A TECHNOLOGY FOR SELF-FITTING OF ORTHOSES

R.Tomović*

D. Popović*

F. Gračanin**

1. INTRODUCTION

The approach to rehabilitation of locomotion functions presented in this paper is based on the technology of so-called soft suits. No matter what specific technical solutions are taken, the common background of soft suit technology for orthoses fitting is total and adaptive man-machine shape matching. Namely, the person in need of an assitive device is dressed into a tight soft suit which is then used as a passive or active (externally controlled) orthotic device.

First attempts to introduce the technology of soft suits into rehabilitation engineering were made by the French company Aerozur. The idea was rather simple, as can be seen from Fig. 1. Once the patient is dressed in the soft suit, it is inflated by the compressed air and thus transformed into an assistive device supporting the standing position of the paraplegic patient. In order to sit down, the patient has to deflate the suit.

* Faculty of Electrical Engineering, Belgrade

** Rehabilitation Center, Ljubljana

Although the conditions for total and adaptive man-machine contact are met in the above solution, practical results did not justify the great expectations. Among other things, the one-piece approach requires delicate and time-consuming fitting. Compressed-air pockets may also produce local overpressures at the exposed parts of extremities. On the other hand, inflation-deflation operation reduces the control to its crudest form - on - off states.

Second generation of soft suit technology is much more versatile both in fitting and control potential. Instead of one - piece suit, the segmented approach, corresponding to human body anatomy is applied [1]. In this way, the fitting process is greatly simplified and, at the same time, new potential for locomotion control is added. Fig. 2 represents the segmented soft-suit without external control, while Fig. 3 displays its motorized version with computer control of locomotion. The segmented soft suit technology has been developed by P. Rabishong and Bell at the Cybernetic Institute in Montpellier, France.

The segmented soft suit as shown in Fig. 2 still uses compressed air, however not for control purposes but just for more even pressure distribution. In order to simplify further the soft suit approach and to eliminate completely the need for compressed air, a new technology of soft suit preparation and control is being developed at the Faculty of Electrical Engineering, Belgrade [2]. During the course of this research some new features of soft suit technology have been discovered, in the first place self-fitting potential and self-adjustment of the orthosis. These new properties of soft suit technology are described below.

2. SELF-FITTING

Existing hard-ware for rehabilitation purposes is conceived as off-line equipment. The assitive device to be applied is first produced in modular or non-modular form, then assembled off-line and as a completed product fitted to the patient. Our intetion was to experiment with a different philosophy of assistive devices.

Basic idea of self-fitting orthoses is represented in Fig. 4. The person in need of the assitive device puts on tight, tailor made, trousers. The only difference from normal wear consists in details related to pockets into which the prefabricated mechanical parts are inserted. Mechanical parts of the orthosis are prefabricated in standard sizes and are available as modules in disassembled form. By inserting the mechanical elements into the corresponding pockets of the trouser in the prefixed order, the orthosis is assembled and fitted on-line by the patient himself. For this purpose, no tools are needed except patients hands. The assistive system is so designed that only those joints in need of external support are actually equipped with the hardware.

. The use of the soft suit to support assistive hardware adds new problems. In the first place, rigid fixing of the mechanical system to the human body is not possible any more. There is now no way to maintain invariant position of trousers, i.e. orthosis, with respect to the human body, so that self-adjustment potential of the mechanical system must be built in. This has been taken care of by using the telescope system for lateral axis. Consequently, the axis of the mechanical knee joint follows automatically the leg flexion and extention, Fig.5.

Evidently, the man-machine interaction with respect to force transfer and pressure distribution is much more complex in this type of the soft suit than when the technology with air pocket is applied. In order to overcome this difficulty, careful analysis of force field and pressure distribution in the soft suit in various phases and modes of locomotion is undertaken. On the other hand, it should be kept in midn that this type of soft suit technology is conceived in the first place to cover applications with partial external power supply rather than total power solutions. In our opinion, internal energy resources of the patient should be exploited to the maximum whenever available. Such a rehabilitation approach, especially when relatively small additional external effort is required, speaks in favour of soft suit solutions and simple, reliable, control system. More about such control systems will be said later.

Let us mention that the weight of the mechanical parts to be inserted in the soft suit covering hip and knee joints is 800 grams per leg. At this stage of development no special materials were used so that further weight reduction is quite possible. To the above figure, the weight of actuator per joint must be added in the case of external control. Here again reductions in weight are acoomplished corresponding to the degree to which the ratio of external versus internal power is decreased.

