Obstacle Detection Methods

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Introduction

With the rise of autonomous navigation systems, there is an increasing need for self-sufficient systems that can guide themselves using only information they gather about the environment. Since such systems receive little (if any) external guidance, they must include robust obstacle and hazard detection systems to prevent hazards in the environment from damaging the vehicle. There are a variety of methods for detecting obstacles in autonomous systems, with each suited for different situations and limitations. Some of the most common sensors for obstacle detection include LiDAR (2-D or 3-D), cameras (two or more to create a stereo system), and ultrasonic sensors. Each of these methods have limitations that make them more suited for certain uses than others.

LiDAR

Overview

LiDAR, which stands for Light Detection and Ranging, is a time of flight (ToF) sensor, meaning it measures the distance of an object by emitting short pulses of light and measuring the time it takes for the light to return to the sensor. The main advantage of LiDAR obstacle detection is that it has high precision and a larger range than other methods. However, this higher precision can contribute to longer processing times due to large amounts of data being collected. In more robust systems, LiDAR can be processed in either two or three dimensions. As the names suggest, 3-D LiDAR captures a three-dimensional image of the sensor's surroundings (including x, y, and z axes), while 2-D LiDAR captures a plane of data without including height (x and y axes only).

Methods

The first step in 2-D LiDAR obstacle detection is scanning a series of points to generate a point cloud of raw data. The raw data is then filtered, typically using a median filter, in order to filter out initial noise in the data. The data is then preprocessed, which consists of segmenting the point cloud into blocks of points that have similar distances [1]. Based on this segmentation and the known width of the vehicle, these blocks may be combined into larger blocks if two blocks are sufficiently close enough to each other that the vehicle would not be able to pass between them. Otherwise, the blocks are separated into separate obstacles. Figure 1 demonstrates the

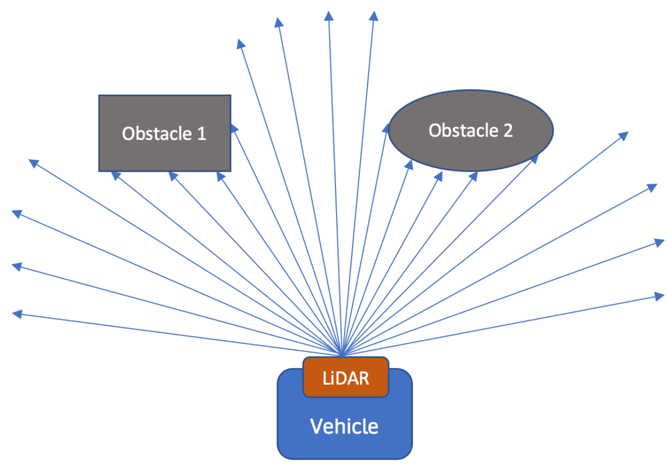

Figure 1: LiDAR pulses (blue arrows) hitting obstacles in the environment of the vehicle.

separation of blocks into obstacles based on the results of the LiDAR data. Once the blocks have been either merged or segmented, the geometry of the obstacles can be predicted using the number of points in the block and the characteristics of their spread. For example, more than 5 points in a block with a width of less than 0.2*length could mean a line geometry [2]. Once all detected blocks are identified, a path can then be planned for the vehicle that avoids all known obstacles in the surroundings. After the vehicle has traversed through these obstacles, this process is repeated until the vehicle reaches its destination.

Camera

Overview

Cameras are another type of sensor commonly used in obstacle detection systems. In such systems, more than one camera is typically used to create a stereo system in which multiple cameras are used to generate a 3-D image of the surroundings. One advantage of stereo vision is that it is a passive sensing technique, meaning it takes measurements of the environment without requiring any additional information (like light used in LiDAR). This method also provides highly accurate depth measurements once calibrated. However, this calibration is the main challenge with stereo vision as finding corresponding points in different images so that a distance estimate can be calculated can be difficult [3].

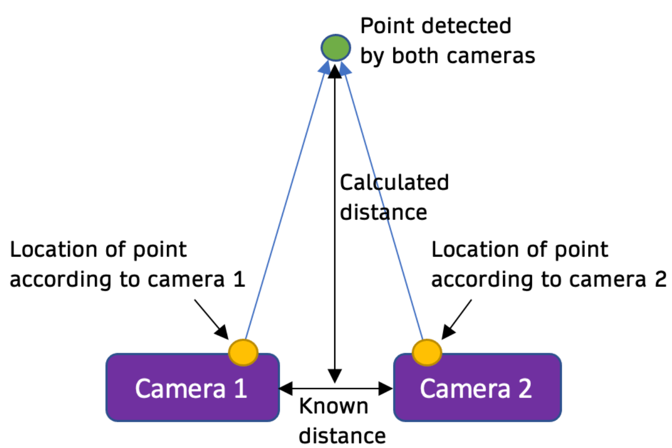

Figure 2: Stereo vision system using two cameras to calculate the distance to a single point.

The simplest form of stereo vision is a two-camera, or binocular system, as depicted in Figure 2. In this system, two images are compared in small windows to find the most similar windows in each image, and the differences between the windows are found. The physical layout of the two cameras can then be used to calculate a distance estimation to the object detected in the images.

