Smart Autonomous Wheelchair

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***Abstract*—Smart wheelchairs are an assistive wheeled mobility device. The world health organization reported 10 % of global population (650 million person) have disability and 10% among them need wheelchair. Wheelchair made it easier for many to pursue their life activities including education, work and social life. A smart autonomous wheelchair is developed in this paper to enhance the maneuvering tasks. The wheelchair requires no human intervention during navigation and perception in addition to processing which is based on computer vision techniques.**

Keywords—Self driving; autonomous wheelchair; computer vision.

I. Introduction

Humans may lose stable mobility not only because losing limbs but also because of disease like Parkinson, tiredness, paralysis, aging… many researchers are working towards improving the mobility and the rehabilitation stages of gait for subjects suffering from movement disability. For instance, in case of Paraplegia, kobetic et al [1] implanted a system in a person made up of 16-channel functional electrical stimulation for more than a year. The person then was able to walk for 20m with a maximum duration of 20 min. Moreover, gait disorders are recorded to increase from 10 % in individuals aged 60–69 years to more than 60 % for subjects who are over 80 years [2] .

Moreover, walking abnormalities are a result of symptoms that would make a person suffer during walking like propulsive gait based on ground reaction force [3], waddling gait [4] spastic (Hemiplegia) gait [5] and many more. That's why in case of walking abnormality, individuals rely on assistive devices and technology to facilitate their mobility. Smart crutches are developed by scientists [6] in which an instrumented forearm crutch is developed augmented with low-cost off-the-shelf wireless sensor in addition to electronic components to transfer the patient's weight, tilt and hand position on the crutch over the period of the rehabilitation program to support the physiotherapists. In another research, pneumatic leg braces were investigated for the treatment of medial tibia stress syndrome and results indicate failure due to low wearing comfort [7]. A new nonintrusive device for gait analysis and monitoring is studied [8]. The developed system is made up of a rollator equipped with inertial sensors and encoders which provide a new walking index for gait analysis. Furthermore, devices like wheelchairs (manual/ Autonomous with assistive navigation/bipedestation), autonomous especial vehicles, external augmentative devices (Mobility-training devices, Self-ported Orthoses, ..) are deployed towards enhancing the ability of mobility [9].

A tremendous effort is being oriented towards the development of wheelchairs. For instance, a new assistive technology, established by engineers at the Georgia Institute of Technology, allows patients to operate a computer control powered wheelchair and interact with their environments by moving their tongues [10]. Another research explores a control framework for both hardware and software in order to achieve a semi-autonomous wheelchair [11]. That research also proposes adaptive motion control with online parameter estimation. Deepesh K Rathore et al. presented intelligent wheelchair assisted with a navigation pad and obstacle avoidance system in addition to real time tracking system using RFID in their paper [12]. An algorithm was also presented for the automated detection of safe docking locations for basic maneuvering tasks with a powered wheelchair for providing adaptive driving aid [13]. ATRS is another entitled smart wheelchair that eliminates the need for an attendant in which light detection and ranging device is used for localization coupled with a hybrid motion controller design [14]. In another work, multi-layered maps were employed in which semantic information showed to progress the effectiveness of path planning and the ability of task planning for the wheelchair [15]. Moreover, a perception sensor array in addition to control circuitry which are integrated to a computer system to perceive and rejoin the wheelchair environment. For that purpose, multiple cameras are used for image processing while a scanning laser sensor to determine the range to surrounding objects for obstacle anticipation within the program [16]. In another paper, a camera was embedded into a smart wheelchair and was used to capture images from the surrounding environment in order to detect the pathway in a hall. Furthermore, a line laser was used in conjunction with the camera to identify different shapes based on the line laser pattern obtained from a certain angle [17].

Wheelchairs are classified as they can be driven by their user, Attendant-propelled chairs are considered to be pushed using the handles, rigid frame wheelchair with a base of support on which the person sits, folding frame wheelchair whose frame is collapsible sideways, and motorized wheelchair propelled by means of an electric motor [18].

