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(出版者 / Publisher)
法政大学大学院情報科学研究科
(雑誌名 / Journal or Publication Title)
法政大学大学院紀要. 情報科学研究科編
(巻 / Volume)
16
(開始ページ / Start Page)
1
(終了ページ / End Page)
6
(発行年 / Year)
2021-03-24
(URL)
https://doi.org/10.15002/00023860

Pose Recognition Based Wheelchair Propulsion from a Stationary Point for Elderly Convenience

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Abstract— **Aging is an inevitable, natural process that reduces the functionality of the human body over time. Many tasks become too difficult to handle and the body barely hangs on. One such task is the mobility for the geriatric society. People from that age group usually find it hard to go from place to place or will have to depend on someone else for assistance. The purpose of this research is to improve the quality of life for the senior citizens. The research focuses on the design of such a robotic wheelchair which incorporates everything from hardware, software to sensor technology, computer processing and power distribution. When the senior citizen wishes to sit, they will perform a pose from a set of specified poses that elicits a response from the wheelchair in the form of forward movement making it easy for them to be seated. Before propulsion, the distance between the user and the wheelchair is calculated and recorded. While in motion, the wheelchair checks for any obstacles on its path to the user using a simple algorithm incorporating the previously calculated distance. Upon reaching the user, the wheelchair is set to alert the user by the sounding of a buzzer. In the case an obstacle is detected, the wheelchair is set to alert the user in a way that is different as compared to that of alerting the user upon successfully traversing the distance. During the experimentation phase, the wheelchair is triggered and reacts appropriately as and when the poses are performed. The Buzzer is also activated as per the case of either traversing the complete distance or encountering an obstacle. Results from the performance testing demonstrate its functionality as a possible care-giving solution to the senior citizens.**

Key-words: Geriatric care, independent mobility, artificial intelligence, computer vision, pattern recognition, obstacle detection, affected computing.

I. Introduction

Several studies have shown that both adults with disabilities and senior citizens benefit substantially from access to a means of independent mobility, including power wheelchairs, manual wheelchairs and scooters. With independent mobility, vocational and educational opportunities are increased, with a decrease in dependence on caregivers and family members which in turn promotes feelings of self-reliance and boosts confidence. While most individuals who are either differently abled or are senior citizens can either manually operate their wheelchairs or can be cared for by a caregiver on manually operated wheelchairs, some of them find it difficult or next to impossible to manually operate their wheelchairs independently. The aforementioned population includes, but is not limited to, individuals with low vision, visual field reduction, spasticity, tremors, or cognitive deficits. The individuals from these groups may lack independent mobility and might have to rely on caregivers for their assistance.

To assist and aid this population, several researchers have used ideas and technologies which were originally conceived for robots to create wheelchairs that can move independently without the assistance from a caregiver. These wheelchairs were later loosely termed as "smart wheelchairs". A smart wheelchair is usually made up of powered wheelchairs with a computer and a set of sensors or a mobile robot platform with an added seating function to it. They can perform various functions like being able to interact with the user in real-time [1], monitor the user's conditions by recognizing the activities performed by the user [2], navigate in a given environment by themselves or detect obstacles and avoid colliding with the said obstacles, climb stairs and transport the user from one location to another and so on. With the increase in potent medicines and a rise in the average life expectancy of humans, the society will automatically have a higher geriatric population. This will in turn result in more demand for robotic assistive systems or automated caregiving systems. The role of smart wheelchairs is increasing and eventually fully automated systems may replace human caregivers.

