ACTIVE PERONEAL ORTHOSIS

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ABSTRACT

The active peroneal orthosis is mainly intended for hemiplegics.On the basis of an analysis of the walk of both healthy and handicapped persons, a method of orthosis control is adopted and also the approprate actuator is choseu.The orthosis is controlled on the basis of the information about the state of the switches built in the foot, and on the basis of the information about the boundary positions of the ankle rotation.The characteristic positions of the system are defined as well as the ways of the transitions between them.Some states are also affected by the usez, his will being included in the control system.The orthosis is driven by a DC motor.

INTRODUCTION

The active peroneal orthosis, an under-knee locomotive apparatus is dedicated to hemiplegics, people who have no control of feet movement and who have lost sensor and motor capability of lower part of the leg. This is usualy followed by some sort of spasm and that causes certain deformation of walk. The secondary consequences, like muscle atrophy and weakening of cardiovascular system, also appear because of increased and irregular use of energy. All this also leaves the psychological consequences and causes a deerease in working ability.

This is the main reason whu the increased attention has been payed to this problem recently. The devices that make the walk of hemiplegics easier, more stable and more natural have already been realized. They are mainly the passive mechanic devices or the stimulators. In this paper a realization of automatic orthosis by means of logic control is presented.

THE LOGICAL CONTROL OF THE LOCOMOTIVE MECHANISM

The problem of finding out the right way to control locomotive mechanisms is very complex, not only because of the system complexity but also because of the fact that the human being is in question, which means that a control system must include his willing action, too. The idea is that certain movements which would influence the control of locomotive mechanisms gradually become a routine, but such a kind of a routine that would not be consćions. These morements would be newly adopted algorithms of locomotion. It is impossible to apply the clasic methods of synthesis from the automatic control theory to a system conceived in this way. The main difficulty comes from the fact that process of locomotion implies willing action for which, at least up to now, it is impossible to set up a mathematical model. That is why this problem still defies a rigorous theoretical treatment. The complexity of the required control asks for the search for new ways and approaches in resoiving problems of this kind. The process of locomiton is characterized by the repetition of specific actions that comes according to certain order. Besides that, during the locomotion process the foot is first raised and then it goes to the ground. These observations lead to the ideal of logical control of locomotion. The original idea is to form logic functions of discrete variables that give the information about the foot and ancle position in locomotive activity. On the basic of thus formed logic function, control could be directly and very simply realized by means of simple logic circuits. The control device designed this way enables extremely quick generation of control signals which is important because of the real-time nature of locomotive process control. That is why this very algorithm reflects the complexity of control.

The logic control approach asks for formation of the essentially different model on the basis of which the logic subordinate functions of chosen state variables are derived. Namely, the synthesis in logical control is reduced to the formation of a deserete simulation model of locomotive process, which directly implies the control algorithm.

The deserete simulation model is conceived as a chain of successive, for the problem we are dealing with, interesting positions of the system. In order to find such a model it is necessary to define some variables that can describe the system position and who can be used for generation of control. In the case of logical control it is necessary to represent the system by a set of discrete variables among which the logic functional dependence is loked for, and not in the form of differential or difference equations.

In order to enable a discrete binary description of the system we introduce the state vector

$$Y = \left[Y_1, Y_2, \dots Y_n \right]^T ; \quad Y_1 = \left\{ 0,1 \right\}$$

The state variables Y_i are not the dynammic ones and that is whu the state vector Y does not describe the system dynamics bat only the system position. These variables are determined on the basis of the date obtained experiments performed on the locomotive process.

THE ORTHOSIS CONTROL

On the basis of the analysis of walk for both healthy and handicapped people a cancept of active peroneal orthosis control is adopted. Since beside the inner forces, namely the muscle forces, some external forces like gravitational and intertional ones olso take part in locomotion, it is concluded that the role of orthosis should be to raise the foot in the swing phase and to enable free motion of the ancle in the supportive phase. In order to achive this, it is necessary to realize four states: the forward ancle rotation, the backward ancle rotation, the state of stall and the free state.

Besed on this the four characteristic positions are observed: the start of swing phase, the end of forward rotation, the start of supportive phase and the end of backward rotation. These positions correspond to: the begining of forward rotation, begining of state of stall, begining of backward rotation and begining of free state, respectively.

To describe these positions the states of switches bult in foot and the states of contacts built in the motor shaft are taken as state variables.

So, the state vector Y is composed from two vectors Y_a and Y_b.

$$Y = \left[Y_a \ Y_b\right]^T ; \quad Y_a = \left[P_1 \ P_2 \ P_3\right]^T ; \quad Y_b = \left[K_1 \ K_2\right]^T$$

Where Y_a gives the information about the foot position and Y_b about the boundary ancle position.

