Synthesis of an Automatic Obstacle overcoming Control Module, dedicated for Manual Wheelchairs

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Abstract: This article presents the concept of an automatic overcome obstacle control module, dedicated to a wheelchair for everyday use. The module consists of a mechanical system which has front and rear lift mechanisms for the wheelchair and drive that performs displacement while the main wheels of the wheelchair are raised. We also discusses the electronics and particularly the control system with all necessary sensors. Two algorithms are proposed to overcome obstacles. The prototype module has been built and tested under laboratory conditions. The paper also presents the results of experiments involving overcoming obstacles with manual control and in automatic mode.

Keywords: wheelchair; overcoming obstacles; automation

1 Introduction

One of the many transport problems with which people with disabilities have to struggle, are architectural barriers. The most common obstacles that people in wheelchairs can meet on their way are thresholds, curbs and stairs. In many cases, the environment is friendly for people with disabilities – sidewalks and walkways are built with ramps or lowered curbs, buildings have elevators, doors are automatically opened [1, 2]. Currently, facilities for the disabled are required by law, but there are still many obstacles present.

The design of a mobility enhancement wheelchair systems are often taken into account at research centers. In the current articles, solutions that allow easier usage and mobility in a wheelchair are presented [3]. Some solutions are based on devices supporting the control of a wheelchair [4], others focus on avoiding, overcoming obstacles, including stairs [5, 6]. An example of a device that facilitates control, especially for people with upper limb dysfunction, is the application of head or chin controls as alternatives to a joystick [7]. In this type of solution, the motors of an electric powered wheelchair are activated by chin or head movements [8]. Sip-and-Puff devices are another solution [9]. In this case, the wheelchair is controlled by air pressure via dedicated mouthpiece, placed on the frame near the mouth. These types of devices are dedicated for people with upper limb paresis.

A very important element in moving, in a wheelchair, is overcoming obstacles like curbs, thresholds or stairs, in cases where they cannot be avoided. To overcome this type of obstacle, the wheelchair must be equipped with special climbing mechanisms [10]. Devices having such features are practically mobile robots [12, 13] equipped with complex sensory systems, including level stabilization algorithms [14, 15].

An undoubted drawback of complicated devices is their high cost, which translates into their availability. Therefore, researchers are looking for less complex solutions, that have the function of overcoming obstacles. The presented module is such a solution. To deal with selected obstacles, one only need equip the wheelchair with a simple mechatronic system [11].

This article presents the concept of an automatic obstacle control module, dedicated to a wheelchair for everyday use. The module consists of a mechanical system which is built into the front and rear lift mechanisms of the wheelchair and function, sensing displacement, when main wheels of the wheelchair are raised. We also present the electronics, in particular, the control system, with the necessary sensors and control algorithms. Additionally, the device automatically executes the process of overcoming obstacles, without significant user involvement.

2 The Overcoming Obstacles Module

The module for overcoming obstacles, for manual wheelchairs, has been developed on the basis of the module for overcoming obstacles with a manual control system [10]. Kinematic structures of the device has been developed using conventional and author developed methods of synthesis [16]. In comparison to the previous lifting system, minor modifications were made to improve the system, the size of the wheels has been changed, rear-wheel drive has been modified and all motors have been equipped with sensors.

The general concept, necessary components and the wheelchair with lifts mechanisms is shown in Fig. 1. Two identical linear actuators (M1 and M2) are used for lifting. The rear wheel lift system is equipped with an additional motor (M3) to ensure the wheelchair moves when the main wheels are raised. The maximum lifting height of the wheelchair can be adjusted by selecting the actuator stroke (M1, M2) and the attachment points (B and E) of the lifting mechanism to the wheelchair. The development of the electronic modules, including the selection of sensors (Front-S1, Rear-S2), control modules and implementation of algorithms has been designed and constructed for the purpose of described system of automation of overcoming obstacles process.

