POWERED LOWER LIMB ORTHOTICS IN PARAPLEGIA

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This brief presentation describes a project in progress in the Mihailo Pupin Institute, Belgrade, under the direction of Professor R. Tomovic, to develop a powered exoskeleton capable of restoring locomotion to the paraplegic patient. The project is supported by the Social Rehabilitation Service of the United States of America.

Members of the BioEngineering Unit of the University of Strathclyde are associated with this project in a consultative capacity, having been asked by Mihailo Pupin to advise on the design of the exoskeleton (or bracing system) and the body attachment. This co-operation and the travel it involves has been made possible by funding from 'Action for the Crippled Child'.

The project has been rather exactly defined as follows—to provide locomotion in the home environment in the following modes:

(*a*) standing upright on level ground,
(*b*) walking forward at a moderate speed,
(*c*) turning during the walk,
(*d*) sitting down from a standing position, and
(*e*) standing up from a sitting position.

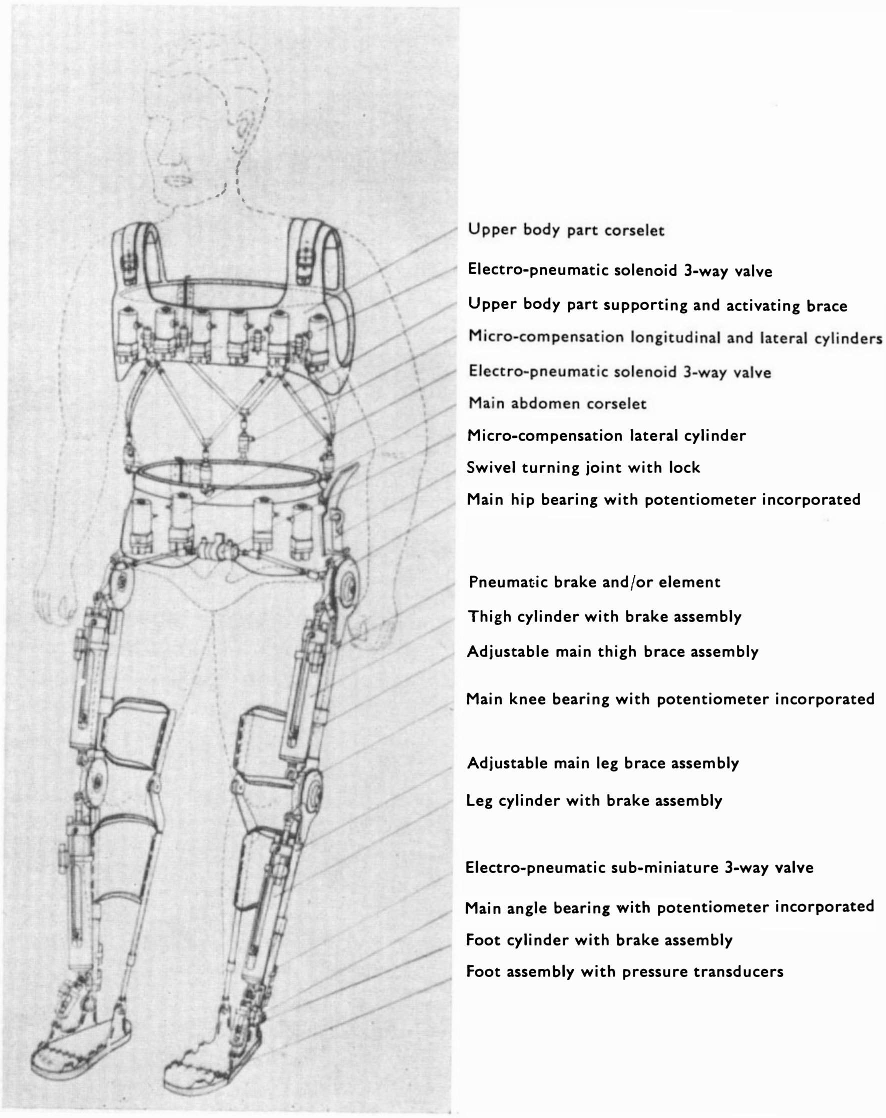
This is a project to establish (1) the feasibility of producing movement with a rather simple form of gait, (2) the possibility of fitting such a system to the patient without damaging tissue and (3) the psychological effect on the paralysed patient of restoring an upright mode of progression. This is not in the initial stage to be inhibited by the absence meantime of a portable power source of sufficient capacity to allow this operation to be independent (of trailing leads, etc.).

