Real-time obstacle detection to assist wheelchair navigation

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Assistive technology (AT) is a branch of technology with the specific purpose of helping people with disabilities or other impairments. AT is a vital resource for many visually-impaired individuals who may encounter difficulties navigating their environments (Bhowmick & Hazarika, 2017). Individuals may experience visual impairment due to traumatic brain injury, which may also include additional cognitive deficits, paraplegia, or other disabilities that may necessitate the use of a wheelchair. In the United States alone, there are around 2.7 million wheelchair users, many of who are blind, otherwise visually impaired, or have trouble identifying obstacles (Koontz et al., 2015). As estimated by the American Federation for the Blind, 9.61% of individuals who are legally blind and 5.25% of people with severe visual difficulties who are not legally blind use a wheelchair (Simpson et al., 2005). Due to this high number of visually impaired wheelchair users, assistive technology is necessary to ease navigation and wheelchair use.

Background

The use of AT to assist, empower, and protect visually impaired individuals who use wheelchairs has spurred inventions and patents that address numerous issues. These include obstacle detection, warning, avoidance systems, and autonomous navigation. Additionally, technologies originally designed outside of wheelchair use may apply to wheelchair users and accelerate the generation of tailored assistive technology.

Devices that provide warnings to users based on their environment use a plethora of computational and hardware strategies to protect the user from potentially dangerous terrain or environments. Abita et al., (1998) patented a device to assist visually impaired wheelchair users who use high-speed railway transit systems in major cities without the help of an additional human. An Infrared Integrated Indicating System (IRIIS), which uses optical emitters to send a warning signal to an external device, is the primary sensor for the device. The emitter creates a beam of light, which checks for potentially dangerous objects that fall into the light. Once the object is identified to be in the way, a warning signal is sent to an external device that the wheelchair user can access. The device is also designed to stop once the user reaches a specific point on the boarding platform (Abita et al., 1998). Light-based scanning is thus a possible method for obstacle detection. We may turn to accessible, modern methods of light-based scanning, such as Light Detection and Ranging (LiDAR).

Additionally, patents exist on technologies that aim to map the potential obstacles in a given environment. Passot (2021) has created a blind spot detection system for robots through the use of sensors. These sensors are connected to the same power source as the robot itself. The primary purpose of the sensors is to constantly scan the area surrounding the robot and then report to a computer system whenever an obstacle is detected. This computer system can map the obstacle on a computer-readable map. The main issue with these sensors is that they can only cover a limited range of view since they are designed more for the small spots that the robots are not able to see. These sensors are only designed for movement through two-dimensional spaces and focus more on ranged distances than rotational adjustment (Passot, 2021).

Electronic Travel Aids (ETAs) are a type of travel aid designed to help people with visual impairments be able to travel without the direct assistance of another person. There are two main types of ETAs, primary and secondary. A primary travel aid, for example, a guide dog, can navigate a new environment independently. A secondary travel aid relies on a primary travel aid, and most technologies fall in this category (LoPresti, 2004).

One piece of technology designed to be used as an ETA is LoPresti's power apparatus for wheelchairs which alerts users about a potential environmental obstacle in the way of a wheelchair. The technology used for this aid is similar to the Nurions Wheelchair Pathfinder, which can alert the users about potential obstacles using sonar sensors and laser range finders (to detect drops) coupled with sound or vibration alerts. However, unlike other past products, this system can act independently and does not require the user to correct its actions, and it is explicitly designed for manual wheelchairs.

Compared to electric wheelchairs, manual wheelchairs do not have built-in obstacle avoidance systems. LoPresti incorporates these add-on features with an ETA (electronic travel aid) that can be adjusted and mounted to manual wheelchairs. In addition to the obstacle avoidance system, which can incorporate bump-switches, infrared range-finders, sonar sensors, the system uses motorized hubs that amplify the force applied by the user on the manual wheelchair and relay information to the user by affecting the amplified force on the wheels (LoPresti, 2004).

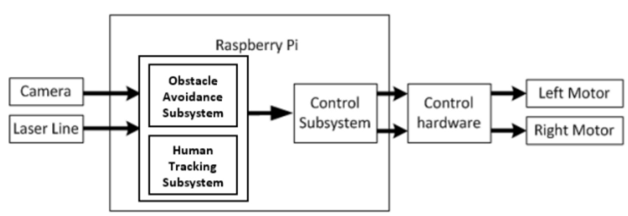


Figure 1. Block diagram of the smart wheelchair system.

