MIT - MANUS : A Workstation for Manual Therapy and Training I

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Abstract - **This paper presents some recent work on the development of a workstation for teaching and therapy in manual and manipulative skills. The experimental workstation, MANUS, as well as the overall concept are described. State-of-the-art aspects of the workstation under development are introduced.**

1 Introduction

MANUS, which means hand in latin, stands for MIT motto *"Mens et Manus"* (mind and hand). MANUS is also the centerpiece of a multi-disciplinary effort that combines robotics and automation technology with physical medicine to develop a novel workstation for teaching and therapy in manual and manipulative skills. Physical contact and manual manipulation play a critical role in physical and occupational therapy, providing a multi-sensory experience, complementing vision and sound with extensive tactile, proprioceptive and kinesthetic information. Direct "hand-over-hand" instruction is a proven, effective technique. MANUS is intended to be a robot capable of safely "shaping" motor skills – a machine implementation of "hand-over-hand" instruction.

2 Typical Session

In a typical session, the occupational therapist will move the hand of the patient/student executing simple tasks such as inserting pegs in holes, drawing, and writing; or the physical therapist will move the hand of the patient/student executing simple exercises such as stretching the arm and rotating the wrist. MANUS will record desired actions and replay them while guiding the patient/student with varying degrees of firmness. Variable "firmness" will be implemented by varying the mechanical impedance of the robot. To promote learning, as motor skill is acquired, firmness may be progressively reduced, thereby reducing the degree of guidance and assistance provided to the student/patient and reducing dependence on the teaching aid.

The population served by this apparatus is composed of handicapped children or adults. In order to make the apparatus user-friendly, the workstation will offer a video-game approach, transforming the session into a fun activity that can recapitulate earlier sessions without the therapist present. The workstation will also permit the application of existing packages for computer aided education. In a future version, the same workstation is envisioned as being expanded to permit a remote session, in which the therapist interacts with a master workstation at the rehabilitation hospital and the patient/student interacts with a slave workstation at his/her home, as illustrated in FIG.1.

3 Hardware

MANUS presently has five degrees of freedom. A direct-drive five bar-linkage SCARA mechanism provides two translational degrees of freedom for the elbow and forearm motion. A differential mechanism mounted on a parallelogram linkage driven by geared actuators provides three degrees of freedom of wrist motion: extension-flexion, abduction-adduction, pronation-supination. This configuration was chosen after exhaustive search for a design which satisfies stringent constrains of low level friction, inertia at the robot end-effector, and an upper bound in the overall robot weight. The design aimed at a predetermined range for forces, stiffnesses, and impedances at the end-effector. Also, other requirements were imposed, such as backdrivability, size of the workspace, visibility for the patient/student and accessibility for the therapist. The result is shown in FIG.2 and the final prototype is shown in the FIG.3 & 4 without the end-effector high-torque DC motors. The manipulator is intended to be attached to an adjustable height desk, but it also permits a minor passive vertical motion of the end-effector through a set of springs.

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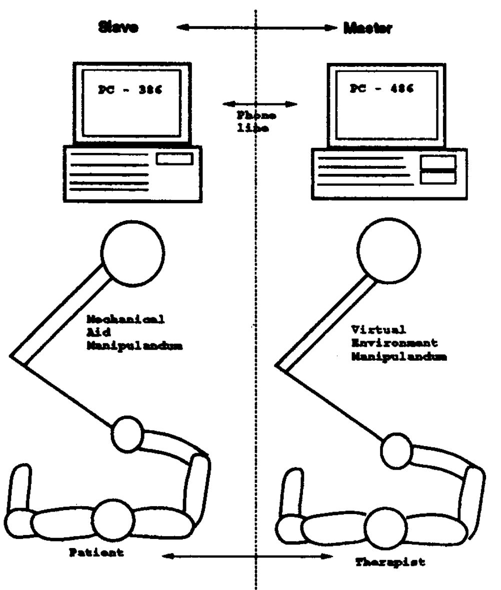

FIG.1. Teleoperation Scheme and Test Bench

Safety is a must in this project, and the patient hand is attached to the device through a magnetic safety lock, which permits him/her to pull free from the manipulator without external assistance.