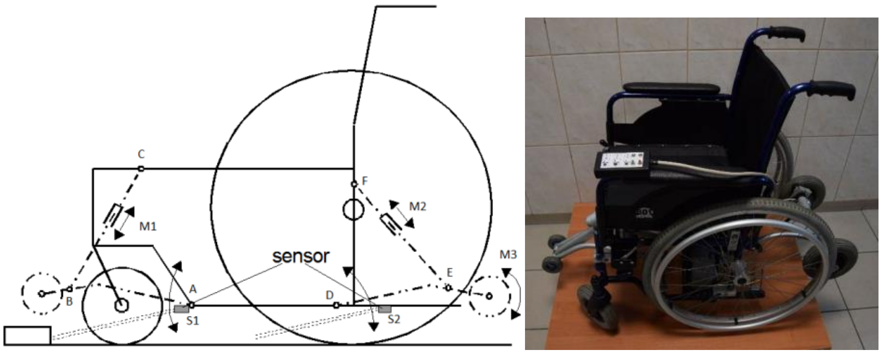

Figure 1

Kinematic scheme of the lifting system and overview of the mechatronic wheelchair

Operation of the system requires minimal user participation at initiation of the process and then the rest of the process is done automatically. The developed device, along with the obstacles algorithm, has been implemented and verified experimentally.

1.1 The Control System Unit

The Central Processing Unit of the control system is a RBC-4242 [17] module with STMF103 microcontroller with an ARM Cortex M3 core. The User Control Panel is connected to the general purpose digital inputs, where the change of the voltage sets the control value of drives individually and is used to select the automatic mode.

Distance measurement is carried out with the IR sensors, whose output is connected to a block of analog-to-digital converter (ADC) of the microcontroller. Motor movement is realized through motor controllers RbMD vnh3sp30-DUAL, built with integrated H bridges, with which drives are connected. Control is performed by giving the input motor driver a PWM signal and two digital signals defining the direction. The distance sensors are placed in the front and rear of the truck. A front sensor determines the height of rise of the front of the chair and is set in an appropriate orientation to detect the edge of the threshold, during the lift process. The rear sensor is directed downward in the vertical axis. It is used to measure the distance from the ground and the detection of the passage over the threshold. In addition, rotary incremental encoders are mounted into drives, which provide information about their movement. As a result, the control module is able to determine the absolute position and motor velocity. The block structure of the control system is shown in Fig. 2.

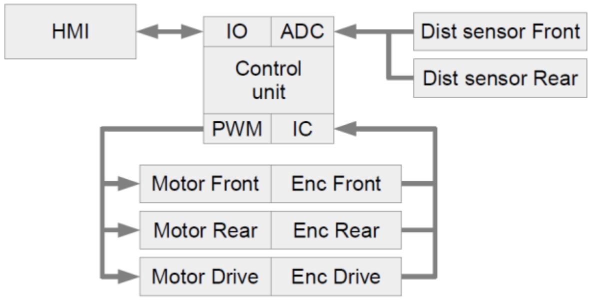

Figure 2
Block diagram of control system

The device can operate in three modes: manual, automatic time and automatic sensory (distance). In all these modes, the process of overcoming obstacles occurs in a very similar way. First, it is necessarily to drive the wheelchair to the obstacles ahead, so that the front wheels were not more than 4 cm from the obstacle.

In manual mode, the user through the control panel shown in Fig. 3, is capable of independently control each of the drives.

Figure 3
Control panel

There are three toggle switches for this purpose that triggers the individual drives in the order: moving the front lift, rotation of the rear wheels, moving the rear lift. The switches are three-position momentary type. Switching one of them forward, results in extension of the actuator (forward rotation of the wheels) and switching back, results in shortening of the actuator (backward rotation of the wheels). With the appropriate control signals, the user can, while sitting in a wheelchair, overcome an obstacle by themself.

1.2 Algorithms of Control

Auto modes allow overcoming an obstacle with minimal involvement of the user, in the form of initiating the whole process by pressing a button, when the wheelchair is in front of an obstacle. The only thing the user need do is, drive the wheelchair to the obstacles so that the front wheels touch the obstacle, then press the automatic mode button. Depending on whether the button is pressed once or twice, different algorithm will run.

1.2.1 The "Time" Control Algorithm

Pressing once starts the time control mode. During operation of this algorithm (block diagram shown in Fig. 4) each drive is operated for a specified length of time.