3. POWERED SOFT SUIT

Soft suit technology as proposed here has evidently advantages and disadvantages. Self-fitting is certainly a significant advantage since in order to apply this technology only the services of a tailor are needed. Mechanical parts come as prefabricated units in a kit. However, the passive system will support only a restricted number of functions such as standing up, sitting down and eventually the crudest forms of locomotion. With active joints and external control more versatile locomotion activities are feasible. Before this can be done, several important design and control problems must be solved which are inherent to this type of soft suit technology.

It was mentioned earlier that automatic self-adjustment of external joint axes must be provided due to unavoidable trouser displacement with respect to the human body. As a consequence of this fact, the orthosis must be of variable length, which is accomplished by the telescopic system. In the case of the powered soft suit, this implies that the rotational actuator, such as the electrical motor, cannot be mounted coaxially to the natural joint but must be co-linear to the lateral axis of the orthosis. The sketch drawn in Fig. 6 explains how an active rotational joint module can be added to the passive soft suit without affecting its potential for self-adjustment. On the other hand, the size of the active module and the power consumption can be significantly reduced if partial external power approach is taken. For instance, when the standing up and sitting down functions are greatly supported by internal resources then the powered knee and hip joints must provide just the energy for limb extensions and flextions.

Elimination of the request for fixed initial fitting conditions affects directly the design of the control system. The locomotion process can be treated no doubt as the trajectory control of a moving mechanical system. However, the need for fixed external coordinate system and the maintenance of initial fitting conditions is in this case highly pronounced. In order to overcome these difficulties in the design of biped ambulators, a new approach to the control of human extremities has been developed. Theoretical and applied aspects of the so-called logical or attitude control of antropomorphic robots are described in various references [3, 4]. At this point we shall only mention briefly the main features of the logical control of locomotion.

Logical control of biped ambulators is based on following assumptions:

a) Existence of artificial proprioceptive and exteroceptive sensory feedback, which provides information about the actual state of limbs with respect to local (joint) coordinate systems. This makes the control insensitive to a large extent to variations of initial fitting conditions as well as to the changes of body position with respect to the fixed external coordinate system.

b) Control laws of the biped ambulator are based on pattern recognition rather than on error reduction as in conventional feedback regulators. Typical control patterns are: terminal joint angles, forward or backward limb position, ground contact, etc.

c) Implementation of logical control leads to asynchronous finite state machines capable of discriminating the sequences of allowed, non-allowed and emergency states.

d) Logical control deals with non-numerical data processing. Thus, extensive numerical calculations affecting the reliability and response speed of the control are bypassed.

As seen, the application of the new soft suit technology for biped ambulation is deeply interconnected with the capabilities of the control system to deal with significant variations in initial fitting conditions. In fact, the development of the self-fitting orthosis is more a consequence of the research in control theory than vice versa.

4. APPLICATION

In the initial phases of the experimental work main attention was paid to force transfer problems. Although the new technology is being developed having essentially in mind biped ambulators, first experiments were designed to apply the assistive device just to maintain the standing position and for standing up process. The motivation is clear. Namely, if the soft suit can function in most unfavourable conditions, i.e. to support the body weight in standing position and withstand the forces appearing during the lifting of the body from sitting state then it should be able to perform so in the process of limb extension and flexion.

A typical experiment with force transfer is shown in Fig. 7, where a normal person is being lifted from sitting position using extenral power. It is interesting to point out that the same experiment can be performed using self-propulsion. Evidently, the case of normal person is trivial. In order to use self-propulsion with patients who have lost for various reasons the capability to stand up, the solution is certainly not trivial. With such patients, a hip-knee coordination algorithm must be built-in in the assistive system. Following consistently the self-fitting concept, an additional passive module can be added to the basic orthosis. This module, which consists of a paralelogram and two levers, establishes automatically the needed hip-knee angle ratio during standing up. Fig. 8 explains the new concept of self-powered orthosis for standing up. Once in up-right position, the patient can easily detach the added module.

5. CONCLUSION

Our main goal when undertaking this research was to explore the feasibility of self-fitting assistive devices. Although other solutions for self-fitting assistive devices may be found, in our opinion following prerequisites are essential to begin with:

1) Control system insensitive to variations of initial fitting conditions.
2) Shape-adaptive man-machine contact.
3) Partial external power involving man-machine interaction at all levels.

These are general factors facilitating the self-fitting applications. Evidently, it will take much more time, effort and experimentation before medical indications for self-fitting orthoses and biped ambulators will be established. The main goal of this paper is to encourage new research in the field of self-fitting assistive devices in order to derive well founded answers as to the usefulness of such an approach to the rehabilitation of disabled persons.

