Gyroscopic Unit as a Safety Module of the System for Verticalization and Aiding the Motion for Individuals Suffering from Paralysis of the Lower Limbs

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Abstract

The subject of this work was to device and design a safety module compatible with the verticalization and motion aiding system. The main idea of the work was a general approach, with no redundant assumptions and limitations in order to achieve the most innovative solution possible. The first step was the implementation of risk management methods which, in consequence, gave a set of undesirable events with their numerical risk factors. After one of them was chosen as a basic function, methods of its realization were devised. Gyroscopic module has used to realization of the safety system. Two of them were chosen to be further tested on mathematical models. In the end a construction and its three-dimensional model were designed, simulations and calculations were made too.

Keywords: orthotic robots, exoskeletons, motion aiding systems

1. Introduction

The paper describes one of solutions of a safety mechanism for the System for Verticalization and Aiding the Motion (referred to as the system or SVAM later in the text; Fig. 1b) that has been developed at the Faculty of Mechatronics, Warsaw University of Technology [Jasińska-Choromańska D. et al. 2013].

Fig. 1.a) eLEGS exoskeleton [www.desigboom.com/cms/images/erica/], b) System for Verticalization and Aiding the Motion (SVAM) [Wierciak J., et al., 2012].
Works on the system are of an interdisciplinary character, including risk analysis, problems related to biomechanics and control; they are very important just now in order to simplify and facilitate life of the disabled. In the last years, there have been developed innovative orthotic solutions, of which a complete system of an eLEGS orthotic robot is presented in Fig. 1a.

2. Functional diagram of the safety module

Operation of the safety module is based on two algorithms: operation and preparation. The algorithms are presented in functional diagrams (Fig.2 and Fig.3).

![Operational Algorithm of the Safety Module of SVAM](image)

**Fig. 2. Operational algorithm of the safety module of SVAM**

![Preparation Algorithm of the Safety Module of SVAM](image)

**Fig. 3. Preparation algorithm of the safety module of SVAM.**
Realization of the above algorithms and the main function is possible while applying a device equipped with the modules presented in the following block diagram (Fig. 4).

Fig.4 Functional diagram of the SVAM safety module.

The safety module is launched at the moment when it receives a signal from the control unit (1). It is a moment, when the aim of operation of the system is changed from realization of the accepted motion trajectories to protection of health and life of the user. Along with the signal signifying occurrence of a hazardous situation, all the necessary parameters are transmitted if need be.

While launching the safety module, it is supplied by the energy form the power supply (2). Because of an occasional character of operation – within long time intervals, yet very intensively, the energy must be supplied simply as a pulse, within a short time. Having supplied the necessary energy, the power supply may be inactive until the safety module is prepared to another launching – whether be it by a service inspection, changing of replaceable parts or hardware reset.

According to the relevant assumptions, the SVAM system is adjustable to individual traits of the user (weight, height, etc.). Therefore, it is foreseen to enable adaptation of reaction of the safety module to analogical traits by mechanical or software adjustment. At the diagram, this function is defined as the parameters modification unit (3).

Mechatronic character of the safety module implies that it should include measurement units (4). Such units are necessary, first of all, in order to check effectiveness of operation of the mechanism, or to realize its control (if required). A peculiar measurement unit, distinguished at the diagram, is the unit monitoring the availability (5), which is required because of the fact that the safety module is to operate reliably at moments that are impossible to predict, what demands its constant availability.

While working on the SVAM project, few methods of realizing the safety function were analyzed; the gyroscopic system described below was chosen, as one of the possible solutions.
3. Block and kinematic diagrams of the safety module

The described solution is shown in a form of block diagram in Fig. 5 as well as kinematic diagram in Fig. 6.

At the moment when SVAM is activated by the high-speed motor (5), the inertial mass (4) is accelerated to a preset speed of gyration. At the moment when a hazardous situation occurs, this unit, supported in the frame (6), is turned by the motor (7) in direction determined by the supply voltage (2) absorbed from the battery (3) and set by a pulse control (1). Turn of the frame (6) generates a gyrostatic moment acting upon the system and the user (8), and through the mechanical structure also on the ground (9). The angular velocity of the control motor (7) is monitored by the sensors (10) in real time; the motor operates in a feedback used by the control (1).
Fig. 6 Kinematic diagram: (a) and 3D model, (b) of the solution to be realized.

4. Results of modeling

Results of modeling are presented in a form of the time graphs presented below.

![Output Torque Graph](image)

Fig. 7 Functional dependence of the output torque on time.

The output torque is lower than it was assumed (i.e. of ca. 240 Nm), however such value has been obtained as an optimal combination of the overall
dimension and the mass, as well as rotation speed and time of operation of the device. In case further studies should indicate a necessity of increasing the acting torque, it will be possible to apply two identical safety modules or to introduce a slight design change (e.g. another inertial mass).

\[ \text{Fig. 8 Functional dependence of the voltage on time.} \]

The graphs were generated while simulating a two-stage control: for angles \( \alpha < 0^\circ \) the control voltage is \( U = 24 \text{V} \), and for \( \alpha > 0^\circ \): \( U = -24 \text{V} \).

\[ \text{Fig. 9 Functional dependence of the angular velocity on time.} \]

Because of the applied control, the inertial mass moves approximately within the angular range of \( <-90^\circ, 90^\circ> \). Having performed one half-turn, in order
to apply another torque pulse, the rotation direction must be changed so that appropriate sense of operation is maintained.

5. Strength simulation of the structural members

Strength simulation of the mechanism was carried out using the Finite Element Method (FEM), with the Autodesk Inventor software employed.

The results prove that the minimal ratio of the internal stresses of the material to the ultimate strength is of 1.29, and it takes place at the edge, where the retainer of the ball bearing contacts the side plate.

Fig. 10. Graphical illustration of simulation results using the Finite Element Method.

6. Conclusions

Designing a safety module for a device of a type of SVAM is a demanding task. First of all, we were required to carry out a broad analysis of the risk, to choose appropriate nomenclature [Szopa T. 2009] and to elaborate a methodology of designing. Most of the possibilities resulting from the initial analysis turned out to be ineffective, hazardous or impossible to be realized. The designed module is a prototype version and therefore it still requires realizing studies, analyses of operation results and modifications, dependently on the obtained outcomes. However, it is a promising solution and potentially it may be a useful enhancement
of SVAM, which reduces the risk of a damage to user’s health and increases his feeling of safety.

References