The fhree variables are taken from the foot. Thase are the states of sensors built in the foot: in the heel zone (P_3). These sensor positions sorrespond to the anatomic formation of a foot and this order comes from the walk analysis. The contack K_1 defines the lower boundary position and the contact K_2 the upper one.

Thus defined variables enable their binary code: 1 means the closed switch and the appropriate boundary position of the contact. 0 means the opposite.

With formerly adopted positions and defined state variables, a discrete simulation model of under-the-knee part of the leg is formed. The model consists of four positions PS_1, PS_2, PS_3, PS_4, which are described by the vectors Y_1, Y_2, Y_3, Y_4.

$$Y_1 = \left[00010\right]^T \qquad Y_2 = \left[P_1 \ P_2 \ P_3 \ 0 \ 1\right]^T$$

$$Y_3 = \left[10001\right]^T \qquad Y_4 = \left[P_1 \ P_2 \ P_3 \ 1 \ 0\right]^T$$

Now, on the bases of the discrete model the control algorithm is determined. That means finding out the way of transition from one position to another, namely the role of man and the actuator during those transitions.

The transition from PS_1 to PS_2 realizes the actuator, while the transition from PS_2 to PS_3 is done by man's willing action. Namely, he realizes the position PS_3 by transfering his leg and then touching the ground. The transition from PS_3 to PS_4 does the actuator and from PS_4 to PS_1 man.

On the basis of thus made discrete simulation model the control is realized directly. A logic function of the state vector components has been formed

$$L = f(P_1, P_2, P_3, K_1, K_2)$$

and it is used as a base for control signals generation.

The positions PS_1, PS_2, PS_3, PS_4, described by the state vectors Y_1, Y_2, Y_3, Y_4, could be repnesented by the values of function L, as followes:

$$L_1 = \bar{P}_1 \cdot \bar{P}_2 \cdot \bar{P}_3 \cdot K_1 \cdot \bar{K}_2$$

$$L_2 = \bar{K}_1 \cdot K_2$$

$$L_3 = P_1 \cdot \bar{P}_2 \cdot \bar{P}_3 \cdot \bar{K}_1 \cdot K_2$$

$$L_4 = K_1 \cdot \bar{K}_2$$

The structural block-diagram of the system is giren in fig.1

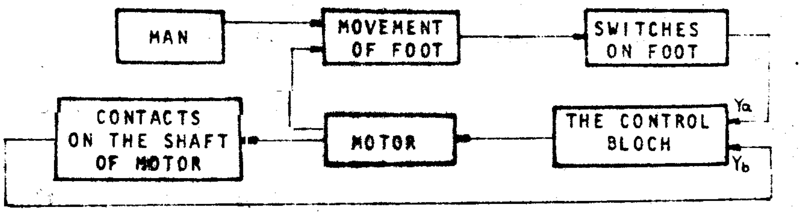

Figure 1.

The control block is shown in fig.2

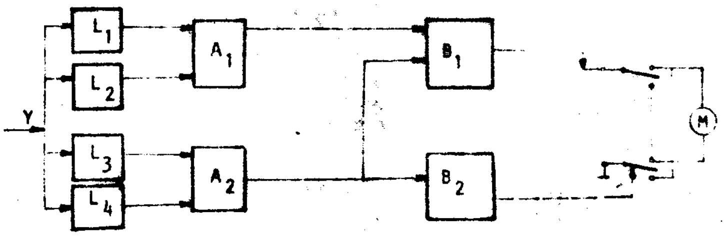

Figure 2.

The control signals are generated and amplified in the blocks A and B.

THE ORTHOSIS DESIGN

A chain of conditions and limitations should be considered carefully in the realisation of orthosis. This means that special attention should be payed to the power, dynamics, supply, weight, gabarit as far as securty, esthetics and psychological adaptation are concerned. The design should guarantee mediolateral ancle stability.

In order to fulfill all these requirements a few version of orthosis, with different places of motor and different ways of transmission of rotation to the foot, have been investigated. The adopted version is the one with the motor blok put at the reinforced segment tied to the under the knee part of the leg. A DC motor with reductor and junion is sittuated vertically along the shin-bone. Specially designod junction enables realzation of the free state. This means that junction in the "free state" phase decouples motor block from the foot thus enabling free movement of the ancle in this phase. Transmission of rotation to the foot is done over the ancle lever. This makes certain compensation of the change of radius of rotation due to disalignement of the motor and ancle axes of rotation. The ancle lever is not tightly connected with the shoe but throngh the ancle and this enables certain flexibility in the monement of foot and its accomodation to the ground. Ancle lever at the same time enables mediolateral stability of the ancle.

