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Synthesis and evaluation of the smart electric powered wheelchair route stabilization concept – a simulation study

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The paper addresses the problem of algorithm synthesis for controlling the motion of an electric powered wheelchair. The aim of the algorithm is to stabilize the wheelchair following a linear path and avoiding obstacles if occurred on its way. The main restriction imposed on the project is the application of simple low-cost sensors. That implies the system to cope with a number of inaccuracies and uncertainties related to the measurements. The goal of this work is to evaluate the possibility of the wheelchair project with a navigation system which aids a disable person to move in a complex and dynamic areas. Exemplary simulations are presented in order to discuss the results obtained.

Key words: autonomous robots, robot navigation, sensory system, electric powered wheelchair, motion control

1. Introduction

Technological advances which can be observed nowadays provide an incentive for robotics development, particularly if one considers the robotics branch which deals with the design and construction of autonomous mobile vehicles. A range of possible applications of robotic mobile devices is very wide, taking military applications on one extreme and homestead applications on the other one. One of the field where robotics based technologies can be very helpful is medicine. It is enough to mention surgical robots, exoskeletons, walking gait re-education machines and many others. All these assistive technologies come from the robotic development experiences. Focusing on the robotics branch which concerns the design and construction of autonomous vehicles, there is a large filed of applications which can improve life quality of persons with mobility impairment. By designing and constructing the more and more technologically advanced, comfortable and agile wheelchairs robotics helps people at least partially regain their

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mobility. Nowadays it is common using by disabled people electric powered manually controlled wheelchairs (EPW) that offers quite new moving quality. Unfortunately, for the people with severe physical or mental disabilities such technological convenience turns out to be insufficient. For most of these patients operating conventional EPWs is a challenge [5]. Therefore there are a lot of researches on wheelchair capabilities improvement by introducing automatic navigation modes [2,6,7,9,10] and providing them with better human-machine control interfaces [1,3,11,14].

There are extensive works on using different communication channels for controlling the wheelchair movement like brain wave electric signals, voice commands, eye movement tracking and many others. However, it should be stressed that providing the wheelchair with autonomy is a very complex and hard to achieve goal. It is due to the critical robustness requirements imposed on such systems. Nevertheless, most of the works that one has been working on, are focused just on this issue [3]. This work deals with a similar problem, which is designing smart controller for a EPWs, and thereby is part of a smart wheelchairs research trend. Unlike in many other works, the aim of the control proposed is not providing the system with autonomous navigation, but stabilization of a rectilinear path of the vehicle. For the patients with severe movement impairments it is very difficult to accomplish relatively simple task which is keeping the wheelchair movement on a straight path. The issue is getting more complex in case of interacting with objects appearing and moving on the wheelchair path. The wheelchair equipped with the smart controller should keep the direction and velocity of movement set by the operator (a patient) as long as the new control command is not issued. If any object appears on the wheelchair path the navigation system should try to avoid them and if succeed, come back to the original path. The maneuvers, in order to satisfy the patient safety requirements [9], have to be smooth without any overshoots and oscillations. The smart controller, discussed in the paper, if properly designed can be a significant aid for disabled patients and improve their moving comfort.

However, the work presented is only a concept study pre-tested using simulation tools. In the end of this paper some relevant simulation experiments are presented to discuss the properties of the approach proposed.

2. Problem description

For the people with severe movement impairments (cerebral palsy, Parkinson's disease and many others) operating conventional EPW can be very difficult or sometimes even impossible to do. Driving conditions are significant factor during manual navigating EPW and may be the reason of accidents. The users of EPW must navigate precisely around obstacles, through corridors (often narrow), pass doorways and deal with moving objects (pedestrians). Generally, interactions with dynamic environment usually is a source of discomfort for the patients driving EPW [5]. In such external conditions even seemingly simple task which is driving straight forward can be the challenge. Moreover if the user suffers from upper limbs disabilities the problem can be simple manual operation of a joystick controller while trying to follow a chosen direction.

In this work the synthesis problem of the motion controller for the EPW is considered. The smart controller which uses sensory system for the environment detection is intended to aid the user of EPW traveling in chosen direction, by automatic continuing (at the user's request) the movement with the current speed and direction. Moreover the navigation system tries to avoid collisions with objects on the course of the EPW. Since the safety of the user has the highest priority, maneuvers should be safe and smooth, without any drive overshoots. In Fig. 1 the conceptual diagram of the control system is shown. The motion controller when re-enabled switches the navigation system into the manual mode again.

