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Panoramic Sensor Based Blind Spot Accident Prevention System

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Abstract **–** There are many automotive accidents due to blind spots and driver inattentiveness. Blind spot is the area that is invisible to the driver's viewpoint without head rotation. Several methods are available for assisting the drivers. Simplest methods are – rear mirrors and wide-angle lenses. But, these methods have a disadvantage of the requirement for human assistance. So, the accuracy of these devices depends on driver. Another approach called an automated approach that makes use of sensors such as sonar or radar. These sensors are used to gather range information. The range information will be processed and used for detecting the collision. The disadvantage of this system is – low angular resolution and limited sensing volumes. This paper is a panoramic sensor based automotive vehicle monitoring..

K***eywords***: Panoramic sensors, Blind spot, Convex lens, Computer Vision, Sonar.

I. Introduction

BACKUP collisions are when a driver puts the automobile in reverse and runs into an object, person, or other car. All cars are equipped with rear view mirrors, which are adequate for detecting vehicles behind a car, but they are often inadequate when it comes to detecting small children or objects that are low to the ground and fall in the car's blind spot. Large trucks have much larger blind spots that can hide entire vehicles and large adults.

According to research by Kids and Cars - an organization devoted to preventing (non-traffic) motor-vehicle-related deaths and injuries to children - 49% of the non-traffic, vehicles that were backing up caused non-crash fatalities involving children under 15 from 2001-2005. The Centers for Disease Control (CDC) report that from 2001-2003, an estimated 7,475 children under the age of 15 were treated for automobile back-over incidents. There are tragic accidents that happen everyday, drivers backing over children they cannot see because of blind zones. Statistics reveals that 75% of automotive accidents are due to blind spots and driver inattentiveness.

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Traditional definition of blind spots is any area that a driver cannot see when only looking in their mirrors as shown in figure 1. There are two main methods currently available: Human Observation – In this method, the blind-spot mirrors are used. This can reduce the range of blind-spot area. Wide-angle mirrors can also be used in this method to view the area directly behind the vehicle. Automated Monitoring Systems – Systems that use sonar or radar to detect obstacles are placed in this category. When the object comes too closer to the rear of the vehicle, it generates an alarm.

The specifications formulated for this project are as follows:

a. The monitoring zone behind the vehicle should be as close to the vehicle as possible.
b. The system should have at least 180º of sensing
c. The working volume should have a radius of 5 meters and height of 3 meters
d. The accuracy of the system should be within 20 centimeters
e. The system should be operable in real-world environments

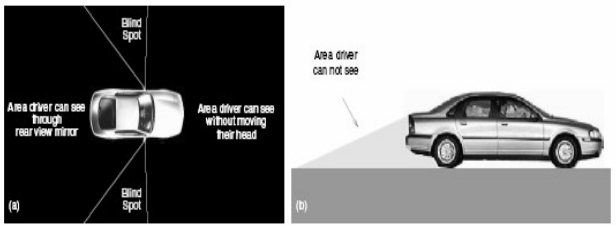


Figure 1 (a & b) Blind-spot definition

II. Related Work

There are large financial costs associated with these rear collisions and blind-spot accidents, apart from severe injuries and fatalities that can be caused. This section presents the currently available technologies, which attempt to solve the problem, and puts forth an introduction to alternative approach. The characteristics of each system will be discussed, and their limitations highlighted.

There are several methods that are available currently to assist drivers in avoiding rear end collisions. These systems falls into two main categories – the first utilizes the human observer i.e., the drivers are presented with raw data, and driver based on this information will take the decision. The second category is automated monitoring systems. This

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uses sensors to determine the position of objects around the car, and warns the driver in the event of impending collisions.:

A. Human Observation

a Blind Spot mirrors

This approach is the cheapest for installation and is designed for installation on the sides of the vehicle, to decrease the unseen area (blind spot). But, there are significant blind spots at the front side in cases of trucks. There are also wide-angle mirrors fixed at the rear of the vehicle in order to provide the view of the area behind the vehicle. But, these images were usually highly distorted and upside down. This system requires the driver to learn how to interpret images. So that, the driver can controls the vehicle effectively. The disadvantage of this approach is efficiency and sensitivity of these mirrors relies solely on the driver's efficiency to interpret images. One more drawback is that in some cases these mirrors will be hided by the payloads inside the vehicle.