The switches that give the information about the foot relative possition to the ground are layed doun in leather insert put in the shol. The realzation of peroneal orthosis is shown in fig.3.

One step of a patient using orthosis is shown in fig.4. The variations of the ancle angle for a healty person and for the handicapped one using peroneal orthosis are given in fig.5. There is the difference in the swing phase, where a small movement of ancle apears with healthy person, while the step of a person using orthosis have such changes because it is "stal state". However this does not essentially affect the normal walk.

The investigation of orthosis is done at the Electrical Engineering department in Belgrade. The medical evaluation that requires more time is being carried ont now. The orthosis is currently being used at the institute for physical therapy "Dr Simo Milošević" Igalo- Herceg Novi. The investigation is carried out as to what kinds of diseases this orthosis could be applied, its use and its influnce on the organs of a handicapped and patient in general, the role of man's willing action in control of orthozis, psychological reactions of patient and degree to which he can accomodate to the use of orthozis.

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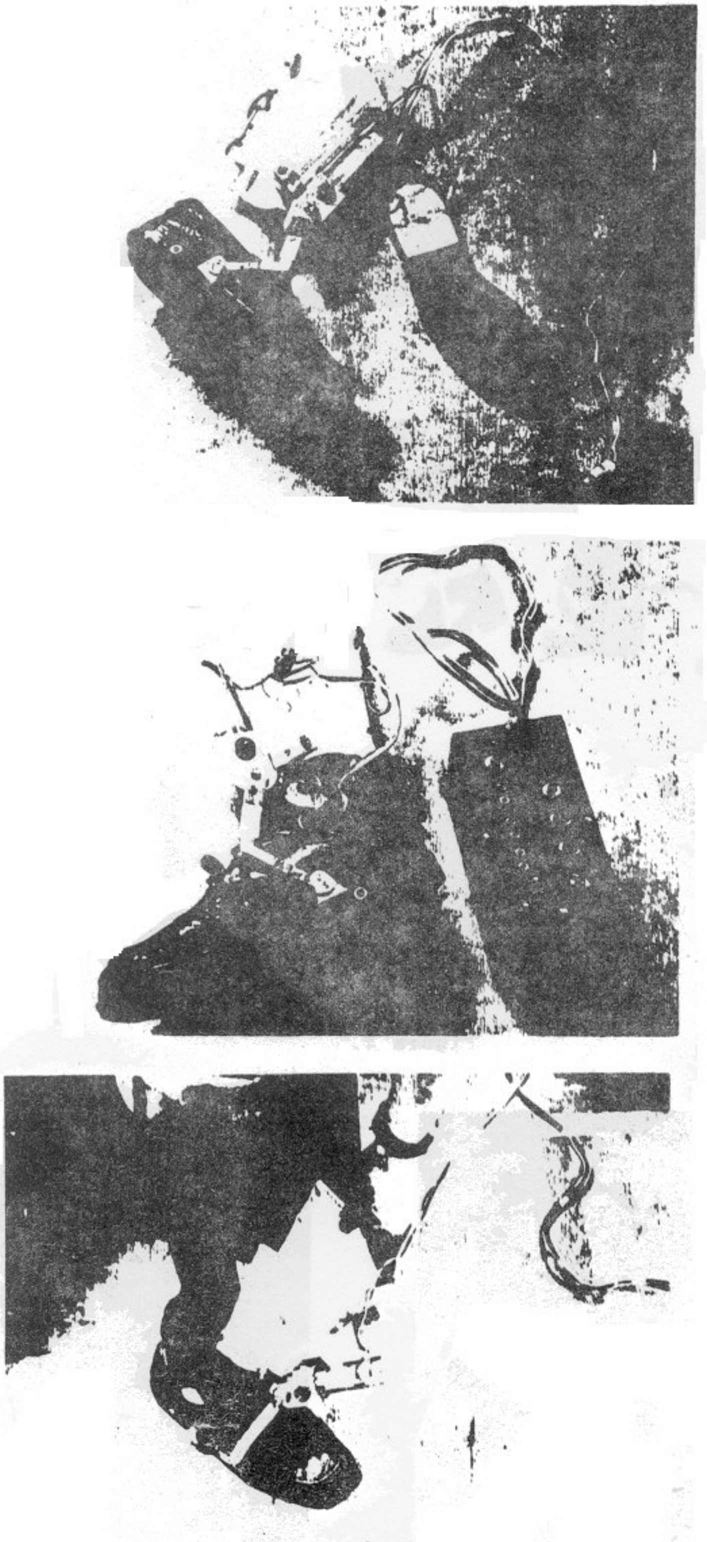

Figure 3.

