User Guide for the
Stereo Panoramic Vision System

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1 Introduction

The stereo panoramic vision system has been designed and built during a Masters project, which was commenced in March 2002. The Australian National University, Volvo Cars and Volvo Technology AB have jointly supervised the project. The software and hardware have been developed with the aim of providing a driver warning system for increasing vehicle safety. The system will use a stereo panoramic vision sensor to detect obstacles in close proximity to the rear of an automotive vehicle. If a collision is likely to occur, the driver will be alerted.

This document is a user guide that describes how to assemble the equipment used in this project. The next section lists the steps required to compile, and run the main program. Details of the system calibration are given, along with a guide to the graphical user interface.
2 Hardware

2.1 System Overview

The stereo panoramic vision system consists of four main parts (Figure 1). The stereo panoramic sensor is mounted on a vehicle, in a position to view an area of the environment unseen by the driver. The sensor captures monochrome images of this *blind-spot*, which are fed to the host computer via a pair of frame grabbers. These images are processed using an on-board PC to determine where obstacles are situated in the work space. The results can then be sent to a system to provide a warning to the driver. However, for experimental purposes the obstacle detection output was generally only displayed on the computer monitor.

![Figure 1: Overview of the panoramic vision system.](image)

2.2 Sensor Components

The list of hardware components for the stereo panoramic vision system is as follows:

- 2 panoramic mirrors of the same profile. See Figure 2(a)
- 2 black needles, for reducing the internal reflections due to the glass cylinders
- 2 glass cylinders with aluminium collars attached
- 2 L-brackets. See Figure 2(b).
- 4 T-nuts, with 2 that are 4 cm long, and 2 that are 1.5 cm long
- 2 camera mounts
• 2 FCB-EX470L Sony video cameras with water proof plastic boxes (Figure 3)
• 1 Rectangular Cross-Section (RCS) bar, with a slot for attaching mirrors and cameras
• 1 modified tow bar, to mount the RCS bar in a vertical or horizontal position on the test car

![Image](image.jpg)

Figure 2: Components of the stereo panoramic sensor. (a) The mirror assembly is on the left, with glass cylinders, mirrors, needles and bolts. (b) The camera mounts, L-brackets, and T-nuts.

### 2.3 Assembling the Equipment

The hardware components listed in Section 2.2 can be assembled in the following manner:

1. **Mirror assembly** - Assemble the mirror, needle and glass cylinder as shown in Figure . A minimum of four M2 bolts are required to hold the mirror in place.

2. **Mounting the mirrors** - Attach an L-bracket to the RCS bar using one of the T-nuts and an M8 bolt. Use the shorter T-nuts for components that will be at either end of the slot in the bar. This ensures that the sensors can be moved to the extremities of bar. Screw the mirror assembly onto the L-bracket using an M10 bolt that is no more than three centimetres long.
3. **Attaching the cameras** - Take the lid off the waterproof box, and place the camera on its side, as shown in Figure 5(a). Screw the camera mount into the base of the camera with a $\frac{1}{4}$ inch diameter screw. Do not tighten the screw completely. Leave enough slack to allow the camera to pivot a small amount, but make sure the camera will not fall off. Bolt the camera mount to the RCS bar using another T-nut. Then, screw the mirror assembly on to the camera. Once everything has been tightened,
position the camera box above one of the holes in the RCS bar, as shown in Figure 5(b). Put the entire assembly on its side. Stick a screwdriver through the hole, and securely tighten the screw holding the camera.

![Images of camera assembly process]

Figure 5: (a) Attaching the video camera to the camera mount. (b) Tightening the video camera onto the RCS bar.

4. **Mounting the RCS bar to the tow bar** - See Figure 6. Place the RCS bar on the tow bar attachment in either a horizontal or vertical position. Secure the RCS bar using two M14 bolts. It may be necessary to unscrew the mirrors from the cameras to reach the holes for the bolts.

![Image of RCS bar mounting process]

Figure 6: Mounting the RCS bar to the tow bar.
5. **Putting the tow bar onto the car** - Twist the green handle from a horizontal to a vertical position, until it clicks. Push the tow bar onto the tow bar attachment on the car. The tow bar should slip easily underneath the plastic skirting. It is in locked in place when the green handle flicks back into the horizontal position, and the red button on the side can no longer be seen.

6. **Removing the tow bar** - Twist the green handle from a horizontal to a vertical position, until it clicks. Pull the tow bar back firmly. It may be necessary to twist it back and forth.

![Back of the PC, showing camera cables.](image)

Figure 7: The back of the PC, showing camera cables.