Another piece of technology used to help visually impaired wheelchair users is a smart wheelchair designed by Utaminingrum et al. in 2017, which is meant to be able to detect both obstacles and humans in the path of the wheelchair. The technology and methods used are vital to understanding the successes and drawbacks of the system. The central processing unit used by this system was Raspberry Pi 2 with 900 MHz quad-core ARM Cortex-A7 CPU, 1 GB of RAM, integrated with Raspbian Wheezy OS and OpenCV 3.0 as the image processing library. The group used the random sample consensus (RANSAC) method (with significantly lower error than linear regression). They combined line laser and camera imaging techniques to accelerate and simplify mathematical calculations while acquiring information on the object in front of the wheelchair. The shape of the line laser changes based on the pattern/outline of the object's surface and its distance from the wheelchair. A diagram further showing the breakdown of the technology used in this device can be seen in Figure 1 (Utaminingrum et al., 2017).

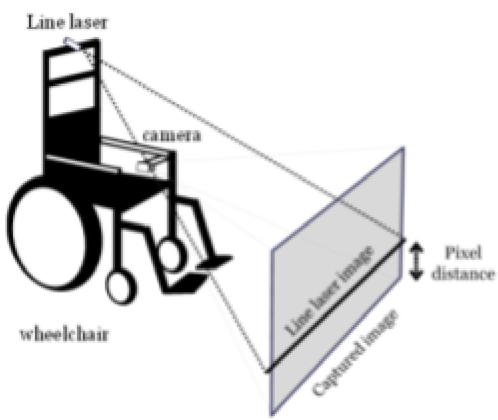


Figure 2. Laser line and camera mounting configuration.

In terms of both hardware and software and how they connected to the goals of the prototype, a camera was placed and aimed at the front side of the wheelchair (See Figure 2). An algorithm was developed based on the captured video to track and follow the human movement to reach a particular location.

An innovative line laser technique was used, which allowed obstacles that the laser line imaged touched to appear on the camera, placed in a high enough position for the user to see them (as pictured in Figures 3 and 4). The closer the object, the higher the position it will appear in the camera (Utaminingrum et al., 2017).

RANSAC is also detailed both in application and method. RANSAC is an iterative method to estimate parameters of a mathematical model from a set of observed data that contains outliers when outliers are to be accorded no influence on the values of the estimates. Therefore, it also can be interpreted as an outlier detection method. It is a non-deterministic algorithm because it produces a reasonable result only with a certain probability, with this probability increasing as more iterations are allowed. RANSAC uses repeated random sub-sampling. A basic assumption is that the data consists of "inliers", for example, data whose distribution can be explained by some set of model parameters, though may be subject to noise, and "outliers", which are data that do not fit the model (Utaminingrum et al. 2017).

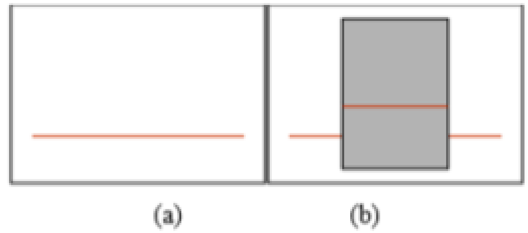


Figure 3. Image captured by the camera with (a) no obstacles, (b) an obstacle in front of the wheelchair.

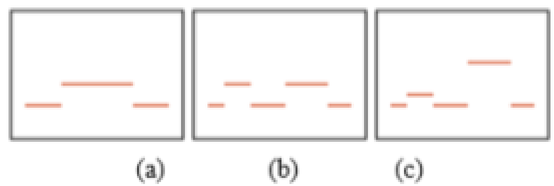


Figure 4. Image of the laser line with (a) one obstacle, (b) two obstacles of the same distance, and (c) two obstacles of different distances.

Lozano and Areco (2018) explored engineering a fully autonomous wheelchair. The content of this patent includes a multitude of designs and features for an autonomous wheelchair, including a control module, a manual control mechanism, a camera, biometric sensors, and an antenna (Lozano & Arceo, 2018).

The biometric sensors can be used to collect necessary parameters to ensure user comfort and efficacy of the device. For instance, the wheelchair can monitor heart rate, temperature, and blood pressure. This data can then be run through additional systems within the wheelchair to adequately respond to the user and ultimately make them more comfortable. For instance, if the user is too hot, the HVAC (heating, ventilation, and air cooling) system within the wheelchair can be activated to cool them or their seat down. These sensors can be customized to fit the needs of the user and specific issues that they may want to be addressed.