It is a known fact that human mobility relies on walking and movement, which are essential throughout our daily activity with no hinders. However, subjects with motor, cognitive, and sensory deficiency rely on wheelchairs. In this

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paper we present an enhanced self-driving wheelchair assisted with computer vision technique that is intended to advance or replace traditional head joysticks, sip-n-puff, chin joysticks, and thought control wheel chairs [19] .

II. Methodology

The system follows a specific structured procedure that starts by constantly waiting for the user to give it the desired room that he/she desires to transport the patient to and stores it in memory. Then, the system waits for the patient to press the ready button to ensure that he/she is ready to be transported. Next the developed self-driving wheelchair starts by estimating its 3D pose with the exit tag attached at the door and modifies its position to become perpendicular with the door to exit properly and executes the Room-Exit routine with all the added safety measures (obstacle avoidance, low speed, etc.). Afterwards, the wheelchair starts the Autonomous-Navigation routine between the rooms detecting the surrounding tags to follow them as they lead it to the desired tag, taking into consideration all the safety measures as well. Last but not least, when the desired tag is reached, the system also parks perpendicular to the tag attached on the door and executes the Room-Enter routine.

Finally, it looks for the parking tag inside the room and once it is detected it follows the same previous Room-Exit procedure to adjust its position with respect to the parking spot to become also perpendicular to it and then it parks correctly and then it stops waiting for another command to be received.

A. Mechanical Construction

The chassis of the wheelchair consists of a frame made out of two aluminum sides connected with four steel bars and four small wheels attached to the frame and driven by two motors. The chair is mounted on top of a box that the patient can sits on. The sides of the box were made up of aluminum, while the bases were made up of wood to maintain isolation of any leakage current that might happen accidently. Direct Current (DC) MERCEDES WIPER motors driven by a 12 Volt GEL Battery, were used. Fig. 1 shows the construction for the chassis of the Wheelchair were a Chain Sprocket a mechanism that translates rotary motion from the motors' rear to the front. A preliminary prototype of the wheelchair is shown in Fig. 2.

Fig. 1. The chasis of the Wheelchair

B. Hardware

The Hardware used are listed below:

1) Raspberry Pi 3 Model B+: It is the main board of the Robot's system at an affordable price. It was chosen since it has Computer Vision processing capabilities and digital control for driving motors.
2) Pi Camera: It is the original camera provided by the Raspberry Pi foundation, it is used to provide the system with frames of the surrounding environment.
3) Dual Motor Drive Board: used to receive PWM signals from the Raspberry Pi and drive the motors for navigation.
4) Motors: used to navigate the Robot.
5) Infra-Red Sensors: used for safety measures as it detects obstacles or humans when they are present around the robot at a close distance while it is moving.
6) 12V Battery: used to provide the system with power.
7) 12V to 5V Voltage Regulator: used to lower the voltage of the battery to provide the Raspberry Pi with the suitable voltage.
8) Push Button: Used as the Ready Button that allows the system to start the transportation process when pressed.

Fig. 2. Prelimiary prototype of the wheelchair model

C. Software Packages

The code is based on python packages listed below:

- "cv2" package: Official open-source OpenCV package for python that provides Computer Vision capabilities.
- "NumPy" package: Enables scientific and mathematical programming in python. It supports large N-Dimension arrays and matrices as the cv2 package reads the captured image as 3 matrices for each color channel (RGB) filled with the intensity of the specific channel color in each pixel.
- "April Tag" package shown in Fig. 3. These tags are designed for robust identification at relatively long distances. It lets the autonomous wheelchair detect the surrounding tags and estimate its relative 3D pose with respect to the desired tag so it can localize itself in real-time and perform autonomous navigation.