b Wide Angle Lenses

This is another cheapest approach that can be used to provide a larger field of view to the driver and are designed for installation at the rear window of the vehicle. A wide angle lens for a vehicle rear window is movably held in a guide device which is fixed to the body of the vehicle. The lens can be moved out of the rear view field of vision of the driver for normal forward driving namely, it can be moved along the guide device. The lens is brought into the rearward field of vision only when the vehicle is to be maneuvered in reverse. The MAA evaluated several products and the following are their observations:

a. The image viewed in the lens was often too small
b. The image tended to be distorted and fuzzy
c. At certain angles of sunlight, the lens appeared "milky", and reduced visibility
d. If the lens was located to provide optimum image quality, the normal view to the rear of the vehicle was obscured.

c *Conventional Video Cameras*

This approach is the most expensive that can be used to prevent reversing accidents. This system usually consists of a video camera mounted to the rear of the vehicle and a monitor mounted inside the cabin for the driver to view. One such device that is currently available in market is Donnelly Video Mirror with Reverse Aid. Standard cameras have a field of view between 30º and 45º. This makes it difficult to monitor all the danger zones behind the vehicle

B Automated Monitoring

The main disadvantage of the human observation approaches is – it relies solely on the human observation. So, the requirement for automated monitoring systems becomes vital. These systems consist of a sensor to gather information around the vehicle, a processor to perform the necessary calculations and device to notify the driver of an impending collision.

a Sonar

Sonar (stands for **SO**und **NA**vigation and **R**anging) range sensors emit ultrasonic signals to determine the distance to an object. A sonar pulse is emitted from the device, and the time taken for the first echo to return is measured. Using knowledge of the measured time of flight and the speed of sound in air, it is possible to infer the distance to the object reflecting the pulse. These devices rely on sound waves traveling through air, reflecting off the surrounding object. As a result there are several potential sources of error when calculating from sonar measurements which are as follows,

a. Low Angular resolution – Beyond the angular resolution of sonar sensors, the signal becomes weak and those signals can't be used for calculation
b. Cross Talk – Many vehicle reverse assistance systems utilise more than one sonar unit, which leads to cross talks from different sonar units.
c. Specularity – Many surface acts as specular surface at ultrasonic frequencies
d. Diffraction – Sonar waves may get diffracted from any corners of an object
e. Dead zone – When a sonar pulse is emitted by the sensor, any returning echos will be ignored, because the device is in transmitting mode. This distance is known as minimum detection distance, which ranges between 15 to 35 centimeters.

b Radar

Radar (stands for **Ra**dio **D**etection **a**nd **R**anging) is a minimum false alarm device, which sounds the alarm only when there was relative movement between the vehicle and the object. The main drawback of this system is the large vertical angular range, making it impossible to distinguish between objects of varying size and position

c Infrared Intensity

These sensors emit light from the infrared spectrum, and measure the distance to objects based on the reflected light intensity. As a consequence, the device gives different results depending on the color of the object. This type of sensor is only effective for determining short range distances of no more than about 1 metre.

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d Laser

These sensors release a thin beam of light, and in a similar manner to sonar sensors, measure time of flight for the light beam to return. It can measure distances up to 100 meters away with centimeter precision. These sensors do have certain drawbacks like,

a. It is quite expensive
b. Can detect objects within a single plane
c. Has difficulty in detecting transparent objects
d. If affected by dirt or water on lenses, it leads to false readings
e. Requires moving parts, which decreases the robustness of the sensor and increase cost

e Infrared Time-of-Flight

This is another time-of-flight sensor that uses an infrared light source to provide a burst of light. The device measures the time taken for the light to return to the sensor to determine the depth to surrounding objects. The main disadvantages are as follows

a. The maximum range of this sensor is 1.3 meters
b. Range is also limited by the strength of the infrared source
c. Maximum field of view is 80 degrees

III. Vision

Each approach discussed in the previous section was able to perform effectively under certain conditions, however in each case there was a definite need for improvement. One avenue that has nit yet been pursued for this application is the use of vision in an automated monitoring system.

From the biological perspective, each vision system is perfectly adapted to enable an animal to carry out tasks that ensure their survival including hunting, evading predators and foraging for food. This paper is concerned about the enabling of computers to extract useful information from visual data.

IV. Panoramic Imaging

There are three main approaches to obtaining images with a wider field of view. One could use multiple images from several cameras, or a single rotating camera and combine this visual information. However, it is preferable to use single static camera with wider field of view.

A. Multiple Images

This type of imaging takes several images and combines them into single panoramic image. This process of stitching images is known as “mosaicing”. A mosaicing can be created using either a multiple camera system or a rotating camera.

a. Rotating Camera

This method uses a rotating camera which is rotated around a vertical axis. The edges of different images are matched and then stitched together to form a panoramic image. The main advantage of this method is that it is possible to obtain high resolution panoramic images depending on the angular resolution of rotation. On the other hand, there are several significant disadvantages of this method:

a. This method requires Long Image acquisition time as many images are required
b. This system requires moving parts, which decreases its robustness and increases cost
c. Although it is possible to view 360º in the azimuth direction, the elevational field of view is limited to that of conventional camera.

