Novel Compact Panomorph Lens Based Vision System for Monitoring Around a Vehicle

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ABSTRACT

Automotive applications are one of the largest vision-sensor market segments and one of the fastest growing ones. The trend to use increasingly more sensors in cars is driven both by legislation and consumer demands for higher safety and better driving experiences. Awareness of what directly surrounds a vehicle affects safe driving and manoeuvring of a vehicle. Consequently, panoramic 360° Field of View imaging can contributes most to the perception of the world around the driver than any other sensors. However, to obtain a complete vision around the car, several sensor systems are necessary. To solve this issue, a customized imaging system based on a panomorph lens will provide the maximum information for the drivers with a reduced number of sensors. A panomorph lens is a hemispheric wide angle anamorphic lens with enhanced resolution in predefined zone of interest. Because panomorph lenses are optimized to a custom angle-to-pixel relationship, vision systems provide ideal image coverage that reduces and optimizes the processing. We present various scenarios which may benefit from the use of a custom panoramic sensor. We also discuss the technical requirements of such vision system. Finally we demonstrate how the panomorph based visual sensor is probably one of the most promising ways to fuse many sensors in one. For example, a single panoramic sensor on the front of a vehicle could provide all necessary information for assistance in crash avoidance, lane tracking, early warning, park aids, road sign detection, and various video monitoring views.

Keywords: wide-angle lens, panoramic, panomorph, immersive, anamorphic, 360 vision systems, vision sensors, automotive, driver assistance systems, transportation.

* Panomorph lens: A very large anamorphic angle with enhanced resolution through optical distortion.

1. INTRODUCTION

Automotive vision is being deployed now in commercial fleet and luxury cars. More and more vision algorithms being developed and acceleration in deployment is anticipated as technologies mature.

The end goal of automotive vision is to have:

- ✓ Driver monitoring to reduce commercial fleet and insurance costs
- ✓ Luxury equipment differentiation
- ✓ Safer highways – vision will enable the next significant reduction in casualties
  - o Similar to previous impact of airbags and ABS
  - o EU already has a goal to reduce casualties to half by 2010
- ✓ Reduced road congestion

There will be several phases in the deployment:

- ✓ Driver convenience / luxury equipment – assisting the driver in making decisions with visual information (e.g.: Rear view, then parking assistance)
- ✓ Driver monitoring – continuous monitoring for driver awareness
- ✓ Driver interactive – signaling the driver when there is a problem
- ✓ Longer term: Driver replacement – allowing the car to make its own decisions

Additionally, intelligent imaging systems for automotive applications will be essential. In real-time events where complex environments need to be quickly interpreted, visual signals are still desirable because they are rich in the information required to understand the surrounding environment. Consequently, imaging systems used in conjunction with other types of RADAR and LIDAR sensors are becoming an increasingly important information source for many automotive applications.

Almost every active safety system under current development integrates a camera sensor, and all major suppliers are currently working on a camera-based sensing technology. However, integrating imaging sensors into cars has suffered from serious delays because high-speed displays and compact, low-cost signal processing units and memories have not been previously available. Also, earlier generation camera sensors did not perform sufficiently well and did not match the stringent automotive industry's needs. Today, with the availability of the newly developed automotive camera sensor, automotive OEMs can create revolutionary safety and comfort features for the car of tomorrow.

The main drawback of the current technology (which offers a broad range of active safety features) is often the cost. The real question then, is how can we improve the efficient use of vision systems in the automotive industry? In other words, how we can optimize these various sensor types, not only for high-end models or as expensive "add on" options, but to allow the adoption of these safety features for all applicable car models.

In this paper, we present various scenarios which may benefit from the use of a custom panoramic sensor. We also discuss the technical requirements of such vision system. We demonstrate how the panomorph based visual sensor is probably one of the most promising ways to fuse many sensors in one. For example, a single panoramic sensor on the front of a vehicle could provide all necessary information for assistance in crash avoidance, lane tracking, early warning, park aids, road sign detection, and various video monitoring views.

