Design of rehabilitation robots using virtual work platforms

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ABSTRACT

The design, implementation and testing of rehabilitation robot like devices is expensive both in time and resources. The use of virtual workspaces based on graphics kinematic-simulation and computer aided design techniques gives qualitatively a design technology in which a full system can be virtually tested and evaluated in advance of actual prototyping. The modelling of the mechanisms plus work environments implies that a virtual test-rig can be built. It allows the preliminary verification of concepts and the generation of useful feedback to designers. The entire cell layout could be changed easily creating complex situations and scenarios.

This paper describes the use of virtual work platforms based on kinematic graphics-robotic simulation for the design of novel rehabilitation devices and other aids, as well as the evaluation and personalisation of existing ones. The objective is to present the techniques available for the design of rehabilitation robots using a software-based approach.

Keywords: kinematic-simulation, design, rehabilitation robots, evaluation

1. INTRODUCTION

The possibility offered by devices that offset the physical-functional limitations of disabled people improves their self-reliance and integration into society in an independent manner. Advances in Information Technology have helped people to overcome the physical limitations affecting their mobility or their ability to hear, see or speak. Much has changed since the first Braille alphabet in the XIXth century, today, it is possible to find equipment for the disabled ranging from robotic devices to virtual reality interfaces (J. Adams, 1994). However, high development costs due to the need of adapting or purposely designing assistive devices to the user needs imply that many of these are still very expensive. Furthermore, much design work and prototyping needs to be done in order to augment the level of functional restoration which would approximate to the capabilities of nondisabled individuals.

The use of rehabilitation robotic enables disabled users to interact with their environments, their physical limitations can thus be extended through the use of manipulator-like mechanisms which respond to their commands. A virtual world enables users to navigate and interact with 3-D, computer generated environments. The immersion capability which provides a synthetic environment could be exploited to design novel assistive devices that coupled to the capability of simulating some of the programmed tasks, constitutes a virtual work platform where novel devices could be designed and evaluated. This paper introduces the use of virtual work platforms that employ graphic kinematics simulation techniques for the design of assistive devices like rehabilitation robots.

The modelling of robots and their work environments means that a virtual test-rig can be built that allows the preliminary verification of concepts and the generation of useful feedback to the designers. In the next section the issues involved in the design of assistive devices are examined, outlining design considerations and objectives. The third section gives a summary presentation of the use of virtual work cells for the design of robotic systems. Finally a description of the manner in which this technique could be used for the design of assistive mechanisms is made. It includes a sample application, the examination of the cell layout of the Master II robotic platform and the simulation of some tasks.

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2. DESIGN ISSUES IN REHABILITATION TECHNOLOGY

In this section an overview is given of the design issues. First some design considerations are described and an outline of aims which the designs should pursue given. Finally, the design issues are described focusing on the design of robots like rehabilitation devices.

2.1 Considerations

Advances in new materials and Information Technology provide new possibilities for rehabilitation technology. Systems are being designed to tackle tasks which were impractical a few years ago. These are becoming more sophisticated and user expectations have increased. The design of rehabilitation devices is both complex and laden of contradictory constraints. While commercial pressures would demand systems to be produced massively, each disabled user has individual needs. Differences are not limited to the degrees of disability but also to their cognitive-communication abilities, perception and physical skills. Another challenge is that each product could provide the sole link (lifeblood) of the person with its environment, most users would depend on these devices everyday and for nearly most of the day.

A large number of assistive robotic devices have been developed since the 70s with the aim to provide disabled people with some autonomy. Nevertheless, the commercialisation of this equipment and acceptance by the user is not easy to attain. Often user needs are misunderstood, nor input from medical specialist heard, reasons why many projects are unfinished prototypes (A. Casals, R. Villa and D. Casals, 1993).

The design of rehabilitation equipment is first of all human-centred and relies on the understanding of the users needs as well as on the manner in which his/her disability would evolve in time. Thus a successful design could only be accomplished with continuous input from and interaction with potential users and specialist medical staff.

2.2 Aims

The overall design aims could be summarized as follows (after I. Craig, et al, 1994):

Flexible-Adaptable Systems, as the conditions of the user evolve physically and functionally, rehabilitation systems must allow the development of new functions and different man-machine interfaces without significant redesign of existing systems. To be economically attractive, the rehabilitation devices should be adaptable to widely ranging needs, skills, environments and tasks.

Maximize the Potential, the goal should be to design products which could be used by as many disable people as possible with minimum changes. The incremental cost of many functional redundancies considered at an early stage would be minimal by comparison to one-off development costs (J. Adams, 1994).

Open-Modular Approach, the use of existing components and standards and to allow other developers to contribute with their design. Modularity simplifies the addition of new-function and reduces the cost of constructing individual systems by eliminating unnecessary items.

