens. Furthermore, the MATS socket network will be connected to the LAN and Internet of a smart home environment facilitating remote monitoring and control capabilities.

The MATS robot system will enable a significant advance in the field of service robotics and comprise the following modules:

- A built environment, i.e. an architectural structure fitted with robot arm docking stations, system control units, user control interfaces, tool stations, power distribution and communication systems.

- A flexible robot arm, able to move from one docking station to another under system control and able to perform assistive tasks and operate end-effectors and tools under system control and user interface control.

- An independent vehicle such as a wheelchair with movement controlled by the user. The vehicle is fitted with a robot-arm docking-station, user control interface and communication systems.

The MATS system will include sockets with mechanical, electrical and computer interface. Sockets can either be rail-mounted or individually mounted on the wall with equal spacing. The robot will be able to move to different working location by using the sockets.

Typical environments for the MATS robot are bathroom (washing, shaving), kitchen (food preparation, eating) and living room (reading, game playing). Figures 1 and 2 show simulated scenario examples of bathroom and kitchen activities. Extensive simulations have been performed to show the capability of the system. Different environments and tasks have been studied on a conceptual level to be able to integrate a user analysis in parallel with the design work. This activity started in the very beginning of the project within the conceptual study phase. This is also in line with a user oriented development methodology as described in [10].

The basic concept of the robot is that it is a symmetric arm which can operate from either end of the arm. Thus, it will be able to move around using docking stations or rails and also connect to an electrical wheelchair. The system will make use of hand held
computers and wireless communication for human machine communication. In this way, adaptation will be made possible at different levels based on the individual need. The same type of communication will also link control commands to the robot which include a local control system and field bus within the arm that minimizes electrical wires to power supply and data signal wires to the arm. The socket connection and rail principle is shown in figures 3 and 4 and a wheelchair adaptation is shown in figure 5. As the robot is symmetrical it can operated from any base of the arm. Thus, a gripper is included in both ends of the arm.

Results from simulations have been used to define the specifications for the detailed design of the robot system. During this process, the use of simulation tool was necessary as it provided a method to model, analyze and visualize concepts and ideas between different groups involved in the development process. This included not only technical people, but users that represent the future market.

### 3 THE DEVELOPMENT PROCESS

In the development of systems within the area of assisting technology, users are in general non-technical but experts in their role as professional users. Likewise, other professionals within health care involved in the development process are also experts within other areas than the technical product development domain. Thus, human resources in the development process represent not only a multidisciplinary group but also a heterogeneous group with respect to common domain language, background, etc. In a normal product development process within a company, similar issues may exist with respect to multidisciplinary, but in such as case, all team members are professional in performing team building for the purpose of the development process and usually also share a common language within the task they perform. In this case the situation is a bit different and a key issue is how to bridge the wishes of the users to a functionality specification and further on to a technical specification and vice versa. In addition, this process must be interactive and instant within a team during different phases such a initial brainstorming, conceptual design and so on to effectively be able to take on board all relevant issues from users but also to be able to justify the rejection of certain things due to constraints of a technical or economical nature. A common understanding of such issues is important and brings motivation and positive thinking into focus.

In our case, we have focused on bridging the gap by introducing simulation with graphical output as a common language in the development process. This together with adapted questionnaires and hands-on experiences put all involved on an equal level which we have found important in this development project.

### 4 MATS FUNCTIONAL AND TECHNICAL DEVELOPMENT

For the first prototype a five-axis arm is under development. User scenario simulations have shown that this is a minimum configuration and can be used as a compromise. As the symmetrical configuration indicates, a key issue is weight reduction together with a relatively short reach to minimize torque on the base axis. As both ends of the arm can be the base depending on how the robot operate the development at the moment focuses on solutions to minimize torque load by reduced weight and maximize torque in the drive system by careful selection of components.

The purpose of the end-effector is in this project twofold; (1) act as a gripper to be able to manipulate objects, (2) act as the robot base when the end-effector is used during docking to rail, socket or wheelchair. Some crucial and sometimes incompatible requirements on the end-effector are identified:

- Handle forces and torque on the docking mechanism.
- Handle deviations during docking
- Space for electrical connectors
- Locking and unlocking mechanism
- Flexibility of gripping different objects
- Secure gripping

The end-effector has two working states. When gripping, the fingers work in front of the end-effector and during docking the fingers are flipped back. In figure 6 the docking state is shown when the fingers are folded back. The MATS docking station is basically a female counterpart of the end-effector. A conical tip of the end-effector makes it easier to dock to the socket. In the end of the docking procedure, a turning movement of the end-effector locks the coupling with a bayonet. After a docking operation with tightening the bayonet, a solenoid is used to lock the coupling to avoid accidental release during arm movements.

![Figure 6: A cross section of both the end-effector and the wall socket during docking. The fingers are in this state folded back. The conical surface can be seen that assure docking when accuracy problems exist between end-effector and socket.](image)

Simulations have been used to validate the finger design. Different object shape and gripping techniques have been tested, see figure 7.

![Figure 7: Simulation of different gripping scenarios.](image)

5 DISCUSSION

The introduction of robot system to serve humans is indeed a challenging task. Discussions that took place within this project focused on the need for modularity and flexibility to decrease cost and increase usability. Moreover, developing complex systems as robots for disabled persons requires a development methodology that integrate users and the different development members in an efficient way. For this purpose, simulation technique has been used based on a robot simulator that can produce realistic graphical output of user scenarios as well as detailed studies of design concepts of subsystems like end-effectors and docking mechanism.

The idea to make a symmetrical robot solves many issues related to mobility within a home environment. However, it also adds certain technical problems that are not fully validated. The most critical one is the optimization of the arm to tackle the issue that both ends of the robot are the base depending on which end is attached to a docking socket. Thus, both ends must be equally strong which is different from traditional arm designs. The solution to this problem is to use selected light structures for the arm and transmissions. For this type of application, the life cycle time is quite different compared to an industrial robot. For use in a home environment we can accept lower accelerations and velocities. The number of operational duty cycle can also in general be expected to be much lower. Thus, given such operational data for the robot it is possible to dimension and optimize the sub-systems that meet the overall specifications, both from a functional as well as a technical point of view.
The on-going project work is now in a build prototype stage where subsystems are built and validated before integration. Several complete MATS systems will be built for evaluation by users and further development of both the system and different applications based on the system.

6 CONCLUSIONS

A general purpose robot for use in a home environment for disabled persons is under development. During the development, user scenarios have been produced to integrate users in the early conceptual phase. The concept of the robot is a symmetrical arm that is able to move along a wall using sockets to different location areas where any end of the arm can be used as the base. A critical part in this system is the end-effector, gripper and docking sockets. Extensive simulations have been made to validate different design concepts both on the detailed sub-system level and the whole system to ensure the intended functionality. The development work is on-going and will from September 2002 enter a prototype building phase for validation and user trials later on to meet requirements of the users.

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REFERENCES