2. 360^{O} VISION SYSTEM IN AUTOMOTIVE SAFETY

Over the years it has been confirmed that there is limited space in a car for sensors to be installed and limited in-car computing power that can support sophisticated data processing and analysis. Consequently, any chosen sensor must be able to provide essential information for as many functions as possible. We believe that these issues are key to implementing panoramic imagers into integrated intelligent sensors.

Panoramic imaging sensors can also contribute greatly to the perception of the world around the driver as shown in figure 1. For a complete vision of the area around the car, several sensor systems are necessary; however, a 360^{o} visual sensor is probably one of the most promising ways to fuse many sensors into one. As an example, a single panoramic sensor, flush mounted on the front of a vehicle, could provide all necessary information required for crash avoidance, early warning alerts and various video monitoring views.

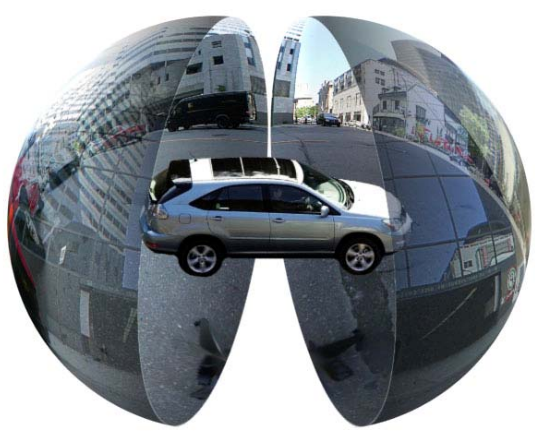


Figure 1: Vision around the vehicle

As another example, an intelligent airbag system might combine seat-specific weight sensors with a stereo 2D overhead camera. Complex software is required to correlate the data from each sensor, and it may take additional devices to discriminate between a 70-lb. box and a 70-lb. child. The alternative is to build a consolidated system around a few or even a single panoramic optical sensor that can recognize and size (range) the object in the vehicle. Combining both ranging and recognition in a single, dedicated, small panoramic sensor will result in a practical imaging system that could potentially reduce the number of sensors required in the car. The same imaging sensor could also be used as a back-seat view camera (for child safety). In fact, a rear, interior and forward-view panoramic camera can handle a large number of applications simultaneously.

3. HEMISPHERIC LENS REQUIREMENTS FOR AUTOMOTIVE SENSORS

3.1 Technical requirements for automotive cameras

Automotive imaging sensors should comply with several requirements in order to meet the automotive market demands:

- The imaging sensor must have a very high sensitivity (low f-number) over a wide spectrum -- typically from the visible to the NIR.
- The image quality is limited by the pixel size, which means that the optical lens resolution will be equal or better than the resolution of the detector (CCD or CMOS).
- All these optical features should work over a broad temperature range, from $-40^{o}C$ to $+85^{o}C$ ($+ 105^{o}$), and be resistant to road vibration.
- The vision system must be compact and designed for cost optimization.
- The imager sensor must integrate many internal features (ADC, anti-blurring, etc.), must be easily programmable, and use common video formats.
- The lens should be customized for the benefit of its specific applications.
- Any un-warping (panoramic distortion management algorithms) software must be light in both memory usage and processing power consumption.