The main aim of the work proposed in this paper is to try and ease the strain of daily life on the elderly by introducing a smart wheelchair prototype that is triggered by poses and does not require the user to wear any sensors to make it work. The smart wheelchair is named Gisu. The term "Gisu" is coined from two words taken from two different languages: "G" stands for "Geriatric" and "isu" is 'いす' (Japanese for "chair"). It uses pattern recognition to recognize the actions performed by the user and moves accordingly. For recognizing the poses a human pose detection and estimation algorithm is used. Human pose detection or pose estimation algorithms are significantly evolved forms of simple human adaptive tracking algorithms [3]. In other words they are in general a set of algorithms that can classify the pose a human subject is performing, be it in real-time or classification from images. This method is usually implemented by creating a human skeleton by forming vertices at joints in the human body, referred to as skeletonization, and then applying learning algorithms to later be able to classify the poses into a particular category. References [9] to [11] are all papers based on Skeletonization followed by pose/pose detection. With the advance in computing power, more and more powerful algorithms have been implemented that can detect the human pose and classify those poses into a particular action category such as walking, running, sitting, sleeping and so on. With improvement in such algorithms the functionality of smart wheelchairs are naturally improved increasing the ease of operation which in turn helps reduces the strain felt on the user.

II. RELATED WORK

For the past decade, automated care-giving to the disabled/elderly has been a hot topic especially in the field of artificial intelligence (AI) and computer vision. AI in the form of smart wheelchairs equipped with pattern recognition, 3-D mapping, obstacle detection and evasion, human-machine interaction, motion control and various other forms are adopted to help ease care-giving. There have been many different researches including one or more of these to assist the said group of citizens.

Usually, most smart wheelchairs have one or two types of controlling interfaces. H. G. M. T. Yashoda et al [4] try to provide as many as three different ways of controlling the powered wheelchair-the conventional joystick, voice and pose based control. The term pose recognition is an all-encompassing word as it can refer to recognition of poses from individual body parts like the hands or the legs to facial expression recognition to complete body pose recognition. This particular paper deals with pose recognition of the hands of the user. With more user interfaces being available the user comfort is automatically enhanced.

When speaking of obstacle detection and avoidance, the most common method of implementing it is by using ultrasonic sensors. While many wheelchairs do adopt obstacle detection and avoidance, they are not the main objective and hence are not state-of-the-art. Research "Laser and Optical Flow Fusion for a Non-Intrusive Obstacle Detection System on an Intelligent Wheelchair" [5] is specifically designed for obstacle detection alone. The authors use laser sensors and build a very precise obstacle detection system. They implement a 16-beam solid state laser sensor to from a virtual, non-intrusive barrier around the smart wheelchair. The main reason for this implementation is because the obstacles encountered are usually of many shapes and the detection using conventional sensors may not be accurate.

Skeletonization has been a field of research with increasing interest and applications by researchers for the past decade. The process of skeletonization, which originally began as a simple field, has now advanced enough to be able to create skeletons of the human body. These skeletons are then used in machine learning applications in many different fields for various purposes. K. Srijeyanthan et.al [9] and Songyang Zhang et. al [10] are two different methods of skeletonizing the human body, namely Pixel density based star skeletonization and Kinect sensor based skeletonization, while being restricted to the two-dimensional plane. Dushyant mehta et. al [11] on the other hand, are capable of visually representing the skeleton on both the two-dimensional and three-dimensional plane by creating an animated character to mimic the actions performed by the user.

III. POSE BASED PROPULSION OF GISU

A. Hardware Description of Gisu

The hardware components of Gisu are the chair, an RGB camera, an ultrasonic sensor, a buzzer, two DC motors, a rechargeable battery to power the system and an NVIDIA Jetson Nano. All the components used are shown in Fig. 1.

Fig.1 (a) Wheelchair. (b) RGB camera. (c) Ultrasonic sensor. (d) Buzzer. (e) DC motor. (f) Rechargeable battery. (g) NVIDIA Jetson Nano.