In order to maximize the range of possible research that this prototype opens, only high resolution and high accuracy sensors were installed [4]. The position and velocity of the two translational degrees of freedom are measured by two 16 bit high-resolution resolvers. Previous experience had shown the importance of an accurate velocity measurement for our controller architecture - impedance control. Redundant velocity measurements are provided by DC-tachometers with a range of 14 mV output at 0.008 rad/sec. Torque sensors were assembled on the brushless motor shafts with rated output of 3200 oz-in. As per the wrist sensors, the position is provided by high-precision potentiometers and the velocity measurement by the miniature high-torque DC motor's tachometers with a 0.07 volts/rad/sec sensitivity. The workstation control center is a PC with a 486-CPU and standard 16-bits A/D and D/A cards, as well as a 32-bits DIO board.

4 Task-Encoding & Controller

For the purpose of modularity and organization a controlled dynamic system is going to be described as a sequence of layers, each one interacting with immediate adjacent one. The highest layer corresponds to the designated high level control, followed by a layer designated as task encoding, and finally the lower layer designated as low level control, which interacts with the hardware.

A layer in the same level of the hardware corresponds to the work object, and both the hardware layer and the work object layer are deposited on the external environment layer, as shown in FIG.5. The dashed line indicates flow of information in the direction shown, while a continuous line indicates an energetic interaction. There is also exchange of pieces of information between the hardware, work object and external environment layers with the control layers.

The high level control is essentially a set of symbolic objectives, directives and rules that are used to build the task planning. They are specified by the operator, either by direct coordination, or by establishing the set of directives and rules used to plan and construct the coordination. This level can be separated in two broad categories:

- autonomous planning mode
- teach mode

In this study, the high level control is assumed to be in the teach mode category, ie. operator directed.

The second layer is the task encoding, which can be defined as a translator or compiler between the high level controller and the low level one. The inherited objective of MANUS, a machine implementation of the "hand-over-hand" instruction, requires the robot to mimic human manipulation. An unique novel task-encoding scheme is being developed. In a nutshell, this task-encoding scheme incorporates the concepts of virtual trajectory and minimum jerk into the concept of a stroke (unit action). It consists basically of an episodic burst of information containing the parameters for human-like motion primitives.

The third layer is the low level control, which can be defined as the effective real-time controller. A fundamental engineering challenge in developing the MANUS robot is the preservation of stability and performance while in physical contact with active, unmodelled objects such as the human arm [1].As our earlier work has shown that a passive driving-point impedance guarantees stability in contact with passive objects, MANUS will be equipped with an impedance controller [2, 3]. The basic idea underlining the concept of impedance control is that controlling the variables of an interaction port, such as position, velocity or force, is not sufficient. It is necessary also to control the dynamic relation between the interaction variables, such as impedance and admittance. Currently this technique is being extended to encompass a broader class of interaction: the interaction between classes of active environments.

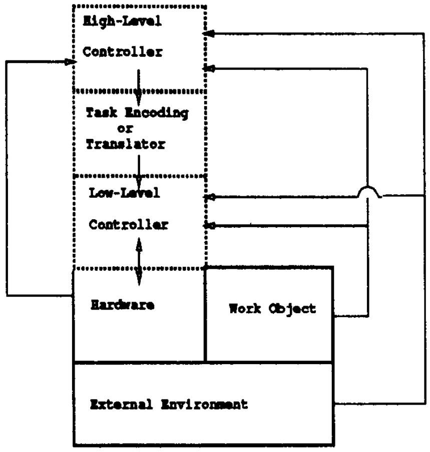

FIG.5. System Interaction Map

5 Conclusion

MANUS will expand the horizons of physical and occupational therapy in a number of ways. Longer and more challenging sessions will be possible, including the possibility of recapitulation of earlier sessions without the therapist. MANUS provides the impetus and the vehicle for rigorous quantification of aspects of physical and perhaps cognitive disability which have hitherto been elusive. However, as the history of technology shows, the user knows best his/her needs and the ultimate impact of this system remains to be seen.