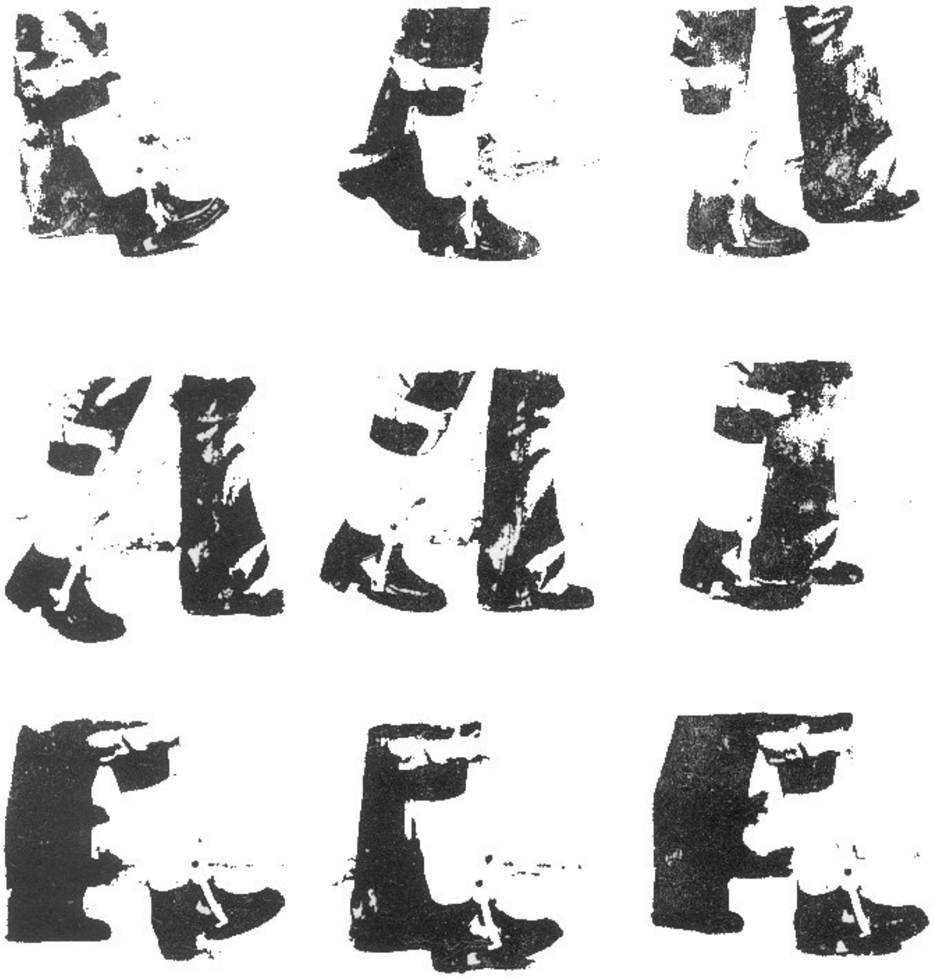

Figure 4.

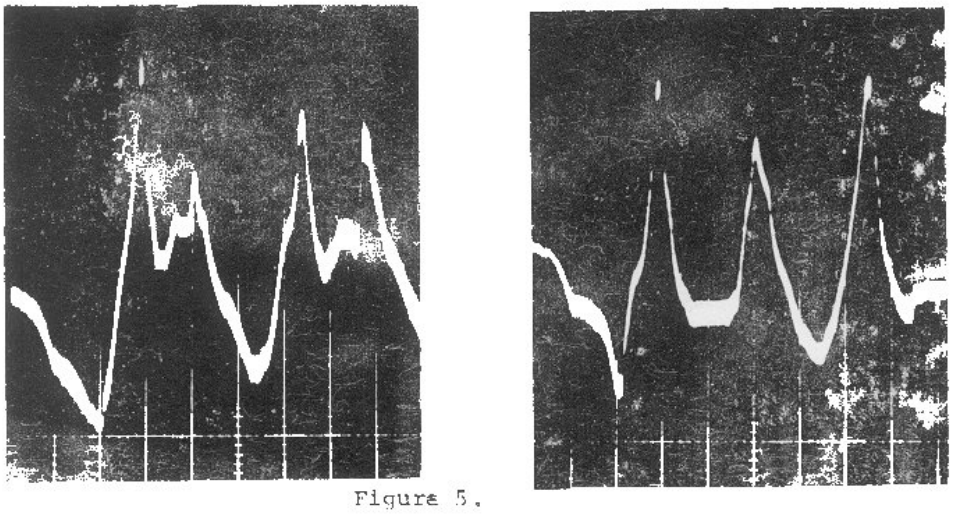

Figure 5.