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AN APPROACH TO AUTOMATING THE MOVEMENT MODE CHANGE OF A REHABILITATION EXOSKELETON, DEPENDING ON EXTERNAL CONDITIONS

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Abstract

The main application of exoskeleton robots in the modern world is focused on the services of medicine, industry, and military applications. A particularly important application is the rehabilitation and improvement of the quality of life for patients with central nervous system damage and spinal cord injuries. In this paper, we propose an approach to automating the movement mode change of a rehabilitation exoskeleton, depending on external conditions. The exoskeleton's movement are modelled in a simulated environment based on the robot operating system (ROS) using external sensors.

Keywords: Exoskeleton; Simulation; Robot Operating System (ROS); Rehabilitation; Automation

1. Introduction

Gait disturbance is one of the main factors that determine the quality of life and the development of possible complications in patients with acute cerebrovascular accidents, patients with the consequences of a craniocerebral or spinal injury, multiple sclerosis, and degenerative diseases of the central nervous system (parkinsonism) with total hip arthroplasty and cerebral palsy. Gait disturbance is caused by disturbances in spatial movements in each joint, both in the sagittal and the frontal and horizontal planes, which leads to the formation of pathological synergy. For example, cerebral palsy is a common cause of childhood neurological disability. Although cerebral palsy is characterized by disorders - not only of motor, but also of perceptual, speech, and often cognitive functions- but it is the pathology of voluntary motor skills which is the main cause of social maladaptation, limitation of life activity, and integration of patients into society [1]. Modern methods for correcting motor disorders in cerebral palsy are aimed at functional neuroplastic reorganization of the structures of the motor analyser, when the nervous system is restructured and adapted, which is based on the formation of new changes in existing neural connections [2], [3]. The researchers note that neuroplasticity can be stimulated by creating a variety of environments, as well as by creating innovative equipment, the action of which is aimed at performing the required movements and increasing the patient's attention to ongoing rehabilitation activities aimed at learning or restoring walking skills.

Till now, the most advanced direction of motor rehabilitation is rehabilitation using robotic devices or complexes with visual feedback from sensors of the lower and upper extremities. Such devices allow you to train the functions of the upper and lower extremities, involving almost all the muscles of the body, and, as a result, activate the cognitive functions of controlling your own body when moving in space.

The advantage of robotic therapy is a higher quality of training compared to classical therapeutic gymnastics due to: their longer duration, the accuracy of repeatedly repeated cyclic movements that implement a real walking pattern with the ability to reproduce the reaction forces of the support under the patient's feet during walking, which excite and send to the cerebral cortex afferent signals, as well as the creation of a training program designed for the individual characteristics of the patient. It should be especially noted that the existing and newly created tools for assessing the success and effectiveness of ongoing rehabilitation measures, when a comparative analysis of the clinical and biomechanical parameters of walking in dynamics in patients at various stages of rehabilitation or diagnosis, makes it possible to create an evidence base for the use of robotic equipment and substantiate the protocol for its use. Such a toolkit makes it possible to operate not only with qualitative but also with objective quantitative data obtained by instrumental methods without elements of subjectivity. Also, the benefit of showing the patient the dynamics of his achievements cannot be ruled out. The parameters obtained with the help of such instrumental methods, which characterize the dynamics of the rehabilitation process, will allow the creation of an evidence base for the effectiveness and safety of the used equipment and methods (protocols) for its use in nosology. Medical exoskeletons for recovery, ~~or~~ walking assistance, support, or other purposes are becoming more common. An increasing number of studies are demonstrating efficacy and safety, as well as showing relevant results in the field of rehabilitation in nosology.

Exoskeletons typically perform pre-programmed movements triggered by switches or sensors. Users (hereinafter referred to as Pilots) can exercise only limited control over their leg trajectory and walking speed to avoid obstacles. In this work, we will use ROS robot operating system [4], [5], [6], [7] and the Gazebo simulator to build a model of an exoskeleton for the rehabilitation of the lower extremities, which moves and interacts with objects similar to a "smart home", depending on the data of an external information device. The purpose of the proposed system is to replace the standard manual movement control by the pilot, who usually uses the buttons on the handles of the exoskeleton for this, with an automated exoskeleton movement mode for typical movements.

2. Relevance of automating the movement mode change

The relevance and practical usefulness of automating the movement mode change of a rehabilitation exoskeleton of the considered type are determined by three main factors:

- Improving the efficiency and reliability of the use of the exoskeleton of the lower extremities
- Improvement of the pilot's psychological state in the process of movement during rehabilitation
- Economic expediency.

In the case of conventional manual control, the pilot must maintain balance and is forced to stop movement to change the movement mode. To do this, he has to use a set of buttons on the handles of the exoskeleton or a special watch that is connected using a Bluetooth. This option is inconvenient, especially when the pilot must change modes of motion to avoid obstacles. Automated motion mode change makes these movements faster and more reliable.