The mode of progression visualised is of a rather simplified kind where limb segments are moved in a controlled manner to specific discrete positions so that the position control is 'step' rather than continuous. The Yugoslav group visualise the control process as taking three parts. These are described as:

1. decision-making level,
2. algorithmic level,
3. dynamic level.

(1) is the only part which is under the voluntary control of the patient. The decision refers to the mode of locomotion, *e.g.* 'walk forward'. Having made this selection the 'algorithmic level' (2) is under the control of the computer which provides what may be described as the 'blue-print' instructions to the actuating mechanisms which move the limbs to the series of positions required to produce 'walk forward'. (3), dynamic level, refers to the corrections which must be made to the related parts of the whole system to maintain equilibrium, *e.g.* moving the trunk forward by a small amount to compensate for a tendency to fall backward—*i.e.* moving the centre of gravity.

To sketch briefly the history of the project the first step was the construction of a biped walking machine. This consisted of a pair of legs with joints at hip, knee and ankle with a 'body mass' which could be moved by the computer to provide some degree of stability. This 'model' proved the possibility of progressing



with the simplified gait already described and proved that one form of the algorithms arrived at using mathematical models was usable. The machine was not capable of dealing adequately with the dynamic adjustments required and so would only make about three steps before the 'build-up' of imbalance was sufficient to make it unstable (and so fall over).

The second step involved the production of a system powered by compressed air capable of moving the lower limb but not providing balance. This was fitted to a patient and a form of movement was shown to be possible. This version was not even as sophisticated in its control system as the biped machine and this stage of the experiment was not believed to be of very great value.

The third stage which has now been reached is a fully-powered version with dynamic balance. It is illustrated in the figure. It should be remembered that the system is connected to a power source and digital computer. The system is seen to be in two parts, the lower part consisting of a 'pelvic girdle' and exoskeleton for moving the lower limbs and an upper 'thoracic casing'. The lower limbs are actuated by independent cylinders at hip, knee and ankle—under 'algorithmic control' by the computer. The dynamic system which provides the vital balance compensation works in the following manner. The soles of the feet of the exoskeleton contain pressure sensors. By means of these it is possible to define the position of the resultant force between the foot and the ground. Now it has been shown that if the system is to stay in balance this resultant force must act within a fairly small area in the central part of the sole. Whenever this force moves out of this 'equilibirium area' the dynamic control compensators come into action. These are of two types. The first are the micro-compensators which move the 'thoracic casing' relative to the pelvic girdle. If this movement of the upper mass of the body is insufficient to restore the resultant force to the 'equilibrium area' of the sole, the macro-compensators act. These move the pelvic girdle relative to the thigh.

This, of course, is a considerably simplified description. The system is now under construction in Belgrade. The problems are formidable. They range from those of fitting the body attachments sufficiently closely to allow the compensator system to function to those of arriving at the correct algorithms for the walking mode. After this come problems of producing compact, high capacity power sources and light, high speed relatively complex computers. One might argue with the philosophy behind this project but it is not possible to form a valid judgement before the event. Even if the eventual outcome is not a feasible powered orthotic system for paraplegics, spin off, in terms of information on orthotic design, fitting methods, tissue load carrying capacity and the like will, it is believed, justify the project.