Additionally, the wheelchair may include an antenna. The antenna can be used to connect to a Wi-Fi system, connect the wheelchair to a cellular line, and/or a GPS antenna which is connected to a GPS system. The GPS aspect would enhance the autonomous navigation of the chair and may also be used for routing a third party in the instance of an emergency. The cellular antenna may be used for communication with a third party (inclusion of a microphone within the wheelchair).

The camera is a guidance sensor that detects objects within the path of the wheelchair while also looking for optimal paths to follow. If a specific area has lane markers, the wheelchair can detect and stay within these markers to ensure safer travel.

The control module of the wheelchair consists of the processor hardware, which executes code, and the memory hardware, which stores the user’s data. The wheelchair includes a customization module that uses recognition (facial or other) to access the user's preferences. This feature can be used to save favorite locations, connect emergency contacts, and adjust the chair physically.

The navigation module allows for the chair to pilot itself. If the user is lost, the chair can map a route back to a predetermined location. With the guidance sensor and the GPS antenna, the chair enables safe and efficient travel in indoor settings. Additionally, the user may pilot the wheelchair through the manual control system by using a joystick or by inputting desired commands into a touchscreen control panel (Lozano & Arceo, 2018).

Obstacle detection technology needs to be adaptive, dynamic, and fast in order to keep an individual out of harm's way. Typical obstacle detection methods utilize image-based analysis by receiving input from a camera, converting the data to motion vectors, and predicting the behavior of those vectors. These systems struggle with moving obstacles, where the motion vectors experience rapid shifts which can overwhelm the computational processing of the detector system. This patent from Okada in 2008 proposes a detection apparatus that is able to accelerate the analysis and detection of moving obstacles, thereby decreasing the impacts of slow processing speeds and allowing for more stable image analysis. The apparatus is described in Figure 5 (Okada, 2008).

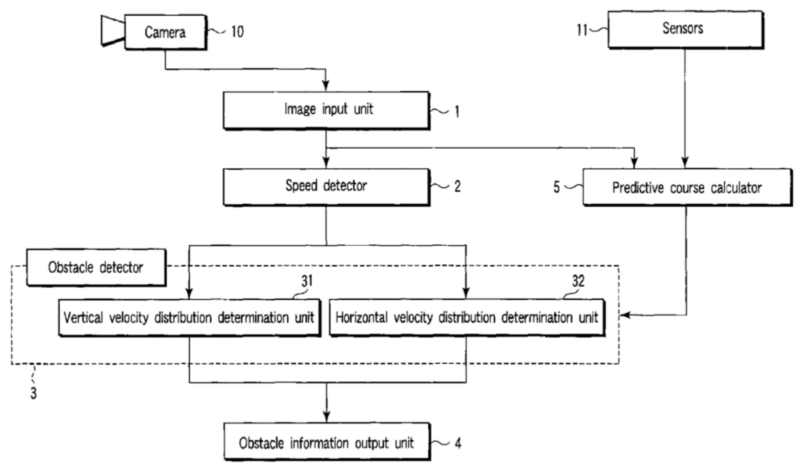


Figure 5. Breakdown of apparatus meant to accelerate analysis and detection of moving obstacles.

More recent innovations in navigation assistance technology have employed the use of LiDAR (light detection and ranging) sensors. LiDAR sensors emit beams of light and interpret interruptions to the path of the light as objects. Grewal, et al. (2017) show LiDAR can be used to assist an individual with severely reduced motor function. Pairing the LiDAR sensor with an ultrasonic module which allows for multi-planar scanning and a robot operating system

Figure 6. Obstacle map using LIDAR and ultrasonic proximity sensor.

(ROS) allows the device to adaptably map the user's environment and pilot the wheelchair (Grewal et al., 2017). The device was highly effective in indoor environments, successfully navigating to the endpoint in all cases. This was accomplished through use of an Adaptive Monte Carlo Localization (AMCL) algorithm, which was able to quickly localize objects in the user's environment (Figure 6). Additionally, an Arduino-based microcontroller allowed for precise movement based on communication with the ROS. The device was placed above the user's head and the autonomous controller was placed on the wheel (Figure 7). Though an effective assistive technology for users of electric wheelchairs, the device is incompatible with manual wheelchairs (Grewal et al., 2017).

Figure 7. Wheelchair affixed with LiDAR sensor and rotary encoders.

Assistive technology devices designed to help visually impaired wheelchair users are becoming even more needed in a growing world. Though many devices have been created to try and solve this problem, many fall into the same issues of only being able to do part of what the user needs and having a high cost. Due to these major issues, this device that will help so many still has a long way to go.