As a result, it improves the psychological state of the pilot when using the exoskeleton. Some people feel embarrassed when they stop and cannot move, but with the help of an automated system, they feel more confident.

A pilot can rent an exoskeleton for a fixed period instead of buying the device or only using it in the hospital, he can rent it and use it at home. And by automating the change of the mode of movement of the exoskeleton inside the house, the pilot will increase the active time of its use, which will make the rehabilitation process more efficient and, as a result, save money and time.

3. Building a model of the rehabilitation exoskeleton

First, we will design an exoskeleton model by defining the necessary joints and links (the main components of the robot model), as well as a "smart home" model containing obstacles [8]. Then we install an external information device into the model – a special type of LiDAR sensor (HOKUYO) [9].

To control the movement of the hinges, a control program (a special "node" [10]) was written in the Python programming language [11] to represent 5 typical modes of movement of the rehabilitation exoskeleton of the lower extremities [12]:

- Straight movement
- Transition to a sitting position
- Transition to a standing position
- Climbing stairs

- Descending stairs

Based on the LiDAR sensor signal, the exoskeleton can determine the type of the next obstacle and determine the necessary movement mode to bypass this obstacle.
The simulation contains a model of an exoskeleton in the form of a mobile robot that interacts with the virtual world (Figure 1).

To design a model, an XML file (.xacro) must be defined that represents the shape and components of the model, the obstacle house, and the LiDAR sensor.

A model of any robot featured in ROS and Gazebo, showing its links, the joints that connect those links, and the transmission that describes the relationship between the actuator and the link. The exoskeleton model (Figure 2) is built on 7 links, shown in Table 1 [13],[14], [15]:

№	Exoskeleton's	Label of link	Label of joint	Connection between	Type of joint
1	Waist	waist_link	RU_joint	1 and 2	rotary
2	Right thigh	RU_link	LU_joint	1 and 3	rotary
3	Left thigh	LU_link	RD_joint	2 and 4	rotary
4	Right leg	RD_link	LD_joint	3 and 5	rotary
5	Left leg	LD_link	RF_joint	4 and 6	fixed
6	Right foot	RF_link	LF_joint	5 and 7	fixed
7	Left foot	LF_link	UP_joint	-	prismatic

Table 1. The exoskeleton model joints, links and connections

In addition, there are virtual links and hinges required for a plugin (libgazebo_ros_control) [16] provided by Gazebo that gives the model the ability to move along the X-axis and Y-axis in linear and angular directions. We can control the model movement in these directions using the computer keyboard.

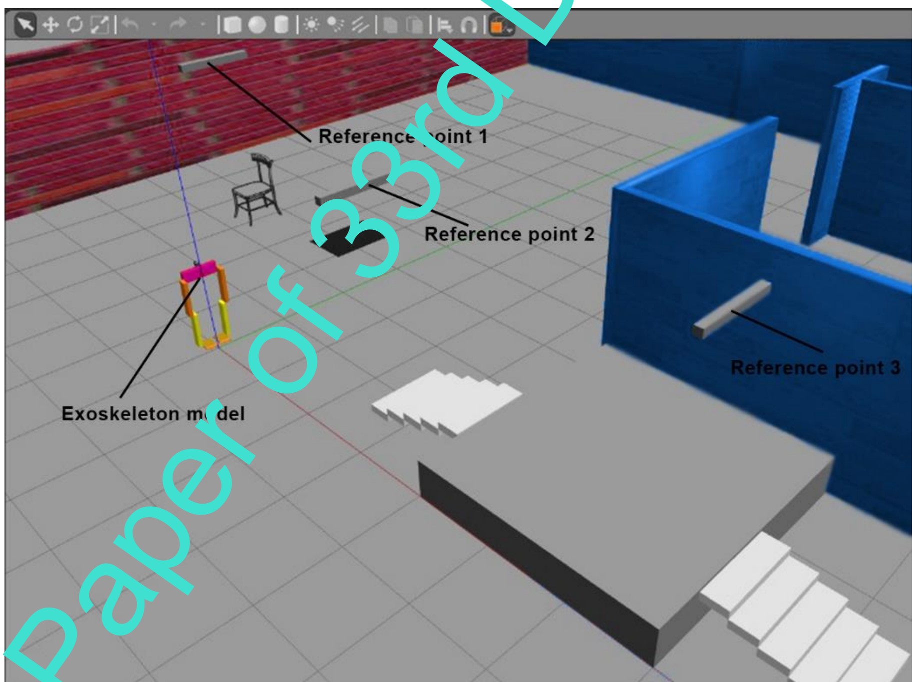

Fig. 1. The exoskeleton model interacts with the constructed world

Since the pilot will move in a specific room [17], the reference points have also been added over all the obstacles that the pilot needs to overcome and move. For example, we added the reference point 1 above the chair where the pilot will sit in the exoskeleton, the reference point 2 above the starting point of stair climbing, and the reference point 3 above the starting point of stair descent. As shown in Figure 1, the distance between the reference point and the sensor differs from one obstacle to others.