References

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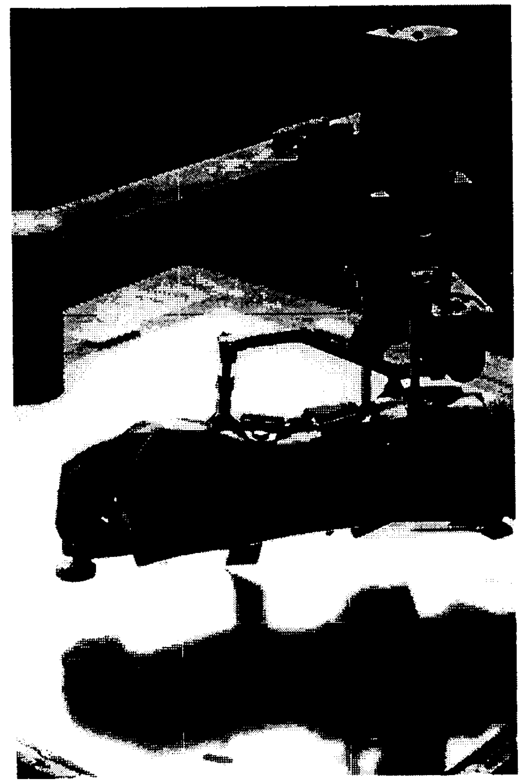
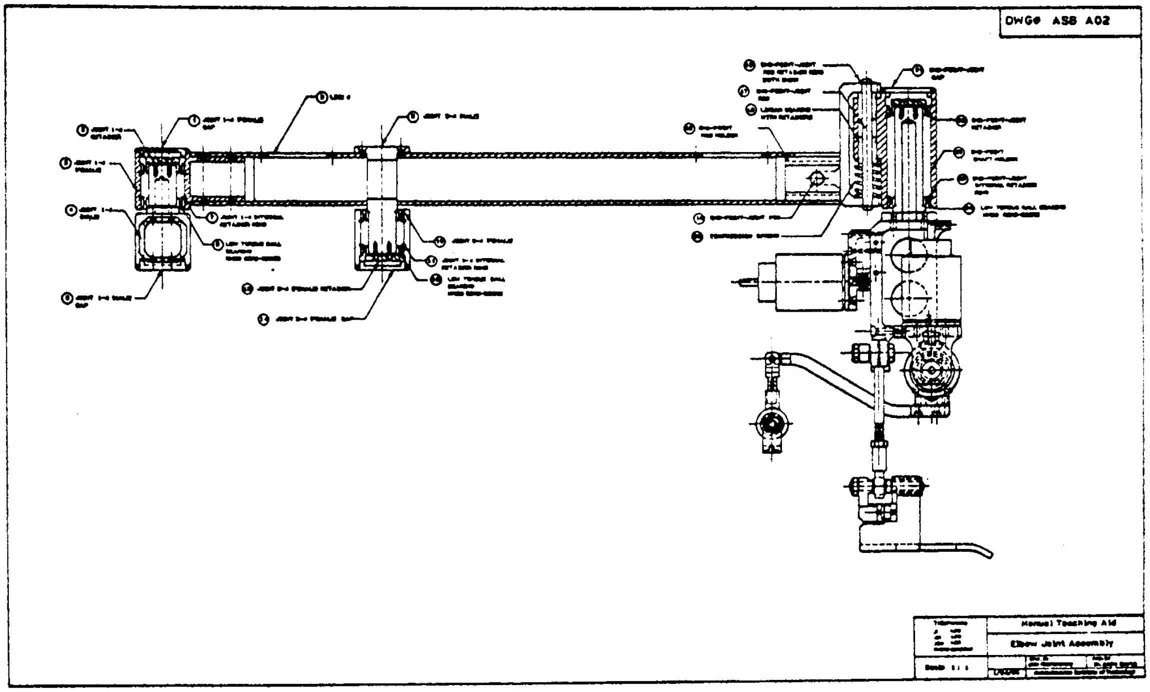


