Measuring Sensor Health in DARPA Grand Challenge

2005 SURF Final Report

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Abstract
The autonomous vehicle Alice is equipped with a number of different sensors. These are focused on overlapping ranges and combined to generate a reliable elevation map.
The purpose of this project is to prevent the camera stereo sensors from sending faulty data to the process that creates the elevation map.
Disturbances due to the sunshine is the main reason of sensor errors.
The sun may cause extremely bright sky and total black ground if Alice is facing it and causes unreliable measurements. It may also dazzle the cameras, producing vertical light regions that when analyzed may cause the elevation map to read them as obstacles.
To solve these problem, the exposure is changed from automatic to manual mode and a controller is implemented. Besides, a sun blocker function is used to black out possible sun dazzle.

Introduction
The DARPA Grand Challenge is a field test of autonomous ground vehicles created by the Defense Advanced Research Project Agency (DARPA). The team that develops an autonomous ground vehicle that finishes the designated route first within 10 hours will win the race. The route will be no more than 175 miles over desert terrain featuring natural and man-made obstacles. The exact route will not be revealed until two hours before the event begins. It includes several different types of terrain such as paved roads, unpaved roads, trails, and off-road desert areas. The DARPA Grand Challenge was organized for the first time in March last year. At that time 15 teams emerged and attempt the race. However, the price went unclaimed as the best vehicle only made about 7 of the 142 miles course. Team Caltech's vehicle Bob made 1.3 miles before he drove into a fence and got stuck.

Team Caltech consists of 30-40 undergraduate students, 4 graduate students and 3 professors. The main idea in the team is to have the students make all the decisions regarding the project. The team is composed of three race teams and some additional teams. Each race team consists of a graduate student as a team coordinator, a professor as an advisor and a number of undergraduate students who are suppose to do most of the work and decisions. The race teams and their responsibilities are:

- Vehicle/ Embedded Systems Team. Responsible for the mechanical and computing hardware in Alice, including interfaces to actuation subsystems.
- Planning Team. Responsible for guidance, navigation and control, including supervisory logic and core software infrastructure.
- Terrain Team. Responsible for state and terrain sensors (hardware and software) and sensor fusion.

The additional teams are used for required activities that are not directly involved in any hardware or software that is part of Alice, e.g. documentation, software build process, sponsors and responsibility for the support vehicles.

Since last years race, the team has a new vehicle named Alice. Alice is a 2005 Ford E-350 van, modified by Team Caltech sponsor Sportsmobile to be able to traverse the off road desert terrain. Alice's software architecture is implemented on a high-bandwidth, multi-computer network that is capable of handling the large amounts of data and processing required for autonomous navigation. State estimation is accomplished through GPS units together with an IMU that measures relative position and orientation. Alice is provided with a variety of sensing modes with overlapping ranges and capabilities to get as accurate sense of the surrounding terrain as possible. Five LADARs are mounted on different places on Alice and pointed out at different distances. A LADAR scans over a certain set of angles and obstacles are detected by finding amplitude peaks in the return signal. Two pairs of Point Grey Dragonfly cameras are mounted on the roof. By knowing the positions of the cameras relative each other combined with SRI´s Small Vision System 3D pointclouds and a stereovision system is generated. The camera pairs are focused on different ranges, respectively, 0-15 m and 15-40 m. An additional single camera also feeds a road-finding algorithm. The raw data from the LADARs and stereo pairs is converted into elevation maps, which are then combined using a fusion algorithm to generate a single unified elevation map. The elevation map is then analyzed to determine at which speed each cell can be traversed. This data is then fused with the information provided by the road finding algorithm to generate the final speed limit map for evaluation by the planning software.

I have been working in the Terrain Team and especially the stereovision module. The purpose of my project has been to prevent the camera sensors from sending faulty data to the algorithm that creates the elevation map. Faulty data is mainly due to the sun and I have solved the exposure and glare problems when facing the sun.

The Exposure Control Problem

Problem

The software provided with the Dragonfly camera allows manual and automatic control of the exposure time. If automatic control is used the exposure time is depending on the brightness of the whole image. The stereovision system used on Alice does not analyze the whole image, since this takes to much process time and also gives a lot of useless information about the environment, e.g. the sky. The smaller region is called the region of interest or sub window and is the part of the image that does not include the sky. Before automatic control was used per default on Alice and caused problems when she was facing the sun. In this case the sky gets extremely bright and to compensate for that, the exposure is controlled such that the ground gets totally black. Of course, this results in unreliable measurements, if anything at all can be seen in the region of interest. Figure 1a and 1 b.

F*igure 1a. Whole image when using automatic exposure control and NOT facing the sun.*

Figure 1b. This image is captured a few seconds after 1a, but Alice is now facing the sun.

Solution

The problem was solved by changing to manual control of the cameras exposure and develops a controller focused on the region of interest. A simple proportional gain controller was implemented, with the error computed as the difference between 128 and the average brightness of the region of interest. 128 is the intensity value between black and white.

Result

Only using this mean value as an input value might seem simple but through testing this has been show to be sufficient. Figure 2a and 2b shows the result.
The images also show sun glare, but this is not to be discussed in this section.