This system can be developed using two cameras, one above the other, rotating on the same axis of rotation. Alternatively, range data can be determined by placing a single camera a certain distance away from the axis of rotation. If an object can be viewed in two images acquired at different points in the rotation, the range to that object can be determined using stereopsis.

b. Multiple Cameras

A simple approach is to use several conventional cameras. Depending on the field of view of the cameras used, it would be necessary to use atleast four cameras to cover 360º in the azimuth direction. But, the system becomes unattractive because of the cost and compactness of the system.

B. Wide Angle Lenses

From the previous section, it is found that the system becomes less attractive when there are multiple cameras in a driver assistance system. Instead of using multiple cameras, the system can be modified with an appropriate sensor and a single camera to capture the necessary field of view. This can be achieved through ultra wide angle lenses; in particular fish-eye lenses and panoramic annular lenses can be used.

A fish-eye lens can provide a field of view in excess of 180º, effectively a complete hemisphere with a single camera. However, these lenses are bulky and expensive. Furthermore, this lens suffers from angular distortion, which is difficult to remove. Images taken with these cameras typically have good resolution in the center, but deteriorate in the periphery.

The panoramic annular lens is fairly complicated, consisting of a single glass section with two reflective and two refractive planes. It has a 360º field of view in the azimuth, but only about 40º in elevation. Unfortunately, it is

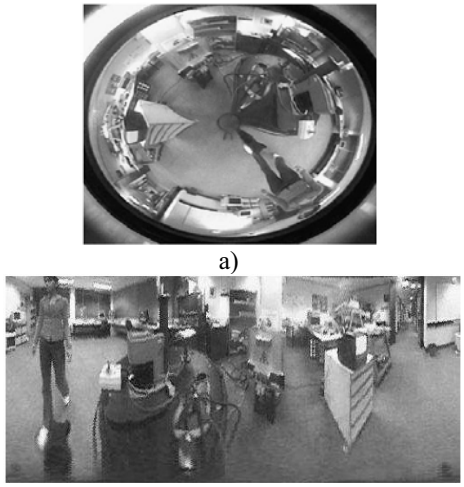
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difficult to increase the viewing region of this sensor in the elevation region.

C. Convex Mirrors

In this approach, a camera is placed below a convex mirrored surface. The optical axis of the camera is aligned with that of the mirror, which enables the camera to view a full 360º of the surrounding environment. The minimum and maximum angles of elevation captured are dependant upon the profile of the mirror surface. This method has several advantages such as,

a. Since it is a passive sensor, the power requirements are minimal
b. There is lack of moving components which means the sensor can be made cheaply, in a robust manner and requires little maintenances
c. Optical distortion caused by the mirror can be minimized easily



a)

b)

Figure 4.1: a) Image taken from a Panoramic sensor with convex mirror, b) The corresponding unwrapped image

An example of an image from a panoramic sensor is shown in figure 4.1 (a). Such raw images are difficult for humans to understand, and require the modification of conventional image processing techniques. However, it is possible to unwrap them to create a more intuitive panorama, as seen in figure 4.1 (b). The distortion can be removed by applying the following methods:

a. Transformation from Cartesian to Polar coordinate system
b. Projection of the wrapped image onto a shape in 3D space, such as cylinder
c. Radial correction around the image centre to create a "bird's eye view"

The effect of first method is to unwrap the raw image about the origin. Assuming that the center of the image is the origin (0, 0) and all variables are scaled to range between 0 and 1, the equations for unwrapping are as follows,

$$x = y_u \cos(2\pi x_u)$$
$$y = y_u \sin(2\pi x_u) \quad (4.1)$$

where (x_u, y_u) is a point in the unwrapped image, and (x, y) is a point in the raw image

In the second method, the image is unwrapped along the radial lines in the image and all other processes are similar to the first method. This process of unwrapping is done by projecting each pixel in the wrapped image back onto a theoretical cylinder in the three dimensional space. Each pixel value p' on the panoramic cylinder is back projected to the mirror, and finally onto the original image to determine p, to obtain the panorama as shown in figure 4.2. This is done using the equation 4.1 to unwrap the image.