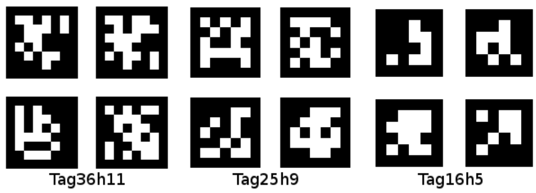

Fig. 3. April Tags

- "Motor" package imported from "GPIOzero" library enables the Raspberry Pi to generate suitable PWM signal to drive the motors for navigation.
- "PiCamera" package allows the Raspberry Pi to access the attached camera and capture real-time frames.
- "time" package provides the use of delays and waits in the system when needed.
- "imutils" package gives us the ability to resize and manipulate the captured image before feeding it to the cv2 package to ensure it is suitable for processing and to improve performance.

D. *Flowchart for the Autonmous Wheelchair*

The wheelchair will be placed at the parking area waiting to receive the command as indicated in Fig. 4 . When the patient is ready, he/she will press the ready button so the robot will proceed in the Room-Exit routine.

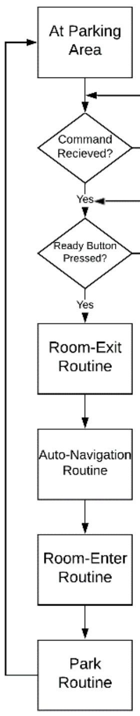

Fig. 4. Main Program Flowchart

At the parking spot the Robot will be searching for the Exit Tag. If the Exit Tag is detected the Robot will try to adjust its position till it becomes perpendicular to the Tag; if the robot did not detect the tag the camera, mounted on a servo, will rotate until it detects the tag. After that process, the robot will be ready to perform the Autonomous-Navigation routine. This is summarized in the flowchart of Fig. 5.

As illustrated in the flowchart of Fig. 6, when the robot exits the room, it will start searching for the desired tag. First, it will turn to the right and then there are two strategies that the robot can follow: A)The desired tag is directly detected: The Robot proceeds to the Room-Enter Routine. B) The desired tag is not directly detected: The Robot follows one of four sub-strategies: B.1) target tag and the detected tag both greater than Current tag: The Robot navigates forward autonomously. B.2) Desired tag is greater than current tag but detected tag is less than current tag: The Robot turns 180°. B.3) Desired tag and the detected tag both less than Current tag: The Robot navigates forward autonomously. B.4) Desired tag is less than current tag but detected tag is greater than current tag: The Robot turns 180°.