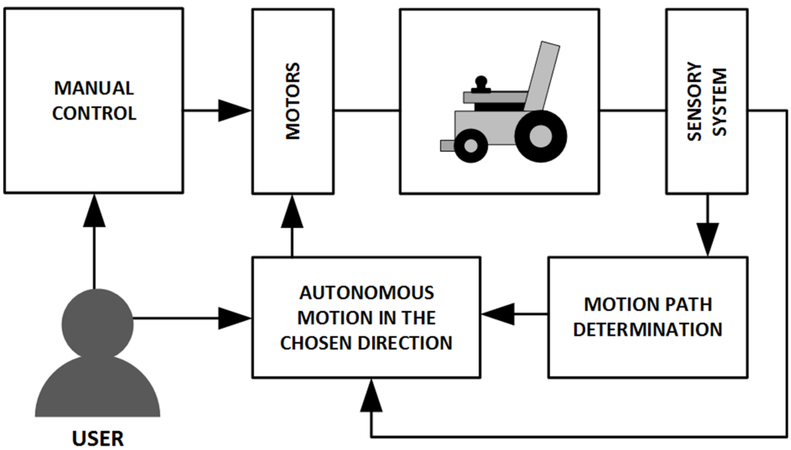

Figure 1: Conceptual diagram of the EPW navigation system.

3. System overview

3.1. The wheelchair model

Most EPW manufactured today base on a differential kinematic structure with two independently controlled drive wheels and passive support wheels [3,12]. Such solution has very good maneuvering properties and therefore is commonly used as a drive-base. In this study it is assumed a wheelchair model that consists of two driving rear wheels and two passive front wheels.

3.2. Sensory system

The EPW sensory system consists of two subsystems. The first one provides information concerning wheelchair motion parameters like velocity, acceleration, heading and so on. In the simulations performed it was assumed that both the wheelchair position and heading are known. The second subsystem gives information on the wheelchair surroundings, particularly it senses the proximity of objects located on the wheelchair course. This information is used further by the navigation system the aim of which is to keep the EPW on its course and avoiding collisions with any object.

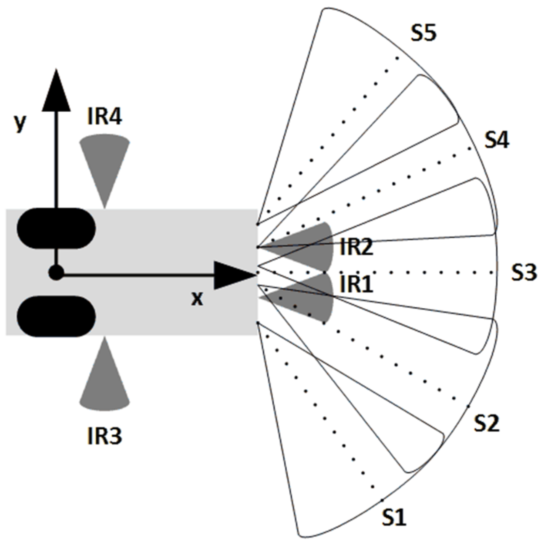

Figure 2: Sensors assembly layout. S1-S5 ultrasonic rangefinders, IR1-IR2 infrared proximity sensors.

In our study it is assumed the EPW model equipped with 4 short range, IR proximity sensors and 5 ultrasonic long range finders. IR sensors are assembled on the front of the wheelchair chassis (2 units) on the left and right side (1 unit per each side). Five ultrasonic sensors are located on the front of the EPW in such a way that they can sense objects in their range in angular field of view: -85 deg, +85 deg. The purpose of range finders is to provide the EPW navigation system with information about the free space available for navigation by detecting and measuring distance to the objects located on the path of EPW.

Information provided by low range IR sensors is used in case when EPW maneuvers in narrow spaces, and passes corridors and doorways. The features and functioning of the sensors [13] are modeled using simulation environment created for the purpose of this work. In the sensor models sound and electromagnetic wave reflection phenomena are taken into account as well as the energy absorption factor for different materials and textures. Thanks to that, simulated functioning of the sensors is very realistic.