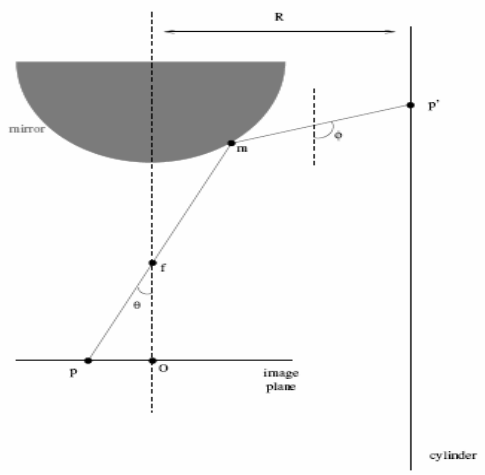


Figure 4.2: Mapping an image point p to a point in the unwrapped image p0. The image point is back projected onto a cylinder in three dimensional space, with a radius R.

In the third method, the unwrapping of images is done by radial correction around the image center, which results in a scaled orthographic projection of the ground plane. It is also possible to produce these ground plane unwrapped images through the use of a specially designed convex mirror profile.

In this paper, the second method has been chosen for unwrapping the images because this removes the wrapping introduced by the curved mirror profile. Thus, the unwrapped image becomes independent of the shape of the mirrored surface used by a panoramic sensor and enables the use of conventional image processing techniques.

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D. Mirror Profiles

When using a convex mirror for panoramic imaging, the camera is pointed towards the mirror with the camera axis aligned with that of the mirror. This provides the camera with a 360º view of the surrounding environment in real time. However, the field of view in the elevation direction is dependant upon the mirror profile. Conical mirrors are the simplest convex mirrors that have been utilized in panoramic sensing. Hyperbolic and parabolic surfaces have an increased field of view, and also have an effective single camera viewpoint. However, this property is not necessary for range sensing, and requires further calibration and specialized optics or cameras. The constant gain mirror profile was chosen because of the constant angular resolution, while the resolution invariant profile produces a panoramic image with invariant pixel density.

a. Constant Gain

An important parameter for describing the profile of a mirror is known as the mirror gain. This is the relationship between the changes in the incidence angles of light rays and the changes in the direction of the reflected rays. If the relationship is linear, it is then known as constant mirror gain, and can be defined as follows,

$$\alpha = \delta\varphi / \delta\theta \qquad (4.2)$$

where α is constant, φ is the elevation angle of a ray of light reflected off the mirror and θ is the angle viewed by the camera, as shown in figure.

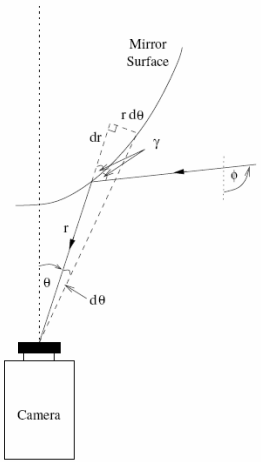


Figure 4.3 : Relationships used to derive a family of constant gain mirror profiles (Conroy 2000)

Basically, the parameter specifies the angular magnification of the surface in the vertical direction. By increasing the gain of the mirror, there will be increase in the field of view of the panoramic sensor. To design a convex mirror, the first step is to decide the maximum and minimum light ray angles of elevation (φ_1 and φ_2 respectively) and to determine the maximum and minimum angles viewed by the camera (θ_1 and θ_2 respectively). The mirror gain can then be found as follows,

$$\alpha = (\varphi_1 - \varphi_2)/ (\theta_1 - \theta_2) \qquad (4.3)$$

Consider a mirror profile (r, θ) in polar coordinates, where r is the radial distance to the camera, and θ is the angle from the optical axis of the camera to the reflection point on the mirror surface as shown in figure. The general equation for the constant gain mirror is,

$$r = r_0 \left[\frac{\sin \underline{\gamma}}{\sin \left[\underline{\gamma} + \frac{(\theta_2 - \theta)(1+\alpha)}{2} \right]} \right]^{\frac{(1+\alpha)}{2}} \qquad (4.4)$$

where $\underline{\gamma} = \frac{\pi - \underline{\theta} - \phi}{2}$, and r_0 is the distance from the camera focal point to the mirror assembly when $\theta = \theta_2$

b. Resolution Invariant

The majority of the work in the field of panoramic imaging has utilized CCD camera technology. These CCD cameras have been used to capture images reflected fro ma convex mirror, which is essentially a polar image of the surrounding environment. A specially designed camera with a polar array of pixels as shown in figure 4.4 (a), which can be used for unwrapping by scanning the pixels radially. Furthermore, the alignment between the camera and the mirror would require a high level of accuracy, and thus makes the calibration process a complicated one.