The camera is attached on top of the chair and functions as the eyes of Gisu. The focal length of the camera is standard 28 mm. The horizontal field of view (fov) of the camera is 42.2, the vertical fov 32.2 and the diagonal fov is 51.6. Pattern recognition is applied to the feedback received from the camera. The camera is also used to calculate the distance from the wheelchair to the user using the method of triangular similarities. The ultrasonic sensor is used to perform obstacle detection and alert the user in case any obstacles are detected. The buzzer has two jobs. The first is to beep thrice in case of coming up on an obstacle midway. The second is to beep twice upon successfully travelling the specified distance and reaching the user to alert them that Gisu is right behind them. The DC motors are used to propel/stop the chair, in other words, they function as the navigation unit of Gisu. All the software codes are saved onto Jetson and it essentially is the controlling unit of the entire build.

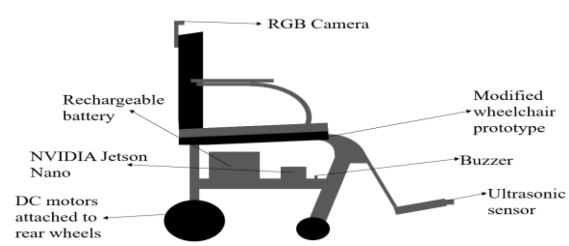

Fig. 2. System diagram of the proposed prototype

The system build closely resembles [4] and [7] with a few specific changes. Fig. 2, depicts the theoretical build of the system where all the necessary components are placed in the ideal positions and the calculations including the seating of the user.

Fig. 3.a, represents the front view of the actual build of the wheelchair, the physical build where the battery, Nano and the buzzer are placed on the seat itself as the actual build is nothing

but a prototype. However, corresponding to the conceptual build, the RGB camera, the DC motors and the ultrasonic sensors are placed in the intended positions.

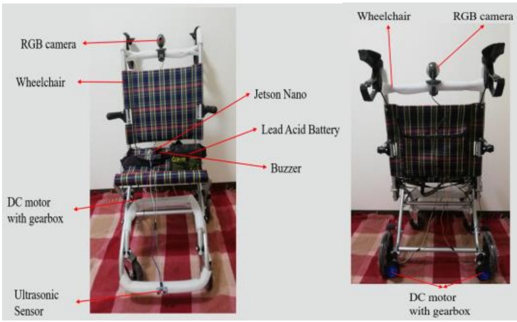

Fig. 3.a. Front view and 3.b. Back view of the constructed prototype.

Fig. 3.b, represents the back view, which depicts the DC motors much more clearly than Fig.3.a. The DC motors have tiny wheels attached to initiate motion and propel the wheelchair forward or to stop it when necessary.

Fig. 3.c, shows the other 3 components of the prototype namely the lead acid battery (rechargeable), Jetson Nano and the buzzer.

Fig. 3.c. remaining hardware of the constructed prototype.

B. *Working of Gisu*

1) Pose recognition algorithm

Pose recognition can be classified as a type of Human-Computer Interaction (HCI) that allows the user (a human) to provide commands to a system (the computer) by performing various poses. The process of pose recognition can be split into a two phase approach. The first phase entitles forming a skeleton of the user by creating vertices on all the major joints like the elbow, the wrists, the knees and joining them in a sequence. After forming a skeleton of the user, which can run at 22fps, the second phase of the pose recognition algorithm begins where a CNN based image classifier, ResNet-18, is used to classify the performed poses into one of the specified categories.

As for the data used for training the CNN, it was specifically created as the required class of poses were not available in any database by taking three hundred pictures of each pose class and then trained based on them. The dataset uses the skeletons formed using the skeletonization as the input. The reason the skeletons alone are used and not just the image of the body performing the pose or both of them in combination is explained below. Regarding the image of the body alone, there are cases when the user's clothes could camouflage the user's pose with the background. For instance, dark clothes on a dark background could lead to massive errors. Alternatively, taking both the skeleton and the body pose image would unnecessarily complicate the script, making it computationally expensive, leading to more resource consumption. After the images of the skeleton based pose are taken, they are used to train the Resnet classifier. These categories are discussed in the next subsection. The proceeding process constituting the entire working of Gisu as a whole that includes all the functions performed by Gisu are discussed in the further subsections below. A flowchart of the pose recognition algorithm is depicted in Fig. 4.