4. Navigation concept

The fundamental assumption adopted in the navigation and control strategy is the safety of the patient moving with the EPW. Thus all the control commands as well as the motion paths determined by the navigation system have to be safe in terms of feasibility perceived by the patient. The control should avoid overshoots and the motion paths should be smooth in order not to stress the patient and not to make him uncomfortable during the ride. Such requirements are difficult to be satisfied. The automatic guided wheelchair should be controlled and navigated in the way similar to the human navigation behavior. Therefore there is a lot of research on human aware navigation [4,8]. In this work we applied navigation strategy based on polar histograms which reflect possible and collision free moving directions which are closest to the desired (set) travelling direction. The histograms are created using data provided by the external and internal sensory system. The final histogram used for determining the control strategy comes from a superposition of the two ones. The first one gives information about proximity of objects located in the operational area of the wheelchair and the second one indicates desired traveling direction with the threshold set for the feasible maneuvers.

4.1. Polar histograms

4.1.1. Range histogram

Particular sensors arranged around the wheelchair chassis provide the navigation system with information on proximity of objects in the given directions. Using this information a range histogram can be created. This form of sensory data representation is convenient for the navigation purpose. Range histogram determines directly the risk of collision during navigating in the given direction α. In this work the range histogram ψ_D is defined by following formula:

$$\psi_D(\alpha) = \sum_{i=1}^{N} w(\alpha, i) \frac{1}{(x(\alpha, i) - p)^2} \tag{1}$$

where x is a distance measured by ith sensor mapped on the direction α. The coefficient p serves as a tuning parameter for the histogram shape and its properties. The value of p is determined in an experimental way. The weighting factor w adjusts an influence of the ith sensor on the histogram value for the given direction α.

If the given sensor does not cover in its reading the direction α then the weighting factor is set to 0. In other case it takes the value from the range [0;1].

4.1.2. Desired motion direction histogram

Desired motion direction histogram (DMDH) is a form of navigation data representation used for determining the range of the motion directions desirable with respect to the task to be accomplished. The goal is keeping the chosen wheelchair motion direction. Therefore the DMDH indicates the direction (and hence the control) which guides the wheelchair to the primary motion path. The histogram argument equal to 0 refers to the current wheelchair heading. The peek value of the histogram indicates the desirable motion direction. In the case the wheelchair is on its path the histogram peek value coincides with the current heading. If the navigation system detects any object on the wheelchair course the collision avoiding procedure starts, this in turn causes the DMDH peek value moves along the argument axis indicating the direction that should be chosen in order to come back to the primary path. The span of the histogram is related to the constraints imposed on the maneuvers amplitude and hence the wheelchair motion safety.

4.1.3. Resultant histogram

The resultant angular histogram is the superposition of two basic information representation models: range histogram and DMDH. These models contain information necessary for navigation task accomplishment - motion directions free of collisions and the wheelchair heading necessary to follow the path set by the operator. The resultant histogram is created by substituting the range histogram ψ_D from the DMDH ψ_R:

$$\psi_W = \psi_R - \psi_D. \tag{2}$$

In order to determine instantaneous angular and linear velocities of the EPW the resultant histogram is used. The linear velocity value is calculated in a proportional way to the maximum of the resultant histogram. The angular velocity value is determined proportionally to the argument value (angle) for which the histogram reaches its maximum.

4.1.4. Return to the primary path

After detecting objects located on the EPW path the navigation system starts maneuvers to avoid the collision. This causes that EPW leaves the primary path set by the operator. If avoiding collision succeed the EPW returns to the primary path and continues its navigation goal accomplishment. This operation is done with the use of information provided by DMDH the peak of which is moved along the argument axis. The difference between the desired and current heading of the EPW is used for determining control that moves the EPW back on the primary path.

5. Simulation studies

The idea of the EPW control outlined in the previous sections was verified by simulations. To do this simulation environment was developed. The software enables creating 2D environment in which the properties of real objects are imitated such as reflection coefficients of the materials objects are taken into account. Moreover the realistic 2D functioning of the sensors was modeled. Thanks to that it is possible simulating the wheelchair navigation behavior with good fidelity. The behavior of the navigation system was tested using various simulated scenarios both in a static and dynamic environment. Reactions of the automatic route stabilization system in typical environmental configurations were checked. During simulation experiments the histogram parameters were tuned in order to obtain feasible behavior of the EPW. In the next part of this section a few relevant simulation examples are presented and discussed to show the properties of the proposed approach.