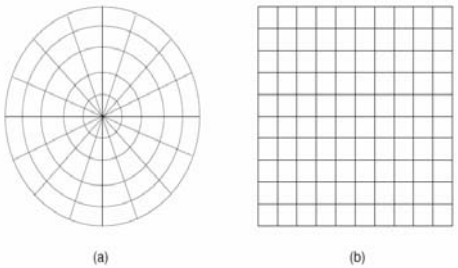


Figure 4.4 a) A polar array of pixels, b) a conventional rectangular CCD array

Another approach is to use a mirror profile which has been designed to compensate for the change in pixel density – the resolution invariant surface developed by Conroy and Moore in 1999. The resolution invariant mirror profile can be determined by solving the following equation numerically.

$$\frac{d\,r}{d\theta} = r\ \cot\left[-\frac{1}{2} \int\ (1 + \alpha(\theta))\ d\theta \right] \qquad (4.5)$$

Where r is the distance from the camera focal point to the mirror surface, θ is the angle viewed by the camera, and α (θ) is given by,

$$\alpha(\theta) = B_\alpha [\tan\theta + \tan^3\theta] \quad (4.6)$$

where $$B_\alpha = \frac{2(\phi_1 - \phi_2)}{\tan^2\theta_1 - \tan^2\theta_2} \quad (4.7)$$

V. Panoramic Vision Range Sensors

The Computer Vision through the camera is to some certain degrees of angle, in order to minimize wide angle lens distortion. It has been described a method for estimating range from a pair of omnidirectional images, captured from a single panoramic sensor on a moving platform [3]. They determined the epipolar geometry for a panoramic sensor, using unwrapped images that had been projected on to cylinders in three-dimensional space. The system was tested only on theoretical, computer-generated images captured with hyperboloidal mirror profiles. The virtual stereo sensor had a horizontal baseline of 50 cm, and was placed at the centre of a box (6m x 6m x 6m) with textured sides and bottom. The panoramic images used were 720 x 200 pixels, and were unwrapped from raw images of 640 x 480 pixels. The distance to the walls was estimated with an average error of approximately 0.2m. A virtual stereo sensor was placed in a synthetic environment, consisting of four textured walls, at a distance of three meters from the sensor. Their results showed that range to the walls could be reliably determined.

An obstacle detection system that uses a single panoramic camera has been described in [1]. The system compensates for ego-motion, and then detects objects that have independent motion. The sensor was mounted 60 cm above the roof of the test vehicle, to provide a 360° view of the surroundings. The road plane motion parameters were estimated using prior knowledge of camera calibration and vehicle speed. These parameters were then used to compensate for motion in consecutive frames, and any remaining motion is deemed to be an object. The accuracy and reliability of the system was not reported. The disadvantages of this system are the impractical sensor mounting, as well as the requirement of vehicle odometer.

Experimental results gained from two different panoramic sensor systems have been shown in [2]. The first system consisted of four panoramic sensors placed at equal height around a room. They were able to generate perspective images of the surrounding environment, and preliminary range estimation, showing only relative depth was presented. The second system consisted of two panoramic sensors, with the camera and mirror axes aligned. Again, only preliminary range estimation results were discussed. In both cases, no evaluation of the range finding capabilities were carried out and there was no further processing of the data.

Examining the research results published by [4], this system has been designed to use camera configuration (1), as shown in Figure 5.1. This configuration was found to have the highest range accuracy, as the panoramic images would have approximately the same resolution at each pixel. To date, there has been a distinct lack of results describing the performance of panoramic sensors in range estimation, in real-world experiments. The majority of the results have been either purely theoretical or only preliminary range estimation studies. This system processes the captured images in order to segment obstacles from a moving platform.

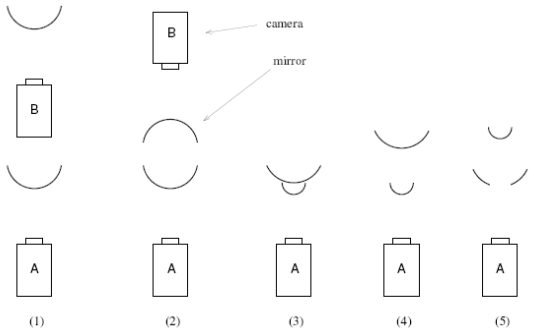


Figure 5.1 Sensor Configuration [4]

VI. Conclusion

This Panoramic Sensor System captures the image of the obstacles and processes these images. The optical axis of the camera is aligned with that of the mirror, which enables the camera to view a full 360º of the surrounding environment. These images are then unwrapped to get the complete image in three dimensional. The distance was estimated from the unwrapped image which is then used for the analysis to detect accidents. The images can be subjected to skin detection [6] for identifying human images as a future work for improving the detection efficiency.

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