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Trajectory Control of an Autonomous System dedicated to Assisted Living

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***Abstract*— In this paper a method of controlling a wheelchair using the video stream from two cameras is proposed. The cameras are placed on the side of the wheelchair having as main purpose to detect the edge between the floor and the wall. The images obtained are processed, thus obtaining an inclination angular error and a lateral error from the desired trajectory, which is considered at the middle of the distance between the two lateral references. With the combined information from the camera and from the sensors conveniently placed on the system, the navigation inside a building with corridors delimited either by walls, by lines or by transitions is achieved.**

Keywords— Embedded, Canny, Hough Transform, AAL, Wheelchair, Assisted Living,

I. Introduction

In the past decade, a significant percentage of the everyday activities have been automated, thus increasing the quality of life, as well as reducing the amount of skills required for certain tasks. When it comes to people with disabilities however, the advancements do not seem to have caused a great improvement in their life and interaction with the environment. Besides the manual wheelchairs, a high popularity has been gained by electric powered systems, which are generally controlled through a joystick or, less frequently, through a touch screen. It has been nevertheless proven by numerous studies, such as [1], that powered wheelchairs require more cognitive abilities in order to have good control over the trajectory and avoid unforeseen encountered objects. Similarly, to how [1] underlines, patients who are dependent on a method of assisted transportation often experience other clinical complications, such as visual deficiencies, low muscle tone or motor speed latency. Moreover, the feeling of independence can be diminished while being included in a form of assisted living, either within the family or with a caregiver [2], while the phycological implications might cause self-esteem and self-reliance issues, self-exclusion at a social level, or even emotional distress and depression [3]. As a solution to overcome the mentioned situations, a strong opinion that the concept of assisted living should evolve towards autonomous systems and technologies gains popularity. The idea is supported both by clinicians and specialists in the medical domain, and through research projects and control strategies [4] [5] [6].

The main focus of this article is represented by a methodology of navigating a wheelchair in an indoor environment with walls and irregular corridors. The trajectory is calculated based on the walls or lines on the floor inside of a building. The wheelchair is equipped with two cameras, one on the right and one on the left side, both pointing down at an angle of 45 degrees. Using a Gaussian Filter, alongside a Canny edge detector and Hough Lines, the separation line between the floor and walls can be detected. The orientation and position of the line are further utilised to compute the trajectory. When only one reference is available and there is no obstruction, the system has the ability to reconstruct the desired path by knowing the last estimated distance between the walls. At the same time, obstacles that might appear in the way are identified using a series of sensors and then avoided accordingly. Besides the sensors, another camera is placed in front of the wheelchair to detect obstacles and other relevant information like doors, stairs or people.

II. Related Work

It is well known the need for an autonomous and intelligent wheelchair to ease the lives of people with disabilities. Instead of manually controlling the wheelchair each time a person wants to go somewhere, he or she can choose the destination, either by speaking, tapping on a map or any convenient method to choose the destination point. It is then the wheelchair's job to take the person safety to the destination point. There is significantly amount of work in the area of reducing the human effort to navigate. Some methods [7], [8] are developed to assist the person to a safer trip while making the whole experience more pleasant. Paper [9] describes a semi-autonomous wheelchair that using vision-based methods can assist the person who is driving to avoid unwanted collision with the walls due to uncontrolled motions. Their solution does not require to know the environment in advanced but using frontal camera to implement an algorithm based on vanishing point detection and wall plane detection that can smoothly correct the manual driving to avoid collisions.