Based on the sensor signal that determines the distance between the exoskeleton and an obstacle, it is possible to determine the type of obstacle that the pilot will encounter and the appropriate exoskeleton movement system. The place or room in which the pilot with the exoskeleton will walk is equipped with these obstacles with appropriate reference points, which are installed in the ceiling of the room at a given height.

As for the used sensor, is a LiDAR (HOKUYO) sensor, which is used to detect the obstacles and determine the distance between the sensor and the obstacle using a laser beam. The sensor is directed in the direction of the Z-axis (the reference points used to calculate the distance between it and the sensor are located directly above the exoskeleton). Typically, the detection range of LiDAR (HOKUYO) is 180 degrees, but in the model, the required detection process occurs only horizontally and directly above the model. Therefore, we only need one laser beam from the sensor to read the distance between the sensor and the reference point (all sensor parameters can be edited through the LiDAR file plugin (HOKUYO).

This type of sensor was chosen because of its ease of use and handling in the working environment of ROS and Gazebo, on the other hand, it withstands shock and vibration, which is important since the designed model is a moving object [14].

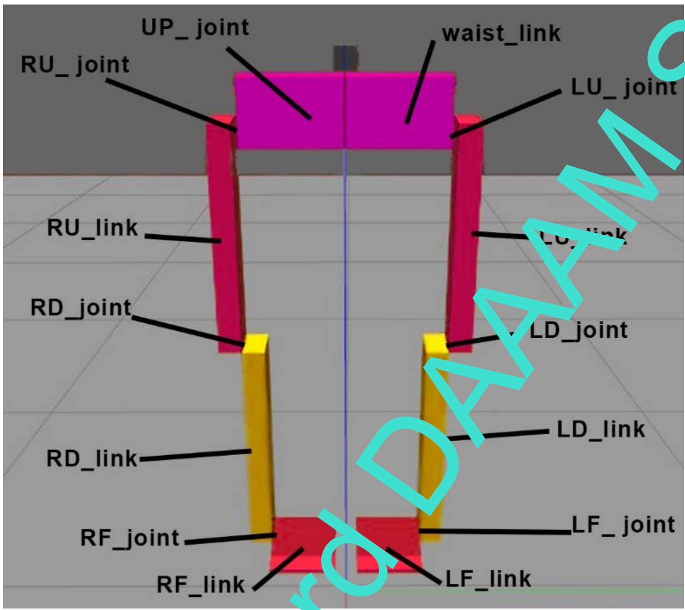

Fig. 2. Joints and links of the model of the rehabilitation exoskeleton

4. Approach to the control of the exoskeleton model

After building a model using an XML file, we can define a Python (.py) file [18] and write an algorithm for managing the model and interacting with surrounding objects.

To control any joint, we must apply the necessary force to the transmission. There are 4 transmissions [13], one transmission for each movable joint:

- tran_RU to control the RU_joint;
- tran_LU to control the LU_joint;
- tran_RD to control the RD_joint;
- tran_LD to control the LD_joint.

As we said earlier, the modelled exoskeleton has 5 movement modes and based on the sensor signal, LiDAR determines the type of the next obstacle and the required mode to overcome this obstacle. Depending on the signal from the LiDAR, we can send a certain amount of force to each joint at every moment to simulate the required movement to overcome a certain obstacle.

For example, after starting the ROS environment and calling the package that contains all the files needed to run the designed model, the movement of the model can be controlled.

When the model passes under the reference point 2, the LiDAR sensor detects this reference point and calculates the distance between the model and the reference point 2. Accordingly, the type of obstacle that the pilot will encounter is determined (in this case, it is "climbing stairs").

In addition to the corresponding mode of movement of the exoskeleton, the amplitude of this movement is calculated, which must be transmitted to each joint in accordance with the size of the obstacle to be overcome.

5. Conclusion

This study presented an approach to automate the rehabilitation exoskeleton motion mode change using an external LiDAR sensor. The model was defined by an XML script and implemented in the Gazebo environment. The required trajectories for each joint are determined depending on the sensor signal and a certain obstacle that the model must bypass. In addition, the Gazebo simulation is useful for visualizing the movement of a prototype exoskeleton. In conclusion, our new model, modelled in Gazebo, is suitable for building a gait training device. The main goal of engineering in general and robotics in particular is to help humans perform certain tasks with less time and effort, and by automate the movement mode change of the rehabilitation exoskeleton for lower extremities, the pilot's mental and psychological state of the will improve due to the confidence that he will gain by using the simulated model. Moreover, the time of the rehabilitation sessions will be more efficient, since the period of time needed by the pilot to change the movement mode of the exoskeleton will be zero. In the future we can improve the sensing system of the model to overcome other obstacles

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