2.3 Issues

Safety, one of the primary issues, the motion of the device and interaction with the user need to be assured, every possibility of system malfunction has to be explored. Users by their conditions could be very vulnerable, their capacity of reaction in case of malfunction is limited thus safety is a priority.

Effectiveness-Reliability, tailoring of equipment and their commissioning is costly, the proposed systems need to demonstrate their effectiveness against other solutions. Equipment which is to be used daily and that could be the lifeblood of the user requires to be very reliable. The level of confidence of the user must not be eroded.

Man-Machine Interface. CONTROL INTERFACE. The motion command of rehabilitation robot like aids is different from industrial robots, motions are simpler and slower, orders are imprecise and in general the user remains part of the control-loop. The tasks performed serve as interactive aids and for performing personal and vocational activities. In general, keyboards, joysticks, switches or the voice are the most common control interfaces used. Small motions on these devices would enable the user to control motions or actions on the environment.

There are two main constraints physical and cognitive. The physical ones are linked to the upper and lower limbs. These could be due to difficulties found in approaching the interfaces, force control, tremor, amplitude of movement, gestural control, fatigue, etc. Cognition constraints are more problematic and could inhibit any use of these devices (J. Ibañez-Guzmán, and G. Jehenne, 1996). Thus the command of an assistive device presents more difficulties that those encountered in classical tele-operation. Users can generate only very few actions capable of producing a command towards the input device, a universal solution would thus be impossible.

Feedback To The User. The system must provide a clear indication to the users of what it is doing; the user must be able to perceive how the system acts. The usefulness of an aid is highly linked to its adaptation to the characteristics of the users, not least their sensory means. How successful is the information input to the user depends largely on how well it fits to the properties of the human sense involved (G. Jasson, 1994).

Visibility and the sense of action are very important when using rehabilitation devices, they provide the information by which the user knows what is going on with the system.

Personalisation

All individuals are different, in the case of individuals with disabilities, their physical abilities, perceptual skills and cognition are also different. Therefore, although rehabilitation devices could be designed for groups of individuals, these need to be tailored to the needs of users. For example a wheelchair has to be adapted first to accommodate the user in comfort, then to allow him an ample field of view and easy access to the control interface, next this would be adapted to his physical capabilities. Consequently, rehabilitation equipment should be highly adaptable to user needs.

Training

The use of certain devices require particular skills and hence training. The level of confidence of the user would depend on them. The question is how to coordinate training with the development aspects, knowing that the interface control equipment is to be adapted to user needs concurrently. The manner in which this is approached would influence the success of acceptance of the device.

Environmental Factors

The manner in which the rehabilitation mechanism would be integrated into living/work environment needs to be considered. Questions such as the layout of living spaces, logistic concerns, maintenance and the interaction between the rehabilitation systems and surrounding environment need to be addressed.

In summary, the design-implementation of rehabilitation equipment is multi-disciplinary and very iterative, requiring a high degree of testing/evaluation. That is testing the correctness of the design (safety), reporting the effectiveness of training and support time and costs. The possibilities brought by the use of virtual reality techniques together with simulations tools could be beneficial and permit addressing several of the issues cited previously.

3. DESIGN AND VIRTUAL SIMULATION OF ROBOTIC SYSTEMS

In addition to CAD tools, which allow mechanical components to be drawn on computers screens and then edited and processed, there are simulation tools for refining and competing the design of complex mechanical systems such as robots. Software packages are available for studying assemblies of mechanical components in motion, each component and articulation being described mathematically, with the computer calculating the system response at each operating point.

While the use of available 3-D software enables designers to conceptualize new robots and perceive their operation, the utilization of graphics-based kinematics simulation tools would allow designers to evaluate the operation of the mechanisms and optimize alternative configurations quickly and easily (C. Klein, and A. Maciejwski, 1988). The graphics and immersion aspects of the simulation could be used to represent not only the devices but also their environments. It eliminates the need for using physical models to study the proposed robots and to refine their designs. Data obtained from the simulation test runs, plus estimates of weights and moments of inertia of the robot components enable the dynamics to be taken into account. Therefore designers could calculate the forces/torques required at the robot joints and those acting upon attachment points. The control engineer can design the servos and develop control strategies. Consequently, most of the design and modifications needed can be made prior to starting any potentially expensive development.

The availability of graphics-based kinematic simulation packages together with immersion facilities enables designers to perform feasibility studies on novel robotic systems. Hence, it is possible to anticipate which part of the system could collide, to consider safety issues, to determine motion strategies, calculate tolerances and define cell layouts. Kinematics modelling implies a complete representation of the objects in the work cell including a description of how they change over time. Therefore, a kinematic description of the robot and peripheral equipment, together with their 3-D geometric representations, need to be included in the model. Samples of commercially available 3-D graphic kinematic simulators are ROBCAD from Tecnomatix Technologies, CIMstation from Silma Inc.