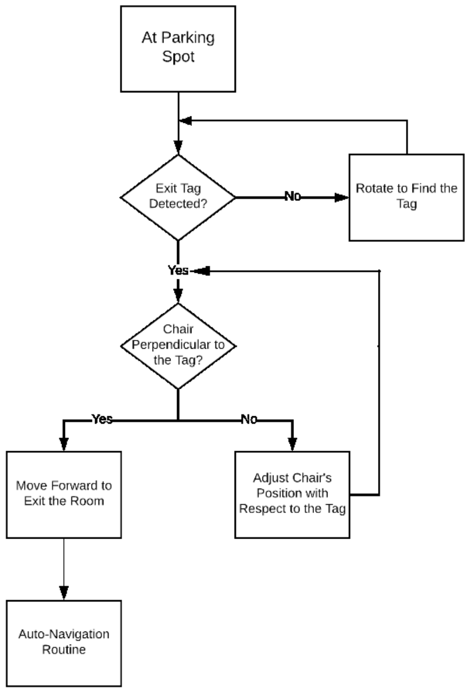

Fig. 5. Flowchart of Room-Exit Routine

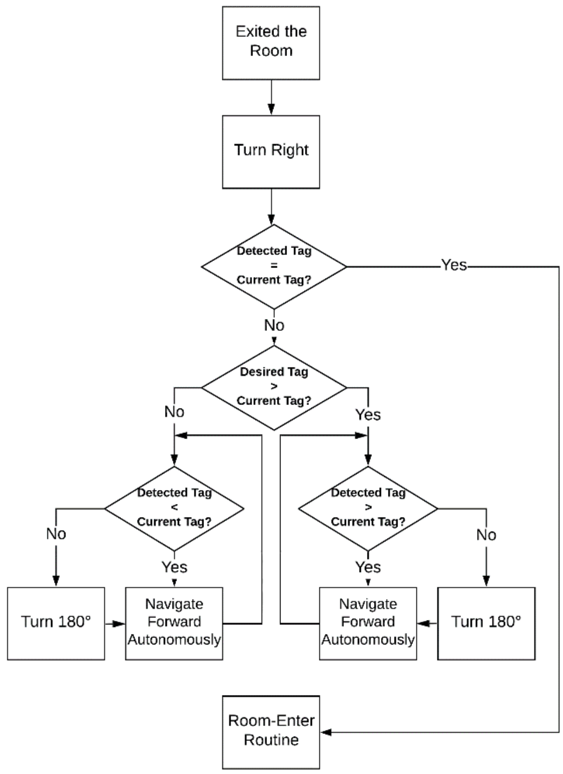

Fig. 6. Flowchart of Autonomous-Navigation Routine

When the Robot reaches the desired room, it will adjust its position until it becomes perpendicular to the room's door. Then, it will check whether the door is open or not. If yes, it will move forward to enter the room and executes the Park Routine; otherwise, it will wait until the door is opened and then performs the previously mentioned steps as shown in Fig. 7.

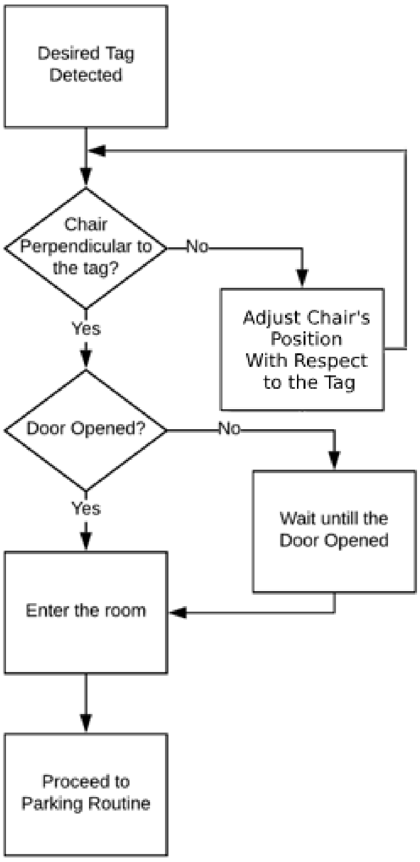

Fig. 7. Flowchart for Room-Enter Routine

After successfully entering the room, the Robot will search for the Parking Tag so it can park correctly; if it is detected, the robot will transport autonomously inside the room until it becomes perpendicular to the tag (i.e. the parking spot) then it will park safely and returns to its initial state awaiting for a new command to be received. If it is not detected, the Robot will turn around in the room to find the tag. Fig. 8 illustrates the whole process.

Due to the fact that a person may stand in the hallway and block the view of a required tag for navigation, SLAM will be employed during the progress of the work as in the below section. That is why a development of wheelchair model is required to simulate the SLAM algorithm with data from model. This stage is necessarily done prior to implementing SLAM on the physical wheelchair. After the wheelchair can successfully operate in real time.

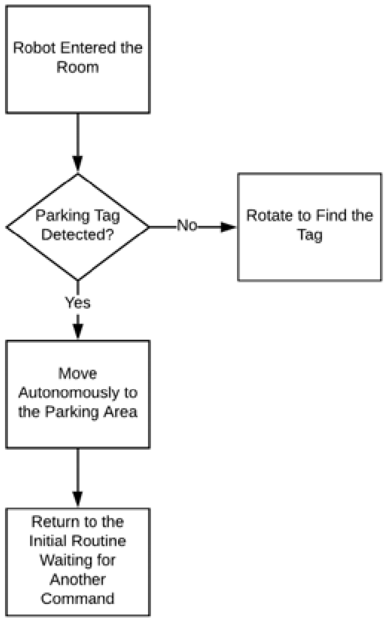

Fig. 8. Flowchart of Parking Routine

E. Simultaneous Localization and Mapping (SLAM)

SLAM means building a map to understand how the environment looks like in addition to localizing the robot to know where the robot is located in its environment. Both tasks are to be done simultaneously. However, in order to determine the poses of the wheelchair, a map is needed. On the other side, to build a map, the wheelchair need to know its location as indicated in Fig. 9.