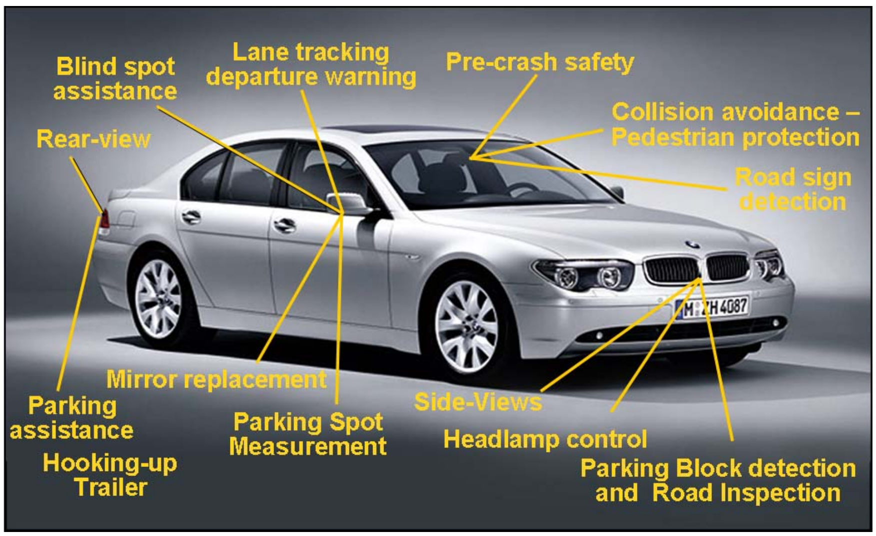
Automotive Tier1 and Tier2 are now designing “custom” products, which are perfectly designed and optimized from both a software and hardware point of view. With modern technologies, this modeling approach plays an even more critical part in imager development. Simulation programs can help identify the trade-offs between various design alternatives.

3.2 Monitoring around a vehicle

In order to develop an intelligent vehicle, we need to “sense” the surrounding environment. A perception of the complete surroundings includes events taking place in the front, back, and sides of the car, which should be the basis of an effective driver assistance system. This driver support system, which can warn the driver of a possible collision, would allow the driver to take timely action to avoid or at least reduce the impact of a collision. Finally, we also need to observe ground objects, traffic signs over vehicles, and the landscape of the road. These facts imply an hemispheric view.

In recent years, considerable efforts have been made to develop driver support systems to enhance safety by reducing accidents[1,4]. As an example, lane detection vision systems help to determine the lateral position of the vehicle and warn the driver in the case of lane departure. This can also help to prevent collisions with other vehicles or fixed objects, or from running off the road. Front-view detection is useful in preventing accidents due to the sudden braking of another vehicle, detecting non-motorized objects such as pedestrians and bicyclists, who are harder to detect than vehicles and more vulnerable. Monitoring the side of the vehicle’s blind spots is useful when the driver intends to change lanes. The figure 2 shows a non-exhaustive list of information that can be provided or required in respect to view zones.

(a)



(b)

Figure 2: Applications of cameras in automotive: a) inside; b) outside

4. PANOMORPH BASED VISION SYSTEMS

Wide field-of-view and a high frame rate are necessary for real-time tasks of the new generation of intelligent vehicles, mobile robots and awareness systems. Providing real-time visual-surroundings information to drivers is very helpful for driver safety and is necessary for the actualization of an autonomous intelligent vehicle. This section describes the panomorph lens features and benefits.

Many of the standard lenses used with a camera sensor (CMOS or CCD) can be mounted to provide surround-monitoring of vehicles. However, due to the large field-of-view to be covered, any virtual view generated electronically and facing any specified direction becomes low in resolution[1]. Consequently, to get a high-resolution surround image, a high resolution sensor is required, leading back to a cost issue. This begs the following question: How can we improve the use of standard imagers in the automotive industry to get an efficient surround-monitoring of vehicles? The panomorph lens may be the answer.

Panomorph lenses use the distortion control concept pioneer by ImmerVision, which is considered a major enhancement in panoramic vision[2]. Specifically, the panoramic imager can be designed to increase the number of pixels i.e. the resolution, in the zones of interest using a distortion-control approach. The main benefit of panomorph optics is that it is based on a custom-designed approach, simply because the panoramic lens application can be designed to meet real and very specific needs, particularly within the transportation industry. Trying to use standard panoramic lens have failed to deliver good product for automotive industry. By including specific distortion during the optical design stage, we can produce a very unique and a cost effective panoramic lens. Moreover, the panomorph lens can be used with any of the standard video format sensors already developed for automotive applications.

The panomorph lens uses only refractive lenses made with glass or plastic, which is perfectly suitable for high volume production. The lens can be very compact and robust to resist to stringent automotive market. Consequently, the panomorph lens image quality, size, cost, reliability and integrity make it suitable for a safety-critical automotive application.