FIG.3. MANUS - Differential Mechanism at the End-Effector



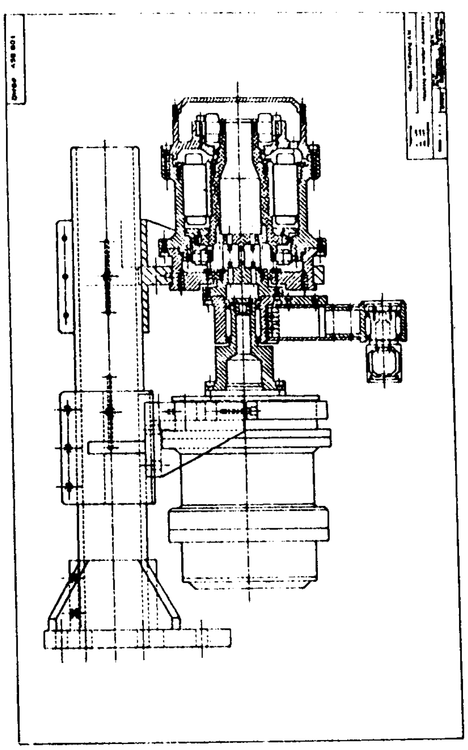
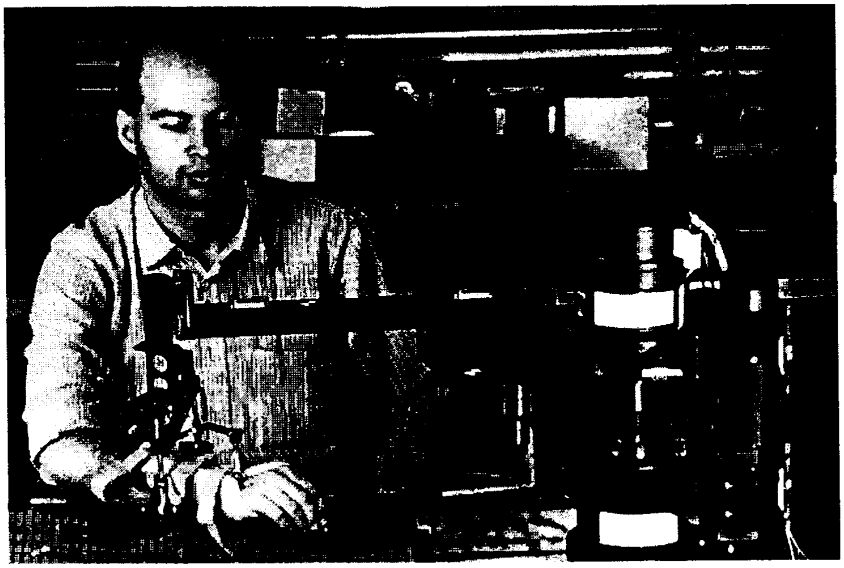


FIG.2. MANUS - Assembly Drawings



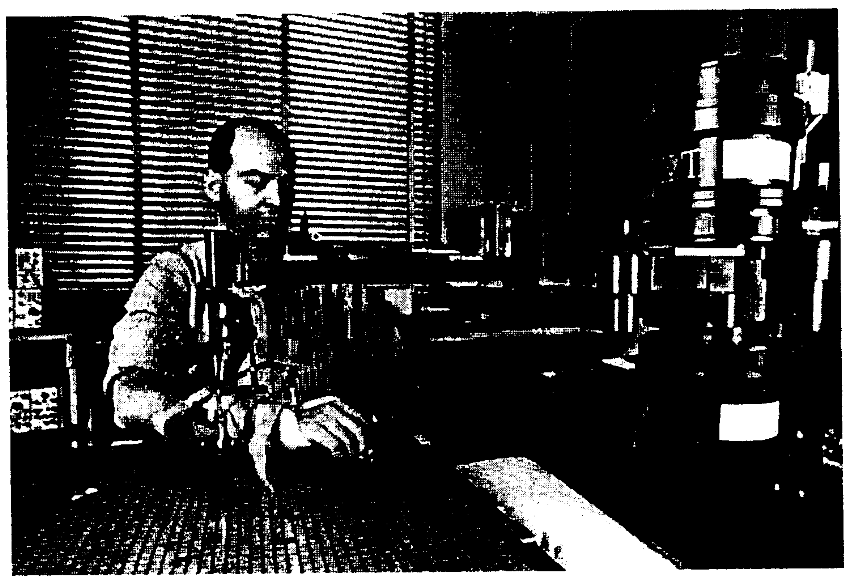


FIG.4. MANUS - General View of the Workstation