Other implementations concentrate on fully autonomous wheelchairs, which can drive themselves through an unknown environment up to a destination point. Paper [10] talks about a method for a vision-based electric wheelchair to follow the walls on a corridor and pass through open doors in an unknown indoor environment. Their solution for this problem is to use three cameras to extract the environment features, one in the front to detect and follow the walls, and one on each side with a specific orientation to detect open doors. The position and orientation of the wheelchair is done by computing the vanishing point formed by the two lines of the walls. This also gives information about the corridor geometry, so it defines a space where trapezoidal shapes are looked for, representing the doors. The paper offers a detailed example of how the route is calculated based on vanishing point and the angle formed by the projection of the median line of the corridor. A different architecture for an autonomous wheelchair that aims to help the individuals who lack the ability to control the wheelchair, thus they rely on other persons for motion is proposed in paper [11]. Their solution involves multiple sensors, like a LIDAR, distance sensors and rotary encoders that provide the necessary information to construct a map of the environment. The algorithm relies on adaptive Monte Carlo localization and runs on the robot operating system ROS platform and based on the information from the sensors, the wheelchair is capable of navigating to a user-defined destination if the path is available. They mapped the indoor environment and also built an obstacle map using the LIDAR and ultrasonic proximity sensors. The wheelchair is capable to adapt to a change in the environment, for example an object emerges so that a new route is taken. Although outdoor navigation and localization systems are advanced and widespread, for indoor navigation there is still place for improvement especially within the new buildings with complex architecture, as paper [12] suggests. Their mobile robot platform, ATEKS, can communicate with an android smartphone and after a location map is passed then the A* algorithm is applied to compute the shortest path to the destination. Paper [13] also uses ATEKS and it presents an intelligent wheelchair with finite a state machine controller and Kinect based navigation algorithm. They managed to achieve an indoor control mechanism with low-cost sensors and open source software. An affordable solution with low cost hardware and open source software that can be implemented on different types of wheelchairs is presented in paper [14]. Their work is concentrated on Ambient Assisted Living field, presenting a solution that is specially designed to be easy and fast to integrate on different types of wheelchairs that are available on the market. Their software structure makes use of ROS framework and a SLAM algorithm that takes the input from IMU, encoders, laser scanner and manages to build a mapping system and robot localization, using concepts of the Adaptive Monte Carlo localization algorithm.

III. Hardware and software architecture

A. Hardware architecture

Figure 1. Wheelchair prototype

As presented in Figure 1, the hardware architecture consists of a modified electric wheelchair, whose initial input was a joystick. A control board was added, based on an ARM Cortex M3 microcontroller, which is in charge of receiving the computed command from a high-level platform and forwarding it to the control unit of the wheelchair actuator system. The high-level platform is represented by a Jetson TX2 developed by Nvidia and it connects the three on-board cameras through an USB hub. Commands are sent to the microcontroller through an USB-to-serial converter, which is also linked to the hub. A total of five additional sensors have been placed on the system, three of which being in the front side, and the other on each lateral. The lateral sensors and the front-left and front-right ones are based on ultrasounds, while the last front sensor is a digital, on-off type, situated underneath the leg carrier. Its role in the design is that of detecting small obstacles, less likely to be recorded otherwise. A block diagram of the hardware architecture is represented in the Figure 2.

Two of the cameras are placed on the lateral sides, nearby the wheelchair handles, and they are inclined downwards, while the third is pointing towards the front, being used especially for obstacles or for detecting passage sections, such as door frames, corridors or stairs. The mentioned setup has been chosen since it should highly simplify the process of filtering out the irrelevant information in the captures, while keeping the focus on the target areas, namely the separation between floor and walls.

B. Software architecture

The software layers can be divided into three main categories: image processing applications running on the Linux-based Jetson platform, communication facilitator and management software, and embedded software. The image processing section is composed of a path detection and computing program, and a program for searching different predefined objects, the two of them communicating with the main application through local sockets implemented over TCP/IP. The main application handles the serial port connection and the sockets, thus creating a bidirectional flow and establishing the priorities of the received information. One simple and efficient way of packing the data was through JSON objects, which are parsed on the embedded side as well. Upon receiving a message and interpreting it, the microcontroller issues a command and sends it through an UART peripheral to the control unit of the wheelchair's motors. The software diagram can be seen in Figure 3.