The panomorph lens[2] uses two main features, a distortion-control approach and anamorphic image mapping to provide a unique full hemispheric field coverage. In contrast to other types of panoramic imagers, which suffer from blind zones (catadioptric cameras), low-image numerical aperture and high distortion, the panomorph lens uses distortion as a design parameter, in order to provide a high-resolution coverage where needed. It also features an anamorphic image mapping of the full hemispheric field, which produces an ellipse-image footprint rather than a circle or annular footprint, as do all other types of panoramic imagers. This feature provides an immediate 30% gain in pixels on the sensor (the ellipse footprint matches the 4:3 ratio of a standard CCD or CMOS imager). The combination of distortion control and anamorphic design provides an important gain in resolution, and an advantage over all other types of panoramic imagers because it make panoramic imaging capabilities available on lower resolution sensor format (like VGA) where any other type of panoramic lens has failed.

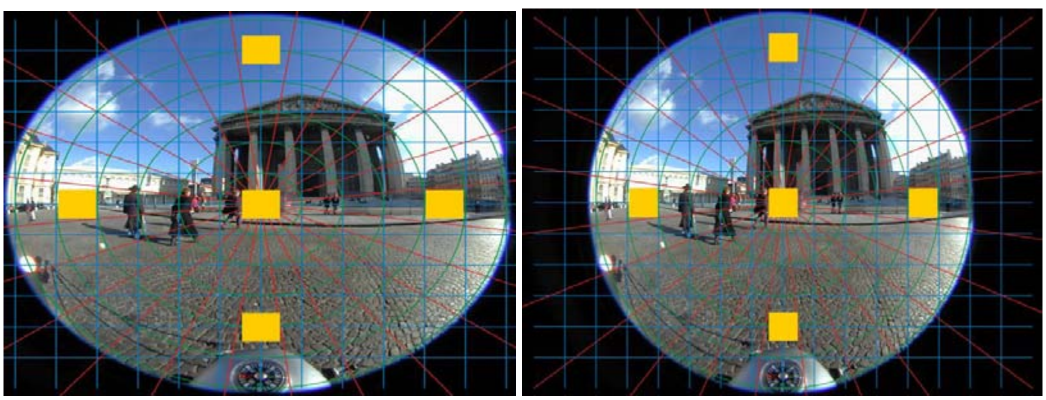


Figure 5: Images taken with a panomorph lens (left) and a fisheye lens (right). Yellow boxes represent equivalent areas.

Figure 6: Increased resolution with a panomorph lens.

Figure 5 shows a front view image in a parking lot, taken by a fisheye lens and a panomorph lens with equidistance projection (linear with FOV angle). The yellow boxes show the relative dimension of an object in the field. By providing an anamorphic correction (elliptical footprint), the panomorph lens also provides a gain in resolution along the long axis of the sensor. Figure 6 shows the same image taken by a panomorph lens with increased resolution on the border. The resolution on the border is double the center resolution. Where the resolution is higher, the camera is able to see at a longer distance. This custom image mapping is the resolution distribution required for a typical application. As another reference, we refer readers to another publications[2,3] of the author, which discusses a case study for a security panoramic imaging and automotive scenario respectively.

5. PANOMORPH LENS APPLICATIONS

Because we want to optimize the use of each pixel on the sensor, proper design configuration is very important to determine the exact image mapping.

5.1 Blind spot monitoring

Consider the simplified situation of a camera flush-mounted on the front of a vehicle that can provide blind spot monitoring and warning system. Based on Figure 7, we can define that the principal zone of interest will be the corner view.

According to a specific need, it is a requirement that the resolution in the corner view (both side) should have high resolution to see at longer distance. Of course, this function can be done by two corner view cameras but it can be done with additional benefit with one Panomorph lens, then only one sensor will be required for this applications. The additional benefit is that the full hemispheric field-of-view available. This hemispheric field of view can be used for other applications (see figure 2).