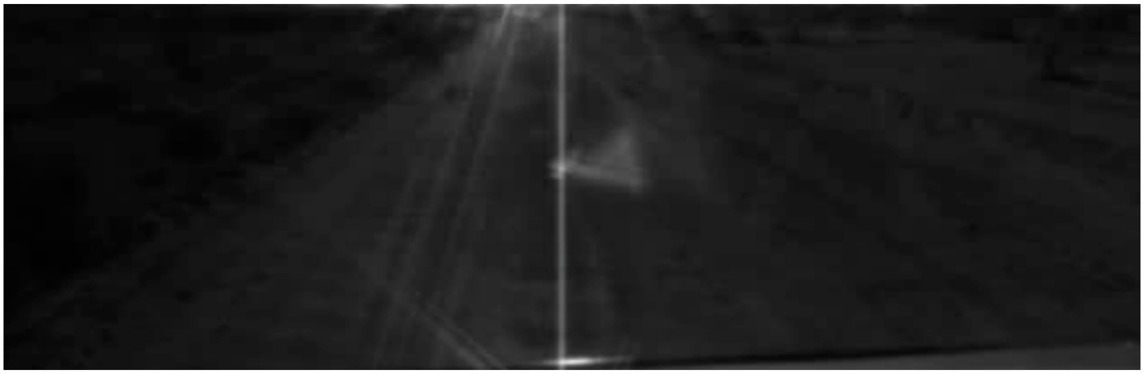

Figure 2a. Region of interest with Alice facing the sun using auto exposure.

Figure 2b. Similar conditions as in Figure 1a, but using the implemented exposure control.

Sun Covering

Problem

When Alice is facing the sun, glare might arise as can be seen in Figure 2a, 2b and 3 and in worst case be detected as an obstacle.

Figure 3. Screenshot when sun covering is active and Alice is facing the sun. On the left side from the top; left image, right image and disparity image. On the right; the display.

Solution

Sun glare due to reflection was solved by adding polarization filters to the camera lenses. The remaining glare was unfortunately not that easy just to remove. The problem was simply solved by implementing an algorithm that keeps track of the position of the sun relative the cameras. A certain area around the sun was painted black in the left image. This means that the closer the center of the image the sun is the bigger part of the image is blacked out. Since the glare remains in the right image, but not in the left, no common points will be found by the stereovision system and hence, no obstacle will be found in this area.

Result

The solution works, however it is a bulky solution and a lot of useful information is disregarded. Figure 3 shows the blacked out area in the left image, where there is a risk of sun glare.

Pitch Control

Problem

The part of the image consisting the sky is usually cut off by the sub windowing, but not if Alice is standing uphill slope, e.g. pitch is positive. That means if Alice position is such that sky is shown in the sub window, the exposure control defined above is not enough.

Solution

To solve this problem a pitch control has been implemented. The pitch control keeps track of the pitch given by the state module and moves the sub window a number of pixels proportional to pitch value. If pitch is negative, the original sub window is used. It is no use to look higher in the image when going downhill.

Result

The result is shown is figure 4a and 4b. As can be seen, with the pitch control inactive half of the sub window consists of sky when Alice is in an uphill slope. In this case the sun is not in the filed of view, but if it was the ground would probably be totally black and no data would had been painted in the map. Compare the sub window in 4a with the one in figure 4b.

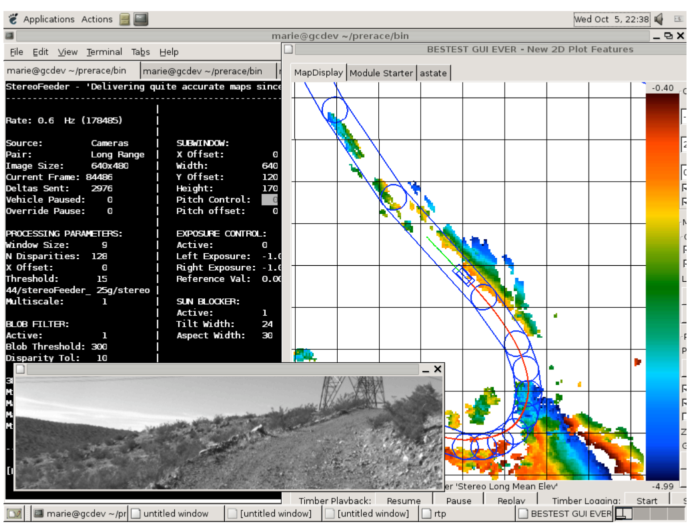

Figure 4a. Screenshot showing elevation map of long range stereo camera pair, left image and stereoFeeder display. Pitch control is off.

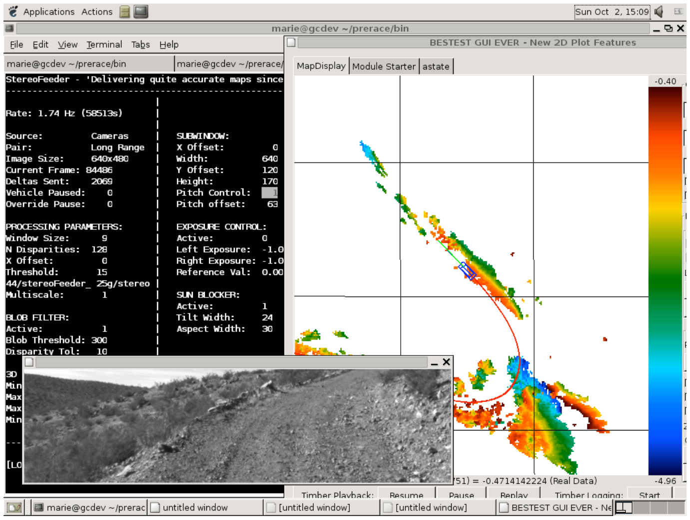

Figure 4b. Screenshot showing elevation map of long range stereo camera pair, left image and stereoFeederdisplay. Pitch control is on.

Conclusions

Due to the time limits in this project, the above solutions are all very simple. There was simply no time to test more complex solutions. That said the above implementations do the job. The team considered to mount a gimbal on Alice, and this would improve the stereovision system as well as all the other terrain sensors.

Acknowledgements

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