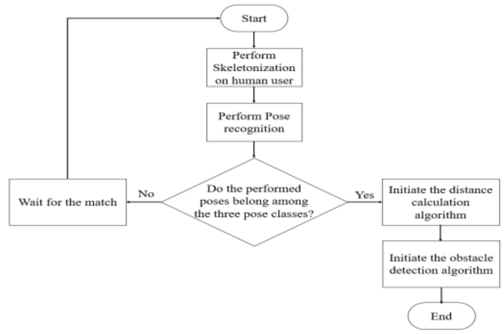

Fig. 4. Flowchart of the pose recognition algorithm.

2) Pose elicitation for Gisu

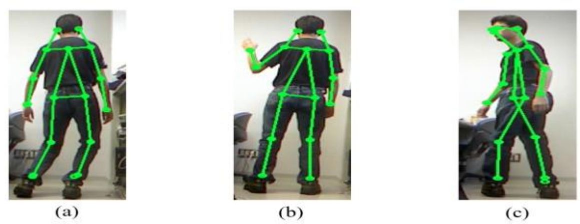

Fig. 5. The three specified poses: (a) Knee pose. (b) Hand pose. (c) Body pose.

The proposed prototype, Gisu, is designed so that the user can operate it with the least effort required. After performing an activity, when the user wishes to sit down, all they have to do is perform one of the three specified poses to prompt the wheelchair into action. The poses are classified as knee pose as shown in Fig. 5(a), the hand pose as shown in Fig. 5(b) or the body pose as shown in Fig. 5(c). The pose classes used here are specific to this particular prototype alone. If and should the need arise, these poses can be altered to the convienence of the user. Senior citizens need not necessarily stick to these particular poses. The main reason for adopting these three different poses was to demonstrate the prototype's capability of being able to react to different pose classes.

3) Distance calculatoin algorithm

Gisu uses the concept of triangular similarity to be able to calculate the distance from its current position to the user's position. The theoretical working is explained in brief followed by examples of the concept being put into actual practice.

Consider two planes, the object plane and the image plane. Then, with an object of known height "H", a camera of focal length "F", and apparent height of the image of the object "P" the distance "D" from the camera to the object can be calculated using (1).

$$D = (H*F)/P \quad (1)$$

The graphical visualization of the triangular similarity concept to calculate the distance is shown in Fig. 5.

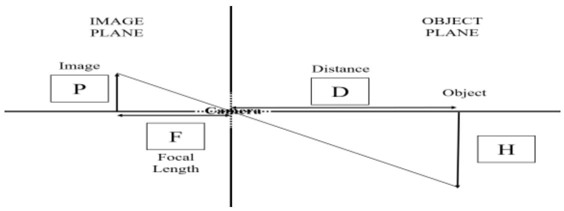

Fig. 6. Graphical visualization of the Triangular similarity concept

Once the distance is calculated according to the above mentioned algorithm, Gisu shall be propelled forward by the calculated distance accordingly to reach the user. Upon reaching the user successfully, without any obstacle getting in the way or being detected, the buzzer shall beep twice. This method allows for precise movement of Gisu, allowing the user to sit down with relatively more ease. In the case of an obstacle being detected, the method of handling this situation is described in the next sub-section along with a flow chart.

As explained at the beginning of this subsection, the concept of similar triangles is used to find the distance from the camera to an object. It works as follows. First the height of the object is input into equation 1. Then the captured image will be converted into greyscale so that edge detection can be easily applied to the image. The image is blurred by an extent to remove any noise that might be present. After applying edge detection, differentiation of all the objects present becomes easier as the assumption is that the object with the largest contour area is the required object. With this the contours of the specific object need to be found. Once the contours of all the objects present in the view are established, the contour with the largest area is assumed to be from the specific object, namely the user. The focal length of the RGB camera used is 14.44 cm and the height of the object will be input beforehand. The measurements of the binding box for the object will be taken in pixels and all these values when input into equation 1, will result in the distance from the required object to the camera.