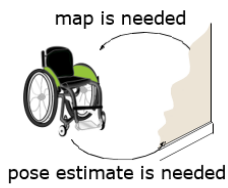

Fig. 9. SLAM Requirments

That is why SLAM will alternate between the previous two requirements. Moreover, SLAM is based on Extended Kalman Filter to update the wheelchair location based on the Landmarks in discrete points in time (every time the wheelchair takes a sensory measurement). Landmarks is anything that the wheelchair can observe and recognize. For instance, the tags are our landmarks for the wheelchair to localize itself. In future design the corners and edges in a building will be used as our landmarks as well. The online SLAM is computed as a probability of estimation as in equation 1:

$$p(x_t, m \mid z_{1:t}, u_{1:t}) = \int \int \ldots \int . p(x_{1:t}, m \mid z_{1:t}, u_{1:t})\, dx_1 dx_2 \ldots dx_{t-1}$$

eq1

where the wheelchair's controls are defined as :

$$\mathbf{U}_{0:k} = \{\mathbf{u}_1, \mathbf{u}_2, \cdots, \mathbf{u}_k\}$$

and the map of landmarks are defined as:

$$\mathbf{m} = \{\mathbf{m}_1, \mathbf{m}_2, \cdots, \mathbf{m}_n\}$$

the path of the wheelchair is represented as;

$$\mathbf{X}_{0:k} = \{\mathbf{x}_0, \mathbf{x}_1, \cdots, \mathbf{x}_k\}$$

The integration is equation (1) is to be done one at a time so the recent pose and map will be estimated.

III. Results

As a conclusion, the fusion of April Tags with Computer Vision enables us to transfer patients between rooms to the right room at the right time as desired by the nurse. Fig. 10 shows how the autonomous wheelchair was able to detect the room and was able to navigate through different locations according to the desired goal. Those tags enabled the robot to exit/enter the rooms correctly, as its pose will always be adjusted to stay totally facing the room's door. Also, this enables the robot to easily localize itself in real-time: outside the rooms in the hospital for finding the desired room, inside the rooms of the hospital to find the parking area so it can park safely. Since Computer Vision is the core of the Robot's functionality, it was able to achieve high accuracy with a good processing time since the framerate was enough for real-time performance (around 16 fps). This assured safety from software crashes or bugs as it possesses high robustness. Moreover, the attached Infra-Red Sensors guaranteed physical safety of the patient, system, and surrounding environment. Finally, our approach gave the Autonomous Wheelchair the ability of being fully autonomous with no need for human intervention during the execution of navigation between the rooms and parking.

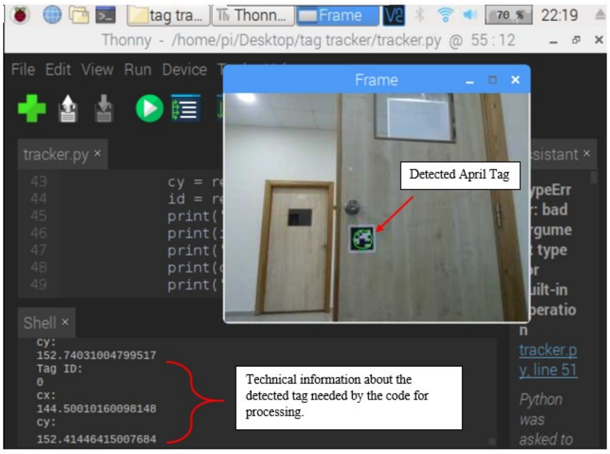

Fig. 10. Manuvering of the Autonmous WheelChair

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