The development of kinematic models for use in the simulators implies that the geometric and kinematic details of the entire system must be translated into the simulator language. By building separate models for the robots, peripherals and the work environment and then positioning them so as to emulate the layout of the cell, it is possible to have a virtual test-rig. Next the motions of all the devices need to be specified. A series of tests can be made on these virtual test rigs to assess

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the performance and operational feasibility of robotics devices. Results from the test-runs can be used to refine the robot's specification. The tests enable the limiting load sizes, permitted tolerances, expected cycle times to be determined.

This approach is used to design, evaluate, optimize the configuration, determine motion strategies and study the operability of novel robots prior to any manufacture. In addition, this technique is used for tele-manipulation operations and to assist with the training of their operators.

4. VIRTUAL WORKSPACES FOR THE DESIGN OF ASSISTIVE DEVICES

Professionals working towards the enhancement of the performance and safety of humans in the execution of tasks (human performance engineering) have encountered software which allows them to create human models and to study their behaviour. Software programmes like ADAMS/Android, Mannequin or JACK allow the virtual representation of humanoid figures (based on anthropometric measurements) and to represent their environments, to create virtual workspaces to study humans. Tests are performed to determine: reach, balance, collision detection, fields of view, etc (P. Vasta and G. Kondrsake, 1995).

By contrast the approach presented focuses on the rehabilitation devices having humans as the centre of view. However, several of the performance parameters measured to assist with the design are based on a combination of those used in performance engineering and those of robotic design. Virtual workspaces could be used primarily for design purposes but also to assist with the commissioning and for the evaluation of existing ones.

4.1 Design

As with the design of robots or special machines, their configuration (morphology) is first defined and simulated. For this purpose, different kinematic and-geometric configurations are described in the simulator language. When there is interaction between the device and the user, a geometrical description of the user would be needed. The *effectiveness* of the device could be examined through the simulation of the tasks which it is supposed to perform. This phase is highly iterative and thus changes to the graphical representation and kinematics would be cheaper than prototyping. *Safety* concerns when the device is in motion and the assurance of a minimum space between the device and user can be examined using the software collision detection capabilities.

Once the basic configuration is defined other features of the work environment can be added. Using these virtual test-rigs, it is then possible to define the layout of the work environment, tolerances and motion strategies. Next several device tasks can be programmed and then simulated. This virtual workspace also allows us to concentrate on the user point of view, the *Man-Machine Interaction*. One issue which cannot address conventional design methods fully is visualisation. We must make the user see what he will "see" when operating the device. His motion capabilities and posture would restrict his field of view. Another important issue is the manner in which the control interface would be implemented. Questions such as: Does the new device need a special control interface or could it be controlled using a conventional joystick require an answer. This issue can be addressed by substituting the standard computer interface (mouse) by one used by potential users and generating the view that they would have.

Most tasks could be preprogrammed and then triggered by the users. Changes of motion strategies or the layout of the cell are easier and cheaper in this virtual world. The user can participate in the design.

The plate presented in Figure 1 shows one of the proposed modified cells for the Master II robotic platform for office work and daily living activities (R. Cammoun, J-M. , F. Lauture, B. Lesigne, 1994). The cell is based on the original configuration of the Master II platform and expected automatic tasks. The robot simulation software ROBCAD was used and most of the office work and daily living activities were programmed and simulated. Emphasis was made on the optimisation of the cell space and the visualisation of tasks (O. Flegeau, 1995).

4.2 Integration

In rehabilitation most equipment has to be *tailored*. For example, if one would like to use the MANUS tele-manipulator, a 6 degrees of freedom manipulator designed for daily living activities and that can be attached to a wheelchair (J.-C. Cunin, 1994), it is necessary to define the attachment point and joint limits taking into account the geometry of the wheelchair and the user anatomy. By modelling the manipulator, wheelchair, the body of the user and the defining points towards which the robot end-effector should move, it is possible to use robotic simulation software to determine the optimal location of the arm and define motion strategies.

User *training* and adapting the *control interface* can also be made. Complex situations and scenarios which are difficult or dangerous in the real world could be generated in safety. That is a virtual reality approach serves as a sort of scene authoring to build virtual environments which resemble real situations.