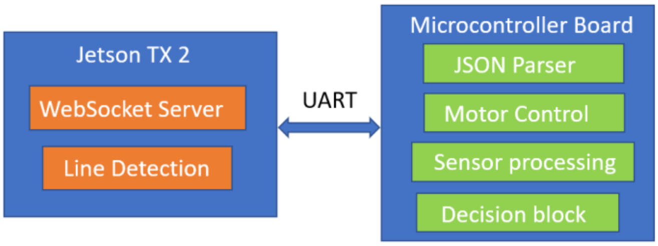

Figure 3. Software Block Diagram

IV. Control strategy

The steps required in order to construct a path are to first apply procedures oriented towards reducing the noise in the captured image, outline the edges and then mathematically formulate the discovered trajectories. Afterwards, both the yaw angles with respects to the wall and the lateral distance to the desired path are fed to a control law that unifies them in a single orientation command.

First of all, each frame received from the two lateral cameras are cropped to keep only approximately one third of the initial height, towards the centre of the image. Thus, not only is the separation region much clearly delimited, but also the influence of any additional lines or patterns is ignored. Consequently, the frame is smoothed using a gaussian blur, the kernel having the dimension of 7. Even though in the initial implementation the blurring has not been employed, the following procedures have proved to have better results.

A Canny edge detector is then applied, with the hysteresis threshold chosen accordingly. The resulting binary image represents the input to a Hough transform, procedure meant at finding the polar coordinates of the edges. Given that the background might contain other linear patterns or transitions, we select from the array of result, those with the highest probability of representing a separation. Therefore, any line described by a theta close to a vertical position is not taken into consideration as a final candidate.

At the same time, a correlation between the two images is made. Thus, when the differences in the angular approximation of the trajectory are significant, the frame can be re-analysed.

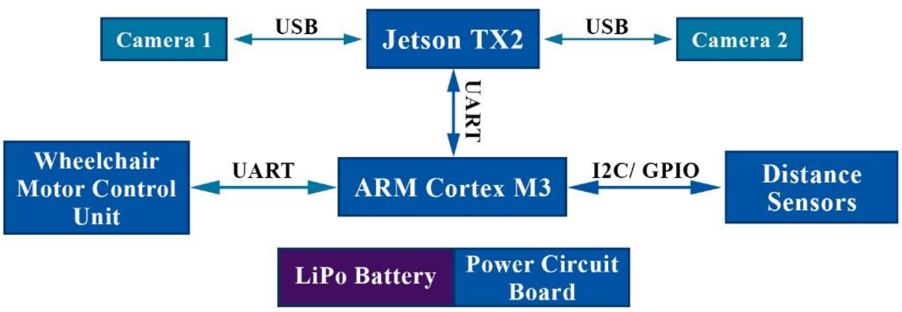

Figure 2. Hardware Block Diagram

Otherwise, the mean of the angles is computed, which will represent the inclination error with respect to the walls or lines. Another relevant factor will be represented by the lateral error, and in order for it to be obtained, the distance between the walls or leading lines must be discovered. When walls are present, an input to the system is activated, and the two lateral sensors measure the distance, a simple summation giving the corridor size. Similarly, we employ the front camera to determine the distance between heading lines when the situation states so. Further on, the lateral error up to either a wall or a line is calculated using the lateral cameras, previously calibrated so that the real space represented by a pixel is known. In the image below, a representation of the system between the two walls or lines can be seen, as well as the element which will lead to the final command.

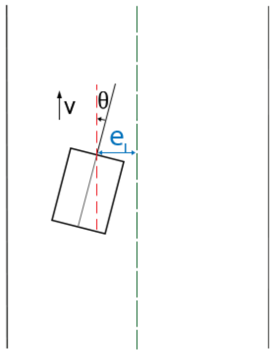

Figure 4. Visualisation of lateral error and angular error

The desired trajectory will ideally be situated in the middle of the distance between the two lateral references, if no obstacle blocks the path. In Figure 4, the target trajectory is represented by the green dashed line.