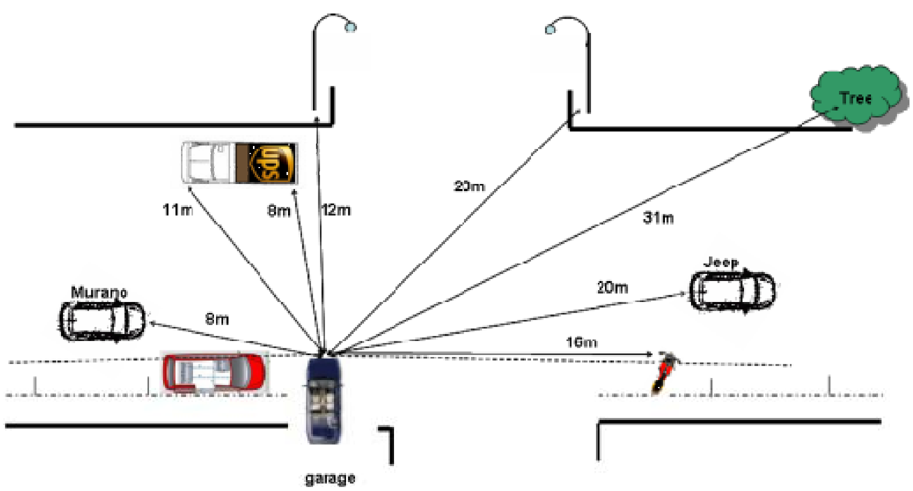


Figure 7: Front view blind spot monitoring

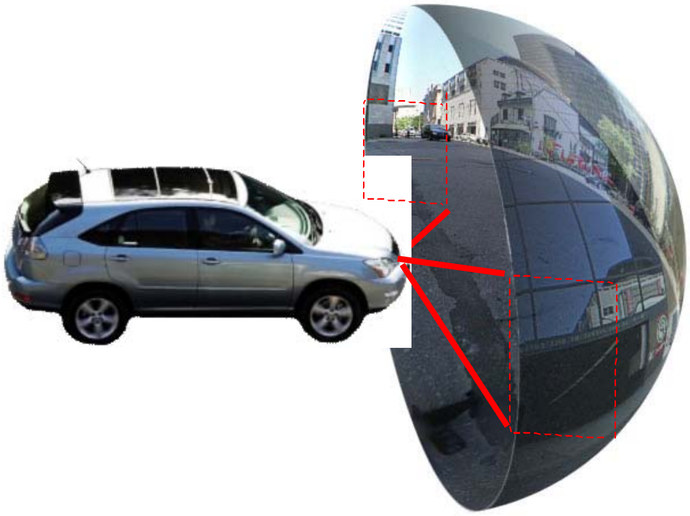


Figure 8: Front-view hemispheric zones of interest.

Using only one standard panoramic lens on a VGA sensor (640X480 pixels) to fulfill these requirements (for this analysis we use 190 degrees field of view), the resolution will be:

The standard panoramic lens will provide a constant resolution over the entire field-of-view. As shown in figure 5 (right), the panoramic standard lens provide a circular footprint that will cover only the small axis of the sensor. The result is the 190 deg FOV will be spread on 480 pixels maximum, for a 2.5 pixel/deg resolution.

With a panomorph lens, we can manage the resolution or the image mapping with the distortion in such a way that the resolution in the zone of interest can be three time (7.5 pixels/deg) compared to the one of a standard panoramic lens. This approach will provide a much better resolution (3 times distance) and make hemispheric imager suitable on lower resolution sensor. To reach the same resolution as the Panomorph lens, the standard panoramic lens should be used with a 2 Mega pixels camera! Consequently the Panomorph lens provides on a VGA sensor the same resolution in the zone of interest (corner view) than a standard panoramic imager on a 2MP sensor. This is an incredible advantages in cost, memories, data transfer, etc

This example shows how a custom-design panomorph lens can provide a higher resolution where required, while still providing full hemispheric views.

5.2 Road Sign Detection

Introducing the Panomorph lens imager as front view camera will provide a full hemispheric field of view that can be used for blind spot monitoring but also for additional features. One application is the road sign detection. The figure 9 shows a typical detection scenario.