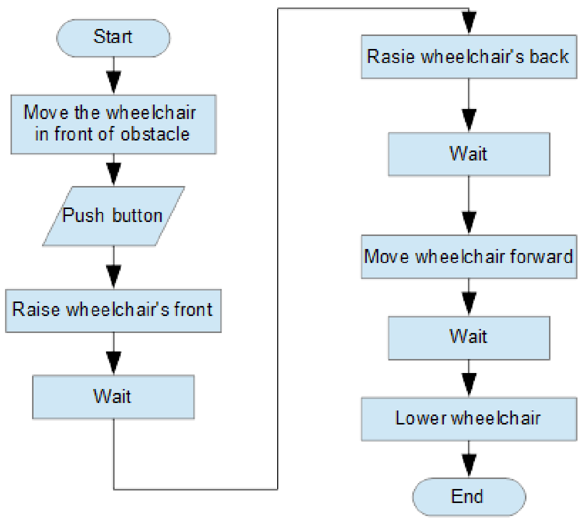

Figure 4
Block diagram of time control algorithm

The time constants are selected so that the wheelchair can overcome the highest possible threshold. The maximum height of the threshold is determined by the geometry of the mechanical system. At the beginning, the front lift is lowered (Fig. 5) so that the front wheels of wheelchair rise over the threshold (Fig. 6). Then the rear lift is lowered so that the large wheels of wheelchair rise above the obstacle (Fig. 7). Next the drive of the wheels attached at the end of the rear lift starts to rotate them. The wheelchair moves forward until the big wheels of wheelchair will go beyond the threshold (Fig. 8). At the end, front and rear lifts rise to the initial positions and the wheelchair is ready to proceed (Fig. 9).

Figure 5

Wheelchair during overcoming threshold, phase 1. lowering front support

Figure 6

Wheelchair during overcoming threshold, phase 2. raise front of the wheelchair

Figure 7

Wheelchair during overcoming threshold, phase 3. raise rear of the wheelchair

Figure 8
Wheelchair during overcoming threshold, phase 4. moving wheelchair over threshold

Figure 9
Wheelchair during overcoming threshold, phase 5. The return of supports to their initial positions

1.2.2 The "Distance" Control Algorithm

Pressing the button twice starts the last run mode of operation, which is based on the use of signals from the optical distance sensors (block diagram shown in Fig. 10). Observing the wheelchair from the outside, the process looks analogous to the previous mode. The movement is made up of the same phases but the start and stop phase conditions, are different, due to the active sensors.

To start, the front lift is lowered until the front distance sensor indicates equal or higher reading than a preset value. The setting of this sensor is, such as to be able, to measure the distance to the front wall of threshold. This value changes slightly while lifting the front of the wheelchair until the distance from the threshold is measured. At this time, the measure line of the sensor is above the edge of the threshold, the indicated value begins to increase rapidly. This is the signal to stop the lowering of the front lift. Then the rear part of the wheelchair rises by lowering the rear lift. The actuator operates as long as the rear sensor indicates a sufficient distance from the ground. Next, the drive of the wheels on the rear lift begins to operate and the wheelchair begins to move forward.