Though ultrasonic sensors are used majorly to calculate distance and also implemented in some smart wheelchair based research efforts [12], the reason for abandoning that approach is due to their instability when considering the scenario of Gisu. Some contributing factors are the issues with the probe and the potential for inaccurate results. As it is quite difficult to control the waves emitted from the transmitter of the ultrasonic sensor, obtaining only a limited structural profile of an object is achievable. Furthermore, non-homogeneous objects like human legs, are harder to obtain data from. But with the camera based approach discussed above, these problems are easily circumnavigated.

4) Obstacle detection.

Obstacle detection is quite important as it helps different between the actual user and any unwanted object on the path between the user and the chair. There are many methods of obstacle detection and [5] represents the most advanced method till date. Gisu differentiates between an obstacle and the user in quite the simplistic manner. After calculating the distance from Gisu to the user, its forward propulsion will be initiated. It is programmed to halt immediately when either the ultrasonic sensor detects any object or when the calculated distance has been traversed completely. If the ultrasonic sensor detects any object in front of it after Gisu has traversed the entire distance calculated in 2) then it shall assume that the object in front of it is the user. If it has not traversed the full distance but detects an object midway, then that object shall be classified as an obstacle. Fig. 8 depicts the flowchart of the obstacle detection algorithm.

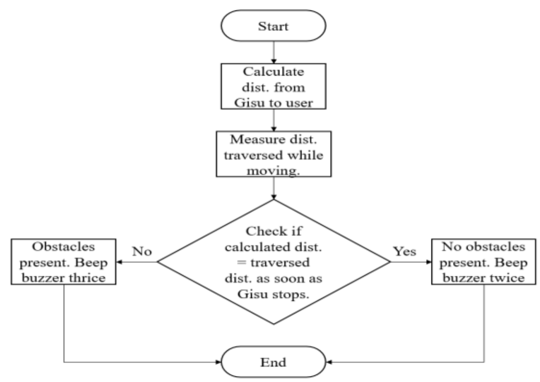

Fig. 7. Flowchart of the obstacle detection algorithm.

IV. Experimental Results and Remarks

To confirm the working of the system as a whole, this section is divided into two sub-sections, which go in-depth regarding the results of each functionality of Gisu.

A. The distance calculation algorithm

The distance calculation algorithm, it is initially performed on two different objects of different heights as shown in Fig. 8.

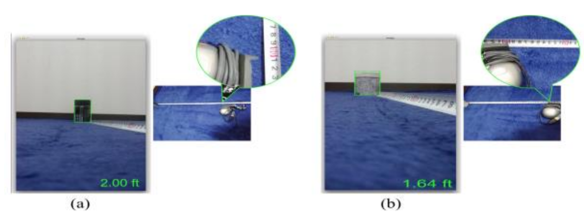

Fig. 8. The distance calculation algorithm being tested with 2 objects of different heights.

To conform the actual results, a measuring tape is placed next to the base of the camera and the results are compared. The image on the left-hand side of Fig. 8(a) shows the screenshot of the distance calculation algorithm running. The right-hand side of the same shows a picture of the camera being placed next to a measuring tape to confirm the distance from the camera to the object. The same can be said for Fig. 8(b) where a different object is tested with the same conditions at a different distance as that of the former.

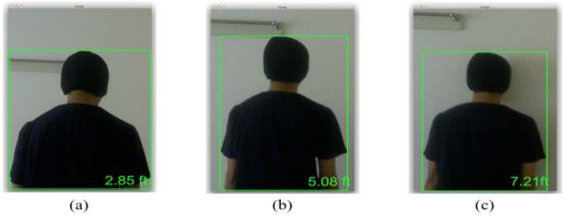

Fig. 9. The distance calculation algorithm being tested with a human subject from different distances

Next, the same algorithm is used to calculate the distance from human subjects to be able to confirm the working efficiency of the algorithm. Fig. 9, shows the algorithm being tested for three different distances with a human subject as the object for this trial. It runs smoothly while displaying the distance correctly with an accuracy loss of two/three cm.