A more complicated version of stereo vision uses three cameras instead of two. One version of this trinocular system consists of one pair of horizontal cameras, with the third camera creating a vertical pair with one of the others. This orientation of cameras can resolve images that may be limited by a two-camera horizontal system, as in the case of a horizontal line [4]. The addition of a third camera allows the system to generate a depth estimate by comparing the two vertical cameras, which in this case would not be possible with only two cameras oriented horizontally to each other.

Methods

Using the example of a two-camera stereo system for obstacle detection, if the cameras are oriented precisely enough with relation to each other, disparities can only occur horizontally between the two images. In order to establish correspondence between the images, blocks of intensity are compared and matched (rather than individual pixels, which would not be possible without very high image precision) [3]. This is accomplished by choosing a block in one of the images, then incrementing through blocks in the second image and choosing the one that is most similar in intensity. Once the images have been correlated, a distance map can be generated using the geometry of the camera system and the detected disparities between the images. This distance map is then used to determine the safest path for the vehicle.

Ultrasonic Sensors

Overview

The final type of obstacle detection covered in this report uses ultrasonic sensors, which transmit and receive ultrasonic pulses to determine the distance to an object. Similar to LiDAR, the time elapsed between sending and receiving the pulse determines the distance of the object off which the pulse was reflected. The advantage of ultrasonic sensors compared to optical and LiDAR sensors is their ability to function even in the presence of environmental factors that can hinder vision, such as dust and smoke. However, due to their relatively low accuracy and sensitivity to air temperature, either multiple ultrasonic sensors or other additional sensors are required in order for the system to function in high-sensitivity situations [5].

Methods

In the case of a system with multiple ultrasonic sensors around the body of an autonomous vehicle, the vehicle is directed forward until an object is detected below a determined threshold of distance in front of the vehicle. It then turns itself until the object is no longer detected by the front sensors and is instead detected by the side sensors, as depicted in Figure 3. By taking the difference between the current ultrasonic reading and the previous reading, the vehicle can either turn toward the obstacle if it is veering away, or away from the obstacle if it is veering too close [5]. The vehicle continues to orient itself such that it is traveling parallel to the obstacle until either the obstacle ends or the vehicle has traveled around it and can thus continue on its path. This method allows the vehicle to traverse unknown terrain without knowing the exact dimensions of the obstacles it may encounter.

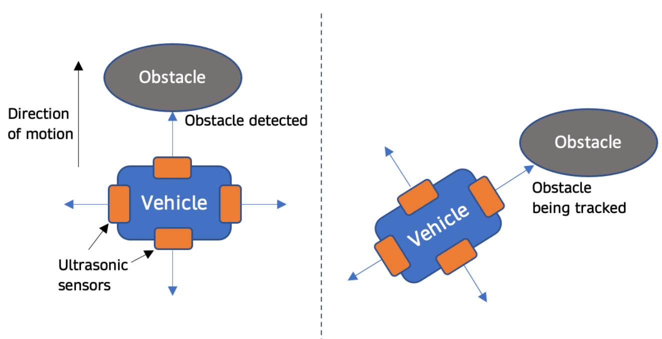

Figure 3: Vehicle with multiple ultrasonic sensors detecting an obstacle (left) and reorienting itself to travel around the obstacle (right).

Conclusion

Obstacle detection can be accomplished with a variety of different techniques and sensors, with each suited better for some applications than others. LiDAR can provide extremely high precision in distance estimates, but such higher precision leads to higher sensor cost and longer processing times. Sensing methods using LiDAR may also be less accurate in certain environmental conditions like smoke. Stereo camera systems can also provide accurate distance measurements using passive rather than active sensing methods, yet additional processing is required when comparing images from multiple cameras. Ultrasonic sensors are less sensitive to environmental conditions, but are inherently less accurate, meaning they must be supplemented with other sensors.

References

1. Ghorpade, D., Thakare, A. D., & Doiphode, S. (2017). Obstacle Detection and Avoidance Algorithm for Autonomous Mobile Robot using 2D LiDAR. *2017 International Conference on Computing, Communication, Control and Automation (ICCUBEA)*, 1–6. https://doi.org/10.1109/ICCUBEA.2017.8463846.

2. Peng, Y., Qu, D., Zhong, Y., Xie, S., Luo, J., & Gu, J. (2015). The obstacle detection and obstacle avoidance algorithm based on 2-D lidar. *2015 IEEE International Conference on Information and Automation*, 1648–1653. https://doi.org/10.1109/ICInfA.2015.7279550.

3. Zhao, Y., Cheng, W., Jia, L., & Ma, S. (2010). The obstacle avoidance and navigation based on stereo vision for mobile robot. *2010 International Conference on Optoelectronics and Image Processing*, *2*, 565–568. https://doi.org/10.1109/ICOIP.2010.14.

4. Murray, D., & Jennings, C. (1997). Stereo vision based mapping and navigation for mobile robots. *Proceedings of International Conference on Robotics and Automation*, 2, 1694–1699 vol.2. https://doi.org/10.1109/ROBOT.1997.614387.

5. Gupta, N., Makkar, J. S., & Pandey, P. (2015). Obstacle detection and collision avoidance using ultrasonic sensors for RC multirotors. *2015 International Conference on Signal Processing and Communication (ICSC)*, 419–423. https://doi.org/10.1109/ICSPCom.2015.7150689.