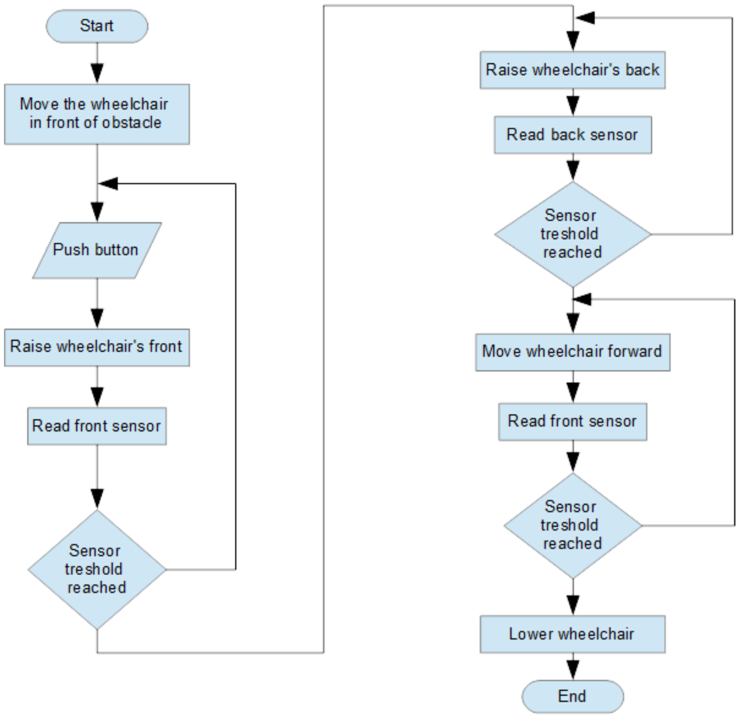

Figure 10
Block diagram of distance sensors control algorithm

This phase is performed as long as the controller registers a rapid decrease in the value measured by the rear sensor, which means exceeding the threshold edge. The vehicle stops, front and rear lifts are lifted to the initial positions. The wheelchair is then ready for further operations.

3 Experiments and Results

Experiments were performed under laboratory conditions. For this purpose a platform with a sill height of 10 cm has been constructed, which is shown in Fig. 5. The position was evenly lit by fluorescent lighting. The task of the wheelchair was to drive onto the platform while overcoming the threshold. All three modes for overcoming obstacles were tested: manual control, automatic time control and automatic, using optical distance sensors.

In manual mode, all of the movements of the mechanism were initiated and completed by the operator. The ergonomics of the control panel are adapted for mounting to one of the armrests and allows control with one hand. Therefore, during tests, the panel was operated with one hand and each drive was handled individually. In this mode, periods of time for individual movements of the drives were very different during subsequent attempts. This was due to manual control, in which the operator was starting and stopping the actuators in the moments that subjectively considered appropriate. Fig. 11 shows the characteristics of the positions of individual drives, for the sequence of movements, so that the wheelchair could overcome obstacles, in the shortest time for manual mode.

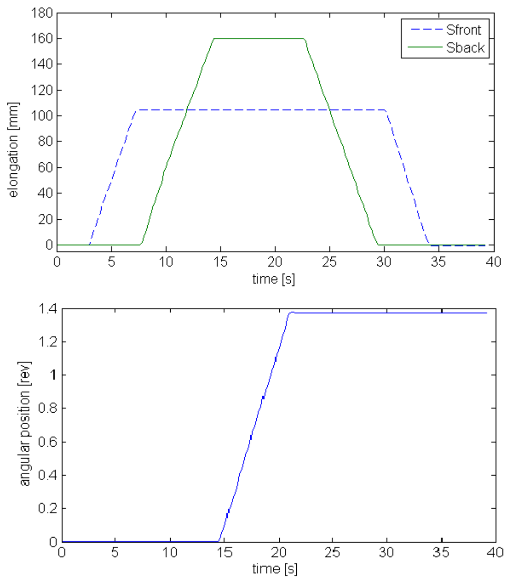

Figure 11

Displacement characteristics of overcoming obstacles module drives in manual mode

In the next tested mode, individual movements of the drives were programmed to have constant period of time operation. In order to overcome steps of varying sizes, the mechanism must be programmed for the greatest possible obstacle, because it does not use any information about the object being negotiated. Therefore, the main advantage of this mode is that it requires no sensors. The characteristics are shown in Fig. 12. The advantages of this solution are a simple construction and a low cost as well as, fewer components and wires that can be damaged. The disadvantage of this solution is the duration of the process, which is adapted to the greatest obstacles.

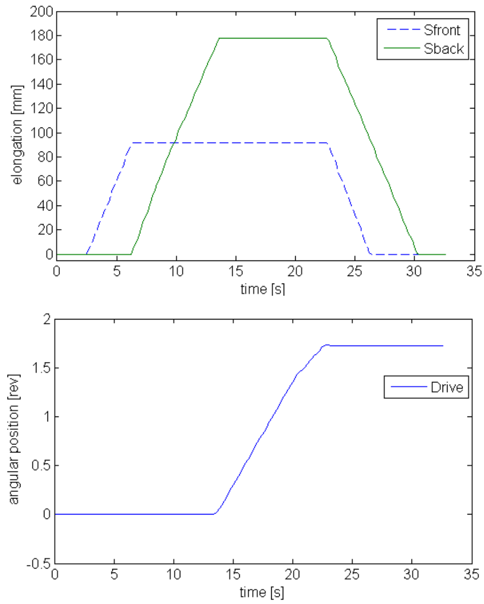

Figure 12

Displacement characteristics of overcoming obstacles module drives in automatic time control mode

Overcoming a small threshold takes as much time as for the greatest obstacle. A further disadvantage of this method is, that it has constant preset value for moving each of the drive, but for proper realization of the task actuators has to operate for a different period of time, which is dependent on the actual load. As a result, this translates into different lengths of extension actuators or rotation of the wheels. Therefore, parameters of this automatic mode must be preset for each user individually.