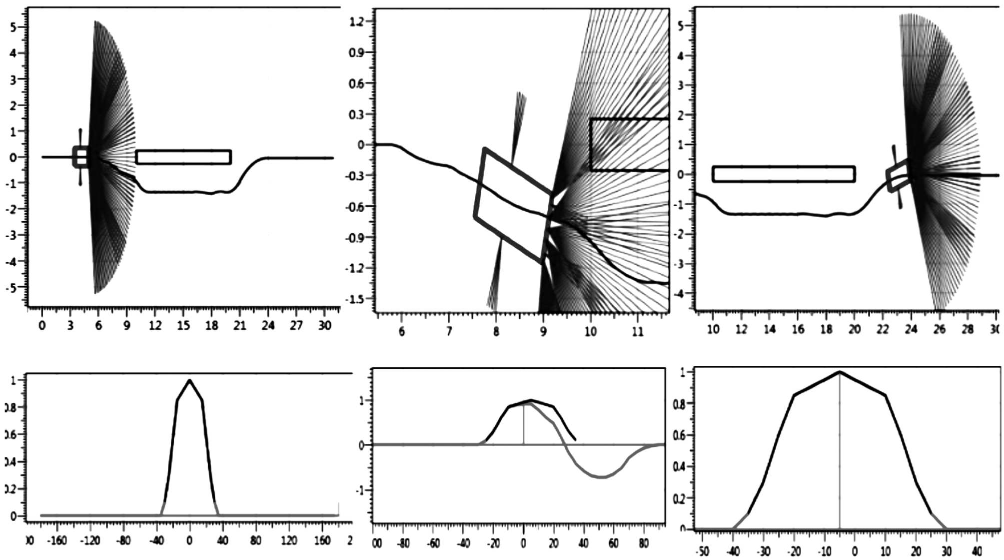

Figure 3: An experiment illustrating oblong obstacle avoiding process.

First experiment illustrates behavior of the navigation algorithm in the case of avoiding a single, oblong obstacle located on the path of the EPW. Three selected phases of the avoiding obstacle process are shown in Fig. 3. It can be noticed that both the obstacle avoidance and the return to the primary path process were accomplished in a very smooth way. It is confirmed by smooth paths obtained in the simulation. Though the model takes into account noise and disturbances influencing the sensory system there were no oscillations in the wheelchair movement along the oblong obstacle. Such oscillations are very common in reactive systems. It was achieved by proper tuning parameters of the histogram.

The second experiment presented in Fig. 4 imitates a situation when wheelchair is directed to go through the narrow passage. Using the data fusion coming from long range ultrasonic sensors and short range IR sensors it was possible to avoid oscillating wheelchair behavior resulting from interaction of the sensory system with a specific configuration of external objects.

The aim of third experiment was to verify the navigation system functioning in the dynamic environment. The situation when paths of moving objects overlap the wheelchair path is very common in a real world. The scenario of the experiment presented in Fig. 5 was as follows. The objects marked with square moves in the opposite direction to the wheelchair on the collision path. The two possible cases were considered. The first one concerns the objects which continues its movement regardless the external

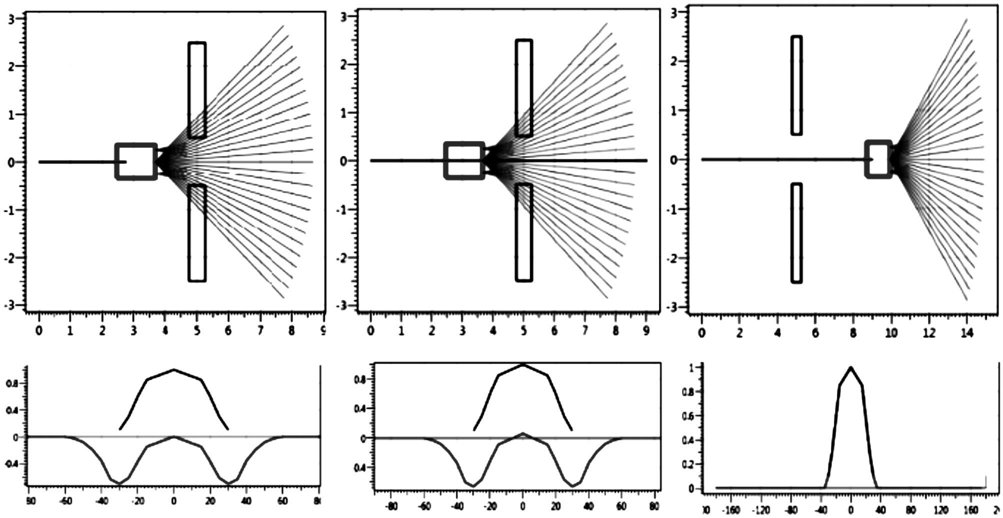

Figure 4: An simulation illustrating the navigation system behavior while passing the doorway.