B. *Overall working*

The overall working of the prototype, Gisu that is the pose recognition, pose classification and the distance calculation are discussed next. Fig.10 contains screenshots of these three algorithms when they work together. Each of Fig.10 (a), 10 (b) and 10 (c) contain proof of the working of each of human skeletonization, pose recognition, pose classification, the accuracy up to four digits in the decimals and the distance calculation algorithms.

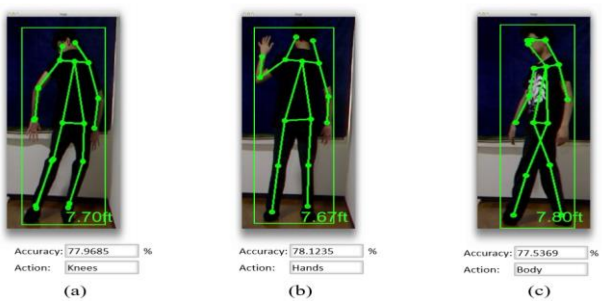

Fig. 10. Screenshots of the overall working of Gisu's software.

C. *Experimental cases.*

1) In this test, the user simply stands in front of the wheelchair by a distance of 236.00 cm. The user then performs the first pose class used for this prototype, the knee pose. Since there is no obstacle in the path the wheelchair arrives behind the user in 5.28 seconds and the buzzer beeps twice to let the user know that the wheelchair is behind them. The distance calculation algorithm calculates the distance during this trial as being equal to 234.69 cm. Even though there is an error of a negative 1.31 cm, as the value is not a large difference, the user can still sit down on the wheelchair.

2) The second trial was run with the presence of an obstacle, a small cardboard box being placed in between the user and the wheelchair at a distance of 100 cm from the wheelchair. The user stands in front of the wheelchair by a distance of 236.00 cm with the obstacle being in between the user and the wheelchair. The user then performs the second type of pose from the pose class used for this prototype, the hand pose. Since there is an obstacle this time around, the propulsion of the wheelchair is stopped the moment the ultrasonic sensor detects an object before having traversed the complete calculated distance and the buzzer beeps thrice to alert the user the presence of an obstacle. Therefore, while the skeletonization and the distance calculation algorithms worked, the wheelchair is halted due to the presence of an obstacle.

3) During the third test case, the wheelchair was tested for, using no obstacles and at a distance of 305 cm. Upon performing the second pose class, the hand pose, the wheelchair reacts satisfactorily by being propelled forward and then buzzing twice upon arriving behind the user. The distance as measured by the algorithm is equivalent to 303.97 cm. Here, the calculated distance is lesser than the actual distance by 1.03 cm. The time required to cover this distance is 6.86 seconds.

4) The fourth trial was a little unique in that a pen was placed right in front of a rear wheel of the wheelchair, but behind the ultrasonic sensor. Hence while the ultrasonic sensor was unable to detect it, it was still as an obstacle. The user and the wheelchair are apart by a distance of 150 cm. After performing the same trial twice, a conclusion was drawn. In the **first trial**, upon performing the body pose, while the wheelchair is capable of detecting the pose and reacting to it, the wheelchair fails to reach the user as the rear wheel slips on the cylindrical pen body, which means that while not having gained any distance, the software calculates the slip as part of the distance traversed and hence the wheelchair stops prematurely before properly arriving behind the user. In the **second trial**, upon performing the hand pose, the wheelchair is capable of detecting and reacting to the performed pose. Then the wheelchair manages to climb over the cylindrical pen body without slipping and loosing rotations. The wheelchair then reaches the user normally and completely, beeping the buzzer once behind them. In conclusion of this particular case, to be able to come over such instances of unfavorable outcomes, either the rear wheels should have greater diameter or the dc motor should be more powerful to achieve a higher speed which can then help negate the effects of the opposite force experienced by the rear wheels upon placing any object right in front of the rear wheels.