Market Research

The Braze Mobility sensor is a blind-spot detection device designed for wheelchair users (pictured on the right) (Braze Mobility, 2020). The device alerts the


The Braze Mobility Sensor

user when something is within the adjustable danger zone, which ranges from one to four feet away from the wheelchair. An auditory, visual, and mechanical alert system is all available for use through an external device that is accessible to the user. On this device, there is 180° horizontal coverage and 55° vertical coverage. This device is small and adaptable for a variety of wheelchairs and has prices starting at $2,255 each (Braze Mobility, 2021).

LUCI is an attachment-based smart technology that is made to fit on existing wheelchairs. It uses stereo vision, infrared, ultrasonic, and radar data in order to provide a warning for both drop-offs and potential collisions. The LUCI device connects to the cloud and is compatible with smart devices such as Amazon's Alexa and Google Assistant. It is also able to be attached to the seats and the wheels of current wheelchairs. LUCI falls into the price range of around $8500 per device (LUCI, 2021). A wheelchair equipped with the LUCI technology is pictured on the right (LUCI, 2020).


The LUCI Sensor

The Whill Model A is an adapted wheelchair that allows users to more easily avoid obstacles in new environments. This device combines responsive mouse control and electromagnetic braking to quickly avoid obstacles. The electromagnetic brakes are also able to stop on an incline. Additionally, it can be remotely driven from an iPhone with a range of 12 miles. For users not remotely driving, the on-chair control can be used by the left or right hand. This wheelchair can clear obstacles up to 3 inches in height and is

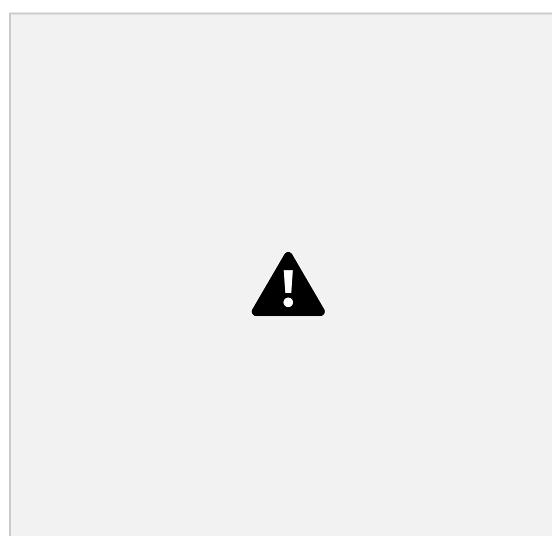

The Whill Model A Wheelchair

an all-wheel drive. This device has a charging time of eight to nine hours. While this wheelchair does work to avoid obstacles, it is unable to alert the wheelchair user or use obstacle detection. This device is priced at $6,999 (Whill Inc, 2021). A Whill Model A wheelchair is pictured on the right (Whill Inc., 2016).

The SenseStat® Wireless Obstacle Detection System is a wireless, stand-alone system designed to allow truck drivers to detect objects they may not be able to see fully when reversing. While not designed specifically for wheelchair users, the device may be mounted onto any vehicle by the user. The device features wireless backup sensors with a detection range of 0.22 ~ 2.5 meters. Additionally, the device has a communication module that provides both visual and auditory cues to the user to communicate the proximity of any obstructions. This device retails for $432.47 (Rear View Safety, 2022). The SenseStat® System is pictured on the right (Rear View Safety, 2022).

SenseStat® Wireless Obstacle Detection System

The Phoenix iWheelchair is an adapted wheelchair that is designed to reduce the impact when the user comes in contact with an obstacle. This wheelchair is light in weight and includes an adjustable center of gravity allowing for more agility and stability. The wheelchair also includes electronic braking, power assist, and impact



resistance. The main issue with this wheelchair comes from the main goal in the design which is to reduce the impact of hitting an object rather than detecting an object and eliminating impact altogether. It also does not have a function that allows for the user to be alerted in case of impact (Phoenix I Wheelchair, 2021).

The next competitor is the Brigade Backsense: Blind Spot Detection device, which is designed for larger vehicles to be able to easily sense their potential obstacles. This device is meant to target specific areas which are known to be harder for large vehicles to be able to see

Brigade Backsense: Blind Spot Detection

and through the use of ultrasonic and infrared sensors, is able to detect both stationary and moving obstacles. Along with all of that, this device has a large angular range allowing for objects to be detected well in advance. One major issue with this product in terms of being used for wheelchair detection is the fact that it is really only designed for use by large-scale vehicles. Not only does this cause large and bulky parts, but on a larger scale, the sensor is less specific, which can cause issues for detecting smaller objects. The interface is also not accessible to users with visual impairments (Radar Obstacle Detection, 2022).

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