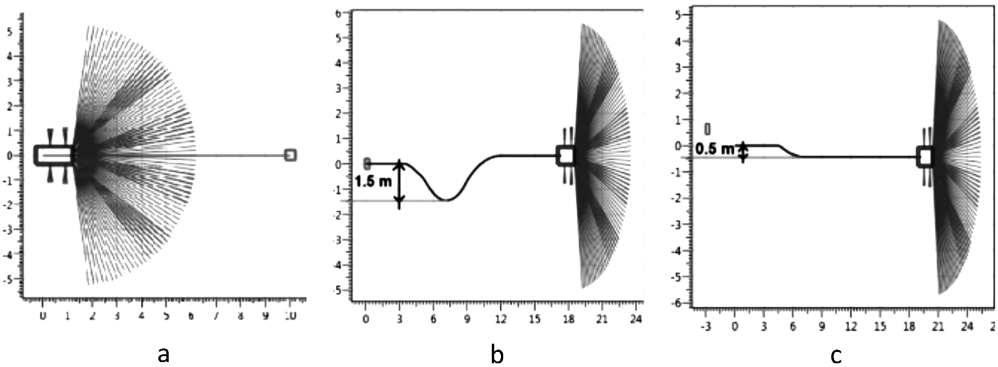

Figure 5: The experiment simulating system reaction to moving object (a) following unchangeable strait-line path, (b) moving, non-cooperative person case, (c) (b) moving, cooperative person case.

world state. In this case the rapid reaction of the navigation system can be observed. It generates steep trajectory of the object avoidance which results in leaving the primary path more than 1.5 m (Fig. 5b). In spite of significant deviation from the original path the avoidance maneuver was smooth and would be acceptable for the patient. The second case was related to interactions with someone who appears on the wheelchair way. It is assumed cooperative behavior of the person who moves away from the wheelchair path. This results in softer navigation system reaction - the deviation of path is smaller than 0.5 m (Fig. 5c).

The last experiment presents yet another scenario (Fig. 6). This time the wheelchair is intended to navigate through the rotary doorway. This kind of task is hard to control by the reactive system. It is mainly due to the strong feedback between the object which is tracked by sensory system and the control generated by the navigation system. The system continuously tracks the object and adapts the wheelchair movement. In such a case there is a danger of generating of overshoot reactions. Nevertheless, by proper tuning of the histograms' parameters the system can achieve the task. However, it must be emphasized that in a real world it would be very difficult to achieve this task.

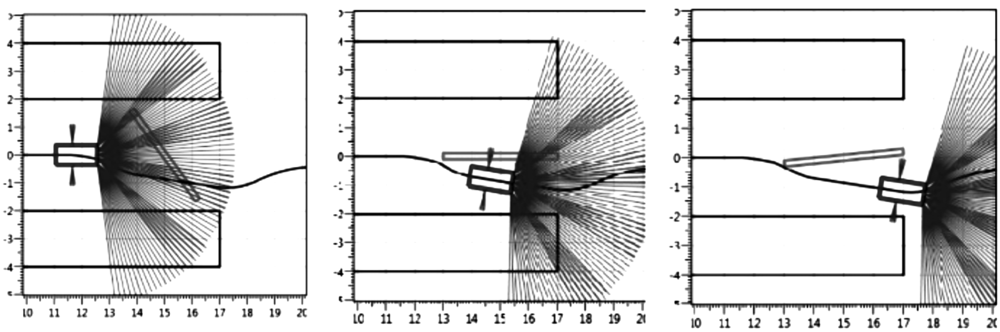

Figure 6: The wheelchair passing a rotary doorway.

6. Conclusion

In this work a conception of the control system designed for navigating an EPW was discussed. It is intended to stabilize a rectilinear movement in a direction set by the user. Moreover the navigation system is intended to avoid collisions with objects on the course of the EPW. Since the safety of the user has the highest priority, maneuvers should be safe and smooth without any drive overshoots. Though the system has some autonomy it must be emphasized that the user has the ultimate role over the system. In the case of any unacceptable maneuvers the system is switched into the manual mode. The main goal of this research was a preliminary evaluation of the navigation system based on the novel conception. The main assumption was to apply the simple low-cost sensory system. The sensory system was modeled in details in this research. The system functioning was simulated in a number of scenarios which follows from reality. In the simulations only the kinematics of the wheelchair were modeled what implies that there are some differences between simulated and the real world system. Although the simulation that was carried out, gave positive conclusions on functioning the system, in the real-world applications, dynamics and inertia of the action-reaction system would play a significant role. However, the research provides the tools that allow to reject wrong ideas in the simulation phase.

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