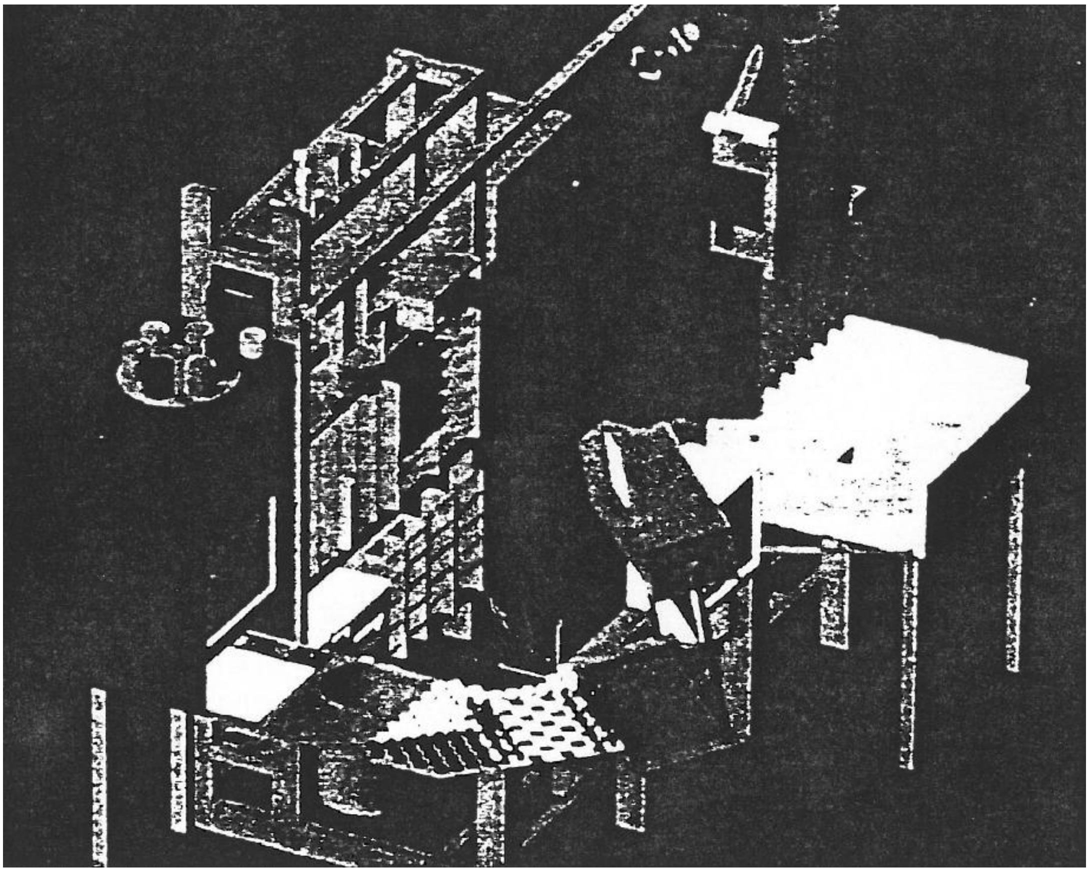

Figure 1. *Proposed cell for the modified Master II platform*

4.3 Evaluation

For a rehabilitation centre testing the correctness of the design, measuring its effectiveness in use, reporting of the effectiveness of training and support time, etc are very important prior to any commitment of usage. The utilization of virtual workspaces offer almost limitless potential for collecting performance data and allowing to perform human-centred test and hence exploring different alternatives in safety.

It should be remarked that the technique described is no substitute for actual prototyping and field trials, however, it reduces the number of interaction and gives the opportunity to examine more alternatives at lower costs.

5. CONCLUSIONS

An approach based on the use of virtual workspaces towards the design of robot-like rehabilitation devices has been described in this paper. Virtual Reality techniques allow users to navigate and interact with 3-D, computer generated environments, these together with graphic kinematic simulators that allows the modelling and simulation of any kinematic chain are exploitable tools for the design of rehabilitation devices. Virtual prototyping of future rehabilitation aids allow us to perform human-centred tests and evaluation of concepts without expensive prototypes. Entire systems can be modelled and exercised on a computer. It is qualitatively a new design technology in which a full system can be virtually tested, operated by the potential users and evaluated. The manner in which safety, effectiveness of design, man-machine interface and personalisation issues linked to the design of rehabilitation robots like systems using a virtual approach has been presented.

The approach can be used also for the evaluation of existing robot like rehabilitation devices. The virtual platforms offer almost a limitless potential for collecting performance data. These platforms can be also used for both selecting the most appropriate device and/or defining the modifications necessary to adapt an existing one to a particular user.

This technique, if compared with actual prototyping does not act as a substitute to the insight which an actual prototype would give. It should be considered as a tool which shortens the number of design changes on the final prototypes and assists with optimisation procedures. It is envisaged that once the connection is established between kinematic graphics simulators and human performance engineering software tools (kinematic models of devices and humanoid models), the possibility of designing rehabilitation devices solely in a virtual manner will be nearer.

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