ADVANCES IN EXTERNAL CONTROL OF HUMAN EXTREMITIES IX

ADAPTIVE REFLEX CONTROL OF ASSISTIVE SYSTEMS

R.Tomovic,D.Popovic,D.Tepavac
Faculty of Electrical Engineering,University of Belgrade
Belgrade

ABSTRACT

In the current development of artificial reflex control of locomotion, main efforts were dedicated to the nonadaptive rule based control. Such a rule based control of locomotion is convinient for stationary gait activities. In this paper, an extension of rule based **control to adaptive features of** locomotion is described. Logical expressions for **automatic gait** mode selection, intention recognition related **to locomotion** initiation and variable step length are presented.

Keywords:Artificial reflex, Adaptive control, Gait restoration

INTRODUCTION

The control of assistive systems for motor deficiencies **by** artificial reflex loops has proved to be very usefull /1/. **In** fact, a new type of orthotic assistive systems for patients **with motor** deficiencies of lower extremities is developed by using **combined** control **of** both biological **/7,8,9/** and artificial reflexes /2/.

The process of initiation of **natural reflex mechanism is** provided by the use of functional electrical stimulation (FES). It improves functional movements of an abnormal neuromuscular system by the application of electrical **impulses to the efferent or/and afferent peripheral nerve fibers. These impulses are volitionally controlled by the handicapped who thus regains to some extent control over his paretic muscles.**

In order to avoid any confusion, it must be pointed out that the artificial reflex has no ambition whatsoever to be a complete replica of the corresponding biological mechanism. The similarity between the two automatic control mechanisms is limited to following aspects:

-Reflex implies sensory driven control,

-Reflex implies pattern matching, i.e. the mapping of the sensory pattern onto the motor act.

Above two features are incorporated into the artificial reflex concept. In addition, the pattern matching operator is derived by knowledge capturing methods based in human behaviour/3/. The Artificial reflex approach has led to development of a comprehensive skill based expert system for the control of biped locomotion covering all main gait modes /4/. However the main emphasis in current application of artificial reflex control of lower extremities has been in nonadaptive production rules. The purpose of this paper is to present advanced research in artificial reflex control of lower extremities intended to extend this approach to higher level decision making.

SENSORY REQUIRMENTS

When speaking on natural reflex mechanism, we are refering on hundreds of thousends microminiature sensors sending information to the central nervous system about both the outside environment and conditions within the body. The interaction of different sensors is extremly important in manipulation and locomotion. For example when a normal individual walks sensors are sending information about the temperature, texture, external force and pressure as well as about the position of each segment of the body. The eye send additional information about the size and position of obstacles, surface geometry etc.

In the nonadaptive application of the artificial reflex control for locomotion the sensory information was quite reduced. There are many constraints implying sensory reduction /10/. The sensing system to be used with the assistive device must be designed so that it fit's under clothing, that it can be attached and removed easily without frequent calibration. These constraints imply that force (pressure) sensors must be thin and flexible, that it works in rough, smooth, wet or dry environment having enough elements for the spatial resolution with restricted number of wires.Joint position sensors must not impede normal joint motion (joints are not pinned hinges). Taking into account these constraints only following sensory data were used to build sensory patterns:

touch sensors at the foot,

angle transducers at the hip and the knee

verticality sensor at the thigh.

The interaction with the normal human sensors is excluded.

Formal representation of these sensory patterns has the form of boolean expressions /1,3,4/

For purposes of adaptive reflex control the sensory information had to be extended in the following way:

-pressure (force) sensors at the foot,

-angle transducer at the ankle,

-hardware or software derivative of joint angle variation,

-accelerometer.

It will be shown below, that in the case of adaptive reflex control the sensory patterns remain still represented in the form of logical and boolean expressions.

MODE RECOGNITION

The main knowledge base for adaptive reflex control consists of three segments /4/

1.The set of production rules controlling normal locomotion cycles.

2.The set of production rules related to abnormal evolution of locomotion cykles, so calling emergency rules.

3.The set of production rules for the change of the gait mode.

There is an intrinsic difference between the effect of production rules (1 and 2) and 3. Production rules (1,2) operate in the following way,

sensory pattern → motor act

while the impact of rules 3 is

sensory pattern → activation of a gait mode.

The rule 3 is operating at the higher control level (planning) from the 1,2 control level (algorithm level).

In this context, we are interested in the third type of production rules. As known, the decision to change a gait mode is made at the voluntary level or automatically. Our concern is automatic change of the gait mode. The need for automatic change of the gait mode is imposed by radical change of the locomotion environment and disconnection of normal sensors (eyes,ears) with the artioficial one. Consequently the automatic change of the gait mode requires the recognition of environmental modifications. So far, automatic adaptation of gait modes to following changes of environment has been considered:

-walking of the level ground,

-walking up and down the ramp,

-ascending and descending the stairs.

Walking on level ground has been described in our previous papers. The switch over to climbing and descending gait modes requires the recognition of the ramp or stairs. For the ramp, this means

1.The ramp elevation angle (α_R),

2.The sign of the angle (positive or negative).

Namely in the case of the ramp and stairs, as different from the walking on level ground the reversal of the dirrection of motion requires the change of the locomotion behaviour.

For the stairs, following features must be identified:

1.Step height (h) and width (L),

2.Direction of motion.