For obtaining the final steering angle of the wheelchair, a control expression inspired from [15] has been applied, having the following expression:

$$\delta = \theta + arctg\frac{k * e_l}{v}$$

In the above relation, v is the current velocity of the system, e_l represents the lateral error previously determined and k is a gain factor which dictates how fast the response should be so that the wheelchair reaches the planned path. δ is the total angle to compensate for.

When an obstacle is identified either with the front lateral ultrasound sensors, or with the calibrated centred digital sensor, from a distance established so that there is enough space for the system to react, a message is issued from the microcontroller to the main application, the system entering a special obstacle avoidance routine.

The avoidance routine includes as a first reaction to steer in the opposite direction of the encountered object, recover the initial orientation and check again for the presence of the obstacle. In the case that the corridor is still obstructed, the frontal camera is activated, and a program meant to evaluate the possibility to continue in the same direction is started. If the decision that there is not enough room on the corridor for the wheelchair to pass is made, the system awaits the user input before taking any further decision.

Distance sensors have been utilized for detecting obstacles, rather than analysing only the image from the front camera, due to the fact that they are not only less computationally expensive, but also, they bring the advantage of attaching an interrupt or setting a threshold at a hardware/ peripheral level. This allows the processor to address more critical issues and only activate the camera when it is absolutely necessary.

Moreover, in the case of an intersection, upon losing a wall that was previously detected, the distance sensor on the side is ignored. The dimension of the space between the walls is considered the last one stored when the autonomous system was enclosed on both parts, while the lateral corrections

In term of odometry, rotary encoders are used for the measurement of covered distance and current velocity.

V. Results

In the current section, a test has been conducted on a 2m corridor, the cameras being placed at approximately 21cm apart, at the back of the wheelchair, making a 45° angle with the horizontal plane.

When the wheelchair is oriented parallel to the walls, it can be observed from the green value in Figure 5. a) that a 90° degree angle is recorded as an inclination error. The value in blue represents the distance from each camera to the lines, measured in pixels. The conversion from pixels to centimetres is achieved through a calibration process made once for one of the cameras used, if the camera model is the same. In our measurements, a pixel corresponds approximately to a 1cm distance in reality. At a speed of 1m/s and a gain factor of 1, the lateral error of 3.38cm translates in a command $\delta = 1.95°$ towards right.

Figure 5. a) Wheelchair is in the middle of the corridor

Figure 5. b) displays a position which is both inclined to the right wall, as well as laterally shifted to the left wall. Thus, the inclination component of the final angle will be – (106°-90°) = -16°, and the lateral error will add another 7.22°, resulting in a total angle of $\delta = -8.78\ ^{\circ}$sent as a command to the motors.

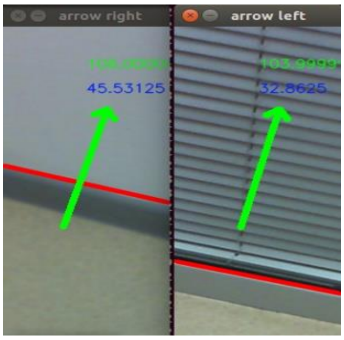

Figure 5. b) Wheelchair is inclined and lateraly shifted

VI. Conclusion

In this paper, a hardware and software architecture for an autonomous wheelchair has been proposed. Hardware-wise, there are three main components, namely a Jetson TX2 development board, which connects the additional cameras through a USB hub, a microcontroller board, that acts as an intermediate layer between the high-level platform and the actuator system, and at the same time being responsible for triggering and reading the data coming from sensors. The last component is represented by a motor control unit, whose functions are implemented by serial commands. The software layers correspond to each hardware part and are represented by a main application, several programs to compute the angular command and to detect obstacles and the firmware running on the microcontroller, which parses commands and communicates with sensors.