The characteristics of the last tested algorithm, which is the automatic mode using optical distance sensors, are shown in Fig. 13. In this mode, the system detects a threshold height and adapts the duration of drive operation time, which is the equivalent of the actuator length, so as not to perform unnecessary motions. Furthermore, the second sensor detects movement when the wheelchair large wheels are passing over the threshold and stops the vehicle at the right time. The disadvantage of this solution is the greater cost of the device. Moreover, cheaper sensors are more susceptible to external noise such as fluorescent lamps in the room or the sun's rays in an open space. The biggest problem with this arrangement is the selection of appropriate sensors that can operate under different conditions simultaneously.

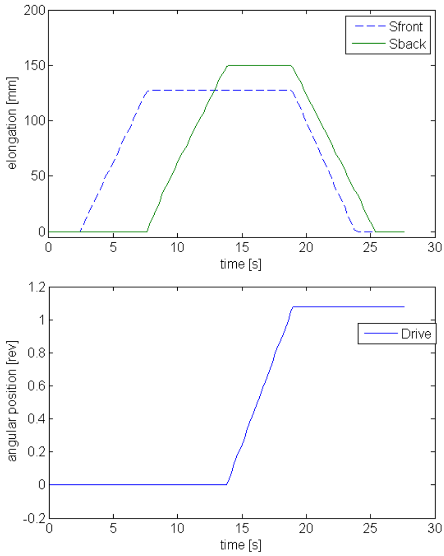

Figure 13
Displacement characteristics of overcoming obstacles module drives in automatic distance sensors control mode

This study shows that both modes of automatic control work correctly, in stable external conditions. A big impact on the quality of automatic control using sensors is the type of used measuring elements and the influence of external conditions. During the test of the automatic mode using the sensors, proper operation was affected by disruption, such as fluorescent lights and shadows cast by the wheelchair components, which cause erroneous distance measurements and stop the actuators at improper positions. Due to the fact that, when determining the displacement of the actuators, sensors data are used to get the information about current position relative to the obstacle, there are no unnecessary movements made, as it happens, in the time control mode. Therefore, in testing this mode, it has proven to be the fastest in overcoming obstacles. Automatic time mode, in addition to increased operating time, as compared to the previously described, is impaired by an error, that comes from the varying dimensions of obstacles and loads (weight of different users, carrying additional cargo). It consists in that the drive working under different loadings running at different speeds. When periods of operation time are set constant, the actuator performs various lengths. Sometimes, the process ended in an unsuccessful attempt to overcome the obstacles. Manual operation was the slowest because of the fact that there was an assumption that the panel has to be operated with one hand, resulting in one drive is driven at the same time. Despite these problems, there was no situation in which the operator of the wheelchair was exposed to a fall.

4 Summary

The automatic obstacle control module correctly realizes the task of overcoming thresholds during stable conditions. The tested algorithms are working correctly within the predicted conditions. Emerging errors were formerly anticipated. The device, during the test, ran in a stable fashion, it did not create any new bugs. Even during a malfunction, the wheelchair acted within the limits of safe use and did not tip, fall or experience any major shocks.

The mechanism now requires further testing under “real world” conditions. Both time control and the use of optical sensors, requires further improvements, algorithms modifications and possible changes of sensors. Furthermore, there were no tests done concerning the possibility of using these other sensors, including a variety of configurations that can be applied to the task of overcoming obstacles. Future studies will include the use of encoders mounted on the motors, in order to determine the instantaneous configuration of mechanisms to overcome thresholds and inertial sensors. They will be progressively tested in future work in order to find the optimal cost solution. Additionally, the platform will be developed for further improvements, such as an auto-leveling wheelchair seat while overcoming obstacles.

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