Abstract—This study is aimed to the development of a research in biomechatronics to be applied in the spatial personal orientation. The personal orientation in space involves the neural integration of proprioceptive, vestibular and visual sensory information. Our work is aimed to the development of vestibular like devices to provide head movement and position information in extreme conditions such as in micro-gravity.

Keywords—mechanoreceptor, biosensor, personal orientation, artificial sensors.

I. INTRODUCCIÓN

WE here present a new approach in the field of applied theory of control for the automatic correction of personal orientation under extreme conditions. The work presented use as an example the problem of the control of motion of the eyeballs in orbit.

I. MICRO-GRAVITY

In orbit, cosmonauts have to control various devices such as the movement of the spacecraft, devices for the rescuing cosmonauts, and the space manipulator under conditions of micro-gravity.

In this condition, the otolith organs of the vestibular apparatus in the inner ear do not function properly, therefore, the cerebellum, as one of the control levels of the central nervous system, reduces the gain of the information derived from the vestibular system to the muscles controlling the eye position.

Micro-gravity can thus also influence the function of the semicircular canals. In connection with this, it has been found that gaze stabilization takes three times longer than it does on the earth under normal conditions, see figure 1. Delay in the gaze stabilization can lead to catastrophic consequences. In this work we are proposing to use artificial sensors, based on the use of micro-gyroscopes and micro-accelerometers to help cosmonauts to cope with this problem. The general idea is represented in schematic form in figure 2. Here MEMS is the micro-electro-mechanical system, which consists of the micro-gyroscope or of the micro-gyroscope and the microaccelerometer, which are intended to provide with information about head movement to the subject under extreme conditions in order for him to improve his gaze stabilization.

Fig. 1. A. Time delay for gaze stabilization in normal gravity. B. Time delay for gaze stabilization in orbit.
To develop this system, we began writing the mathematical model of the horizontal, semicircular canals of the vestibular mechanoreceptors which we created on the basis of experimental data \(^{1,2,3}\).

Let us consider the passive turning of the head to the left around the vertical axis. In order to stabilize the gaze on the object, which is located directly opposite of the eyes, they must be turned to the right. Each eyeball uses two horizontal muscles to turn. The left muscle must be relaxed; the right one - must be contracted in order to complete the turn.

The process of gaze stabilization occurs with the participation of the vestibular system. For understanding the function of the vestibular system in this process, it is necessary to consider the function of the vestibular apparatus. With the turning of the head, the displacement of the endolymph and the cupula occurs in the semi-circular vestibular canals. As this occurs, the hair bundles in the sensitive hair cells of the vestibular system are bent. It should be noted that the direction of the inclination of hair bundles in the paired lateral canals is opposite. The information that will be sent to the ocular muscles depends on the inclination of the hair bundles. The contraction or relaxation of the muscles depends on the information obtained. Thus, for the turning of the eyeballs, it is necessary to obtain information from two paired lateral canals. This is the basis of paired control of the ocular muscles.

**II. VESTIBULAR FUNCTION MODEL**

Initially we developed a model of the cupula-endolymphatic system (Ec. 1), later we add the model of the mechanoreceptor vestibular hair cells. This model is represented in three compartments, in which they are described:

1. The dynamics of the total ion current and membrane potential of the hair cell (V1).
2. The synaptic current depends on the membrane potential of V1.
3. The dynamics of the sodium and potassium currents that lead to the synthesis of the limiting cycle and the appearance of the auto-oscillations (pulses) in the primary afferent neuron (V2).

**All functional parameters of the model were obtained from data of the experiments carried out in the laboratory of Sensory Physiology of the Institute of Physiology of BUAP (México).**

**Fig. 3. Vestibular mechanoreceptor model (1-9).**

All functional parameters of the model were obtained from data of the experiments carried out in the laboratory of Sensory Physiology of the Institute of Physiology of BUAP \(^{4,5}\).

From the model, it is observed that the output signals to the muscles of the eyeball are identical in the absence of stimulus, with background pulsation of a frequency of approximately 60 Hz (Figure 4).

Let us now consider the situation concerning the turning of the eyeballs 20 degrees to the left, when the vestibule-ocular reflex appears. Initially turning of the eyeballs makes it possible to examine the visual target. Then, due to physical limitation of the eyeball movements, the turning of the head helps to stabilize the gaze on its desired object. Then the eyeballs turn to the right as a result of the information supplied from the left semicircular canal to better stabilize the gaze.
In figure 5 we present the kinematics of the short stimulus that corresponds to the turning of the eyeballs to 20 degrees in 1 second. In the figure, it is possible to observe that the displacement of the top hair bundle and a change in the membrane potential of the sensory cell of the left lateral canal repeat the change in the angular velocity of the turning of the head. In the case of the right lateral canal, it is the reverse picture.

As a result of the action of the stimulus, the frequency of the spikes which go from the left semicircular canal increases. These spikes finally lead to the contraction of the right muscle of the eye; and the frequency of the spikes, which go from the right semicircular canal decreases which leads to the necessary relaxation of the left muscle of the eye.

Thus, it is shown that with the short stimuli the biosensor of angular acceleration, which includes the paired lateral canals, gives information about angular velocity which is necessary for the gaze stabilization, see figure 6.

III. AUTOMATIC CORRECTOR

The composition of the automatic corrector for the stabilization of the gaze is determined on the bases of the obtained results (see figure 7):

1. Imitator of the vestibular function:
   a) MEMS.
   b) Computer model of the biosensor.
2. Electronic device for the generation of the spikes.

Automatic correctors can also be used on the Earth:

a) for the stabilization of the gaze during control of an automobile on the road.

b) in the form of the vestibular prosthesis for the stabilization of the vertical pose of elderly people and patients with dysfunctions of the vestibular system.
Fig. 7. Automatic corrector schema.

IV. REFERENCES