It is easily verified that following logical expression is capable of identifying the rump features (Fig 1):

$$\left[M_L(H_L+T_L)+ M_R(H_R+T_R)\right]\left[(\beta- 180-\Delta\beta)\right]=1 \quad \phi_A= \alpha_R$$

The expression for the recognition of stairs has the form (Fig 2):

$$\left[M_L(H_L+T_L)\cdot M_R(H_R+T_R)\right](\beta - 180- \Delta\beta)= 1 \quad \phi_K=\alpha_{S1} \quad \phi_H=\alpha_{S2}$$
$$(\alpha_{S1},\alpha_{S2}) \rightarrow (h,L)$$

INTENTION RECOGNITION

Reflex control of assistive systems can be significatly upgraded if human intentions to modify locomotion are automatically detected or, at least, iniated with the minimum intervention from the voluntary level. It will be shown how this can be done by using man-machine interaction.

Initiation of the locomotion. The decision to start biped locomotion with the left or right leg is taken at the voluntary level. Such a decision is followed with automatic body reactions. In the first place, the body weight must be shifted to the opposite side of the leg which starts the swing phase. Using the compalsory body reaction of the man, one can teach, for instance, the bilateral, above knee amputee to reproduce the same bahaviour if provided with prosthesis with appropriate hardware and reflex control. Following formal rule implements the man s intention to initiate the locomotion cykle by the machine

$$\left[\pm(p_L - p_R) > d_1\right]\left[\Delta\gamma > d_2\right] = 1$$

Symbols p_L , p_R refer to pressure signals of the left and the right leg, dl is a heuristically selected small paramerter, $\Delta\gamma$ is the angular displacement of the shank (thigh) from the vertical line, [illegible] is heuristically selected small parameter. The +/- sign is associated with the left or right leg by convention

Stable standing. The intention to maintain the body in standing position can be detected by the following logical expression.

$$\left[\pm(\text{[illegible]}\ \beta_R) < d_1\right]\left[\beta\text{[illegible]} < d_2\right]\left[\phi_H < d_3\right]\left[\phi_K \text{[illegible]}\ d_1\right]\left[\phi_A = 90 \pm \Delta\beta\right] = \text{[illegible]}$$

All symbols d_i have the same meaning as above, ϕ_H, ϕ_K, ϕ_A, are respectively the hip, knee and ankle angle, $\Delta\beta$ is a small parameter.

Sitting down. The intention to sit down from standing position can be expressed by

$$M_L \cdot T_L \cdot M_R \cdot T_R \cdot \overline{H}_l \cdot \overline{H}_R\left[\beta < 180 + \Delta\beta\right] = 1$$

Standing up from sitting position. Standing up is recognized by

$$M_L \cdot T_L \cdot M_R \cdot T_R \cdot \overline{H}_L \cdot \overline{H}_R\left[\beta < 180 + \Delta\beta\right]\left[\alpha < 90 + \Delta\alpha\right] = 1$$

Variable step length. This is another locomotion variable depending directly or indirectly of the volutional level. In fact, the primary decision is to change the locomotion speed. As known the increased speed of locomotion is reflected in the increase of the step length nad decrease od the cykle period due to higher internal system energy available at the swing phase. Thus, when walking on level ground with variable speed the hip flexion terminal angle in the swing phase must become adaptive rather than fixed. The logical variable which tells that the available rotational energy of the leg has been used up is $\dot{\phi}_H = 0$. Consequently, instead of setting ϕ_H^{t} = Const. in the boolean expression describeing the end of the swing phase, the value $\phi_H^{t} = (\dot{\phi}_H = 0)$ must be introduced where oht stands for the hip flexion terminal angle. Practical demonstration of a legged machine with variable step length is described in reference /5/.

Intention recognition for the ramp and stairs are pointed in previous text.

CONCLUSION

The nature of artificial reflex control makes it highly suitable for applications in rehabilitation engineering. Such a control procedure can be easily integrated in the remaining neuromuscular potential of the patient with motor deficiencies.

The nonadaptive reflex control had limited potential for integration since the sensory driven events were limited basically to motor pattern matching. The adaptive control has much greater integration potential since it pertains to certain aspects of the voluntary decision level. The next step in increasing the integration potential of the reflex control assistive systems will be to endow it with learning properties. Such systems could, acquire behaviour which was not incorporated in the initial control program.

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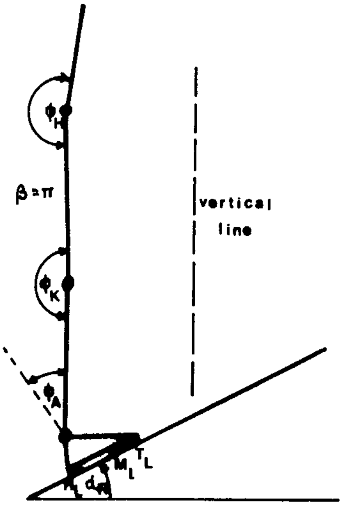
ϕ_H
$\beta=\pi$
ϕ_K
ϕ_A
vertical line
M_L
T_L
H_L
d_R

FIG 1.

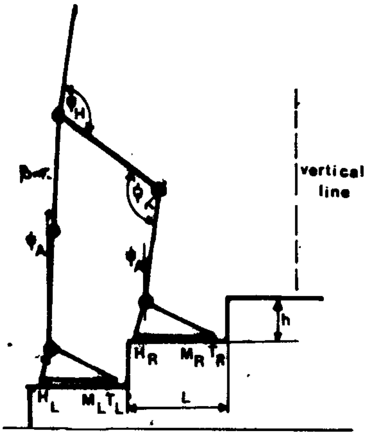
ϕ_H
$\beta=\pi$
ϕ_A
ϕ_A
ϕ_A
vertical line
h
H_R
M_R
T_R
H_L
M_L
T_L
L

FIG 2.