The total angular command is composed of an inclination error determined through applying Hough Transform to parametrize the heading lines and a lateral error, calculated by transforming the pixel count from the image according to a previous calibration. The employed control law has also been used on autonomous navigation systems.

If an obstacle is detected, a special routine is called, which as a first step attempts to avoid on the opposite side of the object, while keeping a parallel orientation to the initial trajectory. In the case that the obstacle is evaluated as impossible for the system to surpass, a form of user input is expected in order to continue the journey.

VII. Acknowledgement

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VIII. References

[1] Fehr L., Langbein WE, Skaar SB., *Adequacy of power wheelchair control interfaces for persons with severe disabilities: a clinical survey*, May-June 2000 [1]

[2] H. Stockes, M. Turnbull, J. Wyn, *Young People with a Disability: Independence and Opportunity A Literature Review*, May 2013 [2]

[3] M. Finlayson, T. van Denend, *Experiencing the loss of mobility: perspectives of older adults with MS*, 2003 [3]

[4] A. Goil, M. Derry, B.D. Argall, *Using Machine Learning to Blend Human and Robot Controls for Assisted Wheelchair Navigation*, 2013 IEEE International Conference on Rehabilitation Robotics [4]

[5] Eric Demeester, Alexander Hüntemann, Dirk Vanhooydonck, Gerolf Vanacker, Hendrik Van Brussel, Marnix Nuttin, *User-adapted plan recognition and user-adapted shared control: A Bayesian approach to semi-autonomous wheelchair driving*, Autonomous Robots 2008 [5]

[6] Brenna D. Argall, *Modular and Adaptive Wheelchair Automation*, Experimental Robotics 2015 [6]

[7] Pablo Inigo-Blasco, Fernando Diaz-del-Rio, Saturnino Vicente Diaz, Daniel Cagigas Muniz, *The Shared Control Dynamic Window Approach for Non-Holonomic Semi-Autonomous Robots*, Conference ISR ROBOTIK 2014 [7]

[8] Sinyukov, D., Desmond, R., Dickerman, M. et al., *Multi-modal control framework for a semi-autonomous wheelchair using modular sensor designs*, Intel Serv Robotics (2014) 7: 145. [8]

[9] Francois Pasteau, Alexandre Krupa, Marie Babel, *Vision-based assistance for wheelchair navigation along corridors*, 2014 IEEE International Conference on Robotics & Automation (ICRA) [9]

[10] François Pasteau, Vishnu K. Narayanan, Marie Babel, François Chaumette, *A visual servoing approach for autonomous corridor following and doorway passing in a wheelchair*, Robotics and Autonomous Systems January 2016 [10]

[11] Harkishan Grewal, Aaron Matthews, Richard Tea, Kiran George, *LIDAR-Based Autonomous Wheelchair* [11]

[12] Ugur Yayan, Bora Akar, Fatih Inan, Ahmet Yazici, *Development of Indoor Navigation Software for Intelligent Wheelchair* [12]

[13] Scott Drew Pendleton, Hans Andersen, Xiaotong Shen, You Hong Eng, Chen Zhang, Hai Xun Kong, Wei Kang Leong, Marcelo H. Ang Jr., Daniela Rus, *Multi-Class Autonomous Vehicles for Mobility-on-Demand Service*, IEEE/SICE International Symposium on System Integration December 2016 [13]

[14] Luca Cavanini, Flavia Benetazzo, Alessandro Freddi , Sauro Longhi, Andrea Monteriu, SLAM-based Autonomous Wheelchair Navigation System for AAL Scenarios [14]

[15] Sebastian Thrun, Mike Montemerlo, Hendrik Dahlkamp, David Stavens et al., *Stanley: The robot that won the DARPA Grand Challenge*, Journal of Field Robotics 2006 [15]