Figure 9 Road sign detection and monitoring

5.3 Lane departure warning

As long as you have a front view of the road, the Panomorph lens vision system can also provide various analytic features such as lane departure warning and up to cruise control assistance. The Panomorph lens vision system output is an undistorted panoramic image then any analytic algorithm can be used on the output signal. The figure 10 shows a particular scenario of image analysis system for lane departure.

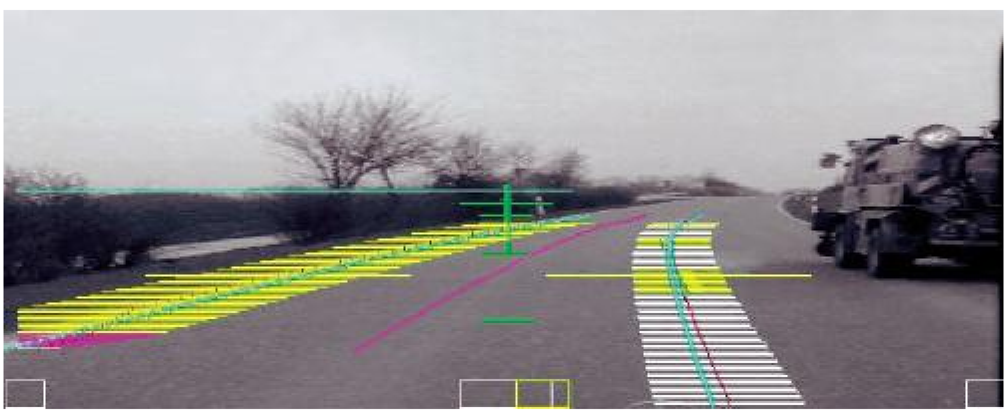


Figure 10: Analytic image for lane departure warning system.

5.4 Parking Assistance

Finally with the front view camera you can also use close view (on the ground) near the car to help parking assistance and block detection (warning system).

Figure 11 : Parking lines and Blocks detection

6. CONCLUSION

In this paper, we propose the use of a panomorph lens for efficient auto vision systems. With the panomorph lens, we can acquire a full hemispheric image with the use of a single standard camera sensor like VGA. Panomorph is the only panoramic technology that allows pixel optimization and resolution augmentation to provide a unique full hemispheric field coverage. In contrast to other types of panoramic imagers, which suffer from blind zones (catadioptric cameras), low-image numerical aperture and high distortion, the panomorph lens uses distortion as a design parameter, in order to provide a high-resolution coverage where needed.

The panomorph lens has no moving parts, can be used with any standard camera sensor, is as small as a digital camera lens, can use either glass or plastic optical material and provides both visible and NIR images at a very competitive costs. Consequently, a refractive panomorph lens is well suited to fulfill the strict requirements for camera lenses in the automotive industry. Furthermore, when using plastic optical elements, the lens can be manufactured in high volume, by using moulding techniques to reduce material costs.

In conclusion, a panoramic imaging sensor contributes most to our perception of the world. Several sensor systems are necessary to obtain a complete vision of the environment around a vehicle, a robot, an airplane, or a security vehicle; however, a 360^{o} visual sensor using panomorph lenses is probably one of the most promising ways to fuse many sensors into one, and thus reduce risk and cost.

REFERENCES

1. T. Gandhi, M.M. Trivedi, Vehicle Surround Capture: Survey of Techniques and a Novel Omni-Video-Based Approach for Dynamic Panoramic Surround Maps, IEEE Transaction on Intelligent Transportation system, Vol 7, No 4, December 2006, pp. 293-308.
2. Simon Thibault, Enhanced Surveillance System Based on Panomorph Panoramic Lenses, Proc. SPIE vol. 6540, paper 65400E, 2007
3. Thibault S. Distortion Control Offers Optical System Design a New Degree of Freedom. *Photonics Spectra* May 2005, pp. 80-82.
4. S. Li, Monitoring Around a Vehicle by a Spherical Image Sensor, IEEE Transaction on Intelligent Transportation system, Vol 7, No 4, December 2006, pp. 541-550.

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