5) The last and final case was about tests performed on an inclined plane, with an inclination angle of 15 degrees. Sub-case one: Here, the wheelchair was placed upon an inclined plane without any obstacles in between the user and the wheelchair. Upon performing any of the specified actions, the wheelchair can successfully maneuver towards the user though the speed is considerably lessened, leading to quite a delay as compared to the other tests. However, upon traversing the calculated distance, the wheelchair does halt properly and beeps the buzzer twice. If the inclination angle is more than 15 degrees, then there are chances of the wheelchair slipping backwards.

6) The efficiency of the wheelchair, however, drops drastically when used in a dark environment as the camera used is a regular RGB camera and cannot accurately form a skeleton of the human. Hence, the prototype has to be used in a well-lit environment.

V. Conclusion and Future Work

The objective of this research was to develop a prototype for a smart wheelchair that would assist the elderly in living their day-to-day lives with relative ease. When the user performs a certain pose the wheelchair is propelled forward eliminating the strain and effort required to search for the wheelchair behind them, locate it and then sit down. Experimental results show that the wheelchair indeed reacts to the performed poses appropriately.

In the two-phase process of skeletonization and classification, the first phase of forming a skeleton of the user's body is done with relative ease as compared to the pixel density based star skeletonization of [9] and the LSTM approach used in [11]. The second phase of classifying the pose into one of the three categories of poses is performed by a ResNet-18 with an accuracy averaging 77.87%. The distance calculation module is capable of calculating the distance from Gisu to the user accurately with an error of just a few centimeters. There seems to be very few problems concerning the obstacle detection module as it is capable of classifying any object it encounters when not having traversed the entire distance as calculated by the distance calculation algorithm and alerting the user by sounding the buzzer thrice. Upon traversing the full distance calculated, Gisu beeps twice as intended to let the user know that the wheelchair is behind them. The difference in the number of beeping can ensure that there are no misunderstandings between the user and Gisu.

Though there are many wheelchairs aimed for the differently abled and the geriatric population of the society, in a manner similar to [2] and [3] the proposed prototype, Gisu, introduces a new concept and possibly a new nuance of functionality for the smart wheelchairs. Just like how [1], [6] and [8] introduce different functionalities to smart wheelchairs, this paper aims to be able to contribute an entirely new method of easing the strain of carrying out daily activates on the elderly. While the motive behind this research was to build a prototype, Gisu, that can assist the elderly in their daily lives, it in no way means that the prototype as a standalone is a superior product that can help cater to every single need of the user. The aim was mainly to be able to add another novel means of assisting the elderly in their daily lives, which when put together with other such similar work, helps ease the strain.

Since the proposed work is but a prototype that focuses on one particular aspect of improving the quality of life for the elderly, Gisu incorporates the functions discussed previously. Some major areas of future work include more rigorous training and testing of the classification algorithm. Implementing automatic obstacle avoidance instead of just detection. Another major feature that can help improve the prototype is to use Lidar or IR sensors to compensate the prototype being unable to work in the dark.

Wheelchairs when equipped with more functions, the quality of life improvement provided by them is that much more profound in the lives of the elderly. Hence, some other added aspects of future work may include usage of many other research themes and/or ideas. Some such functions are the automatic navigation around given environments much like [8]. There are other methods for auto navigation like incorporating LIDAR sensors or using GPS oriented navigation. This would make life for the elderly much more simple as they can completely depend on the wheelchair for navigation.

Acknowledgement

I would like to offer my deepest and sincere most gratitude to my supervisor, Runhe Huang for the constant support and the invaluable guidance.

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