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Fig. 1. First generation of soft suit technology of lower limb orthoses.

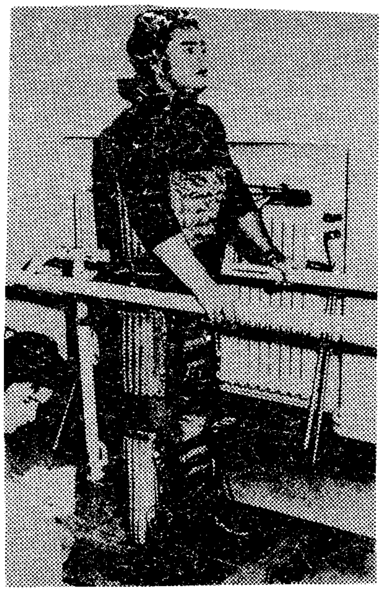
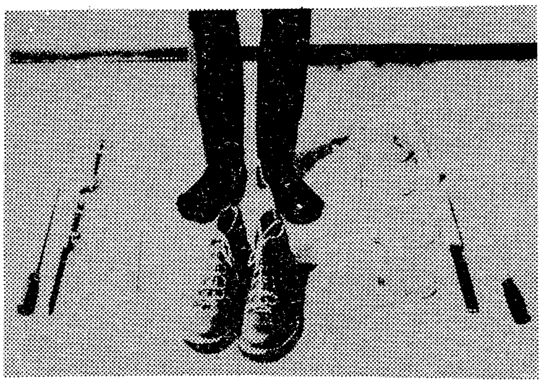


Fig. 2. Second generation of soft suit technology, passive version.



4. Basic elements of a self-fitting limb orthosis.

Fig. 3. Externally controlled segmented soft suit.

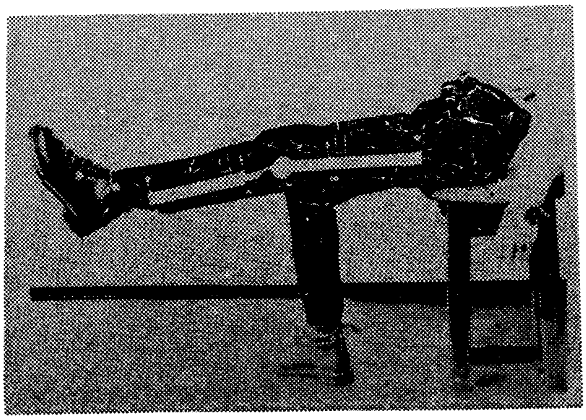


Fig. 5. Self-fitting orthosis in operation.

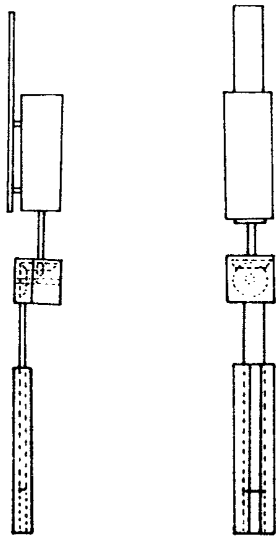


Fig. 6. Powered joint with self-adjustment capabilities.

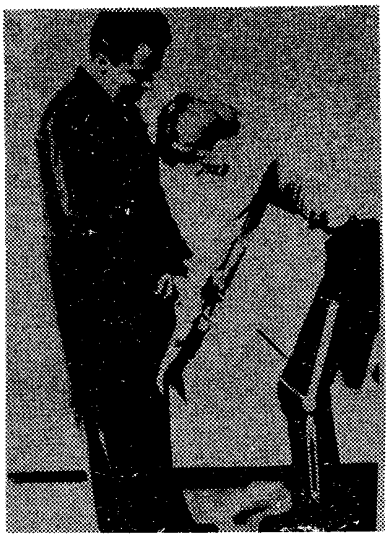


Fig. 7. Experimenting with force transfer using new soft suit technology.

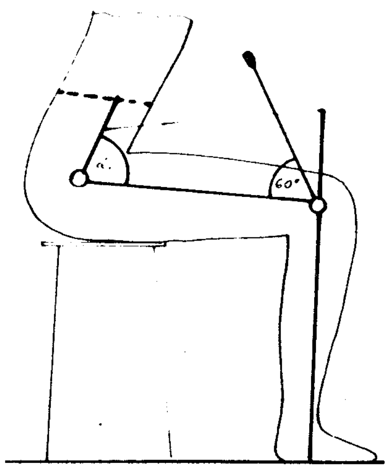


Fig. 8. Mechanical program for self-lifting of the sitting patient.