7. **Plugging in the cameras** - Plug the cables from the cameras into the back of the computer as shown in Figure 7. The S-video cables for the cameras have not been labelled, as they are interchangeable on the RCS bar. To determine if they have been plugged in correctly, start up the GUI. See Section 3.2 for instructions on how to do this. Wave an object in front of the lower camera. This is the camera closest to the end of the RCS bar, shown in Figure 8 on the right hand side. The waving object should appear in the GUI as the image under the label Camera 1 in the Raw Images window.
3 Software

3.1 Initialisation Files

Initialisation files enable the user to change the initial parameters for the program without having to recompile the entire program. This is particularly convenient when calibrating the system, and setting the default unwarping parameters. There are several files supplied with the software, each storing default values for different purposes. For example:

- **pov.ini** - For use with saved images generated by POV-Ray, a computer graphics software package.
- **live.ini** - Used for set the default parameters for processing live images.
- **saved_sweden.ini** - To be used in conjunction with image sequences saved in Gothenburg, Sweden. These are in the **sequences** directory, in directories with a prefix of 2003-04-16. Eg **sequences/2003-04-16_vert_cars**.

Of course, the user may also create their own initialisation file.
3.2 Compiling and Starting the Program

Complete the following steps to compile and run the software for the stereo panoramic vision system:

1. Change into the directory where the software has been installed.

2. If a Makefile has not yet been created, automatically generate a make file, using the `tmake` program with this command:
   ```
   tmake stereo_pan.pro o Makefile
   ```

3. Compile the program by typing:
   ```
   make
   ```

4. To run the program type:
   ```
   ./stereo_pan [initialisation file]
   ```
   For example, when processing live images, run the program as follows:
   ```
   ./stereo_pan live.ini
   ```

5. An initialisation window will pop up as seen in Figure 9. The user may choose the mirror profile, sensor orientation and between live and saved images. The defaults for this window are stored in the file `initialisation.ini` and can be changed to suit the user. The variables in the file are `MIRROR_TYPE`, `CONFIG`, and `DISPLAY_MODE`. The mirror profile can be set to either `c` (constant gain) or `r` (resolution invariant). The orientation can be either `h` (horizontal) or `v` (vertical). The display type can be set to `1` (live images) or `s` (saved images).

![Image of initialisation window]

Figure 9: Initialisation window.
3.3 Graphical User Interface

3.3.1 Raw Images

The *Raw Images* window displays the unprocessed images from both cameras, and enables the user to adjust the system parameters at run time. The parameters can be found in a series of tabs, at the bottom half of the window.

1. **Video controls** - (Figure 10) This tab is only present if the program is processing saved images. The drop down list enables the user to choose the image sequence they would like to display. It is also possible to only load a section of the sequence by changing the values *First Image Number* and *Last Image Number*. The user can step forwards and backwards by pressing the up and down arrow keys. However, this can only be done if the keyboard focus is on the *Raw Images* window, otherwise the user may accidently toggle other parameters. This can be achieved by clicking the mouse on the *Display Controls* tab, and pressing the up key until the sequence progresses. The user can automatically move through the sequence by pressing the *Play* button. The video sequence may be stopped at any time pressing the *Stop* button.

2. **Display Controls** - (Figure 11) The buttons in this tab are fairly self-explanatory. The user can choose to skip frames to increase the program execution speed, or the display can be turned off completely. The tick box labelled Save video sequence enables the user to save a series of images. This can be toggled several times during the program, and the image will be saved to the *sequences* directory. To avoid overwriting the images, the user should copy these to a separate directory before restarting the program and saving more video sequences.

3. **Camera Controls** - (Figure 12) This tab is only present when the user chooses to process live images. It contains the controls for the camera such as zoom, brightness, and shutter speed. The values can be changed independently for each camera, or the controls may be linked by selecting the *Synchronise* check boxes.

4. **Unwarping Controls** - This tab is used mainly for system calibration. It is also possible to change the orientation of the unwarped images, to suit the configuration of the panoramic sensor. The images can be inverted, and/or flipped from left to right. The orange arrow depicts the wedge of the warped image that will be extracted for the unwarped image. The unwarped image begins at the green line, and ends with
Figure 10: The video controls tab in the *Raw Images* window.

the red line. A full explanation how to set the rest of the unwarping parameters is given in Section 3.4.2.

5. **Panoramic Sensor Parameters** - (Figure 13) The focal lengths of each camera, and distance from focus to mirror should not be modified unless the zoom has been changed. If it becomes necessary to change the zoom setting, the cameras need to be recalibrated to determine the new focal length. The distance from focus to mirror is also dependent on the zoom setting. However the distance between the cameras (i.e. the baseline) can be modified easily by the user.

### 3.3.2 Unwarped Images

This window displays the raw unwarped images (Figure ). The user can also toggle between displaying the optical flow field, and segmenting the flow by thresholding the magnitude of the vectors. Increasing the flow step size decreases the density of the flow field. The
threshold parameter is used to segment the optical flow.

3.3.3 Results

This window displays the results of the image processing that have been carried out on the unwarped images (Figure ). Each component of the image processing can be turned on and off using the GUI, and the algorithm parameters can be modified.

The Save unwarped images and Save depth map buttons allow the user to save individual unwarped images and depthmaps without the overlays drawn on. The user may save several images during run time, however to these must be moved once the program has been terminated to avoid overwriting.

The Select points button enables the user to manually select corresponding points from the left and right images. These points are then mapped from image to real world coordinates,
Figure 12: Camera controls in the Raw Images window.

and saved to the file saved_points0.txt. If the user saves points more than once during run time, the file is not overwritten. The number at the end of the file name is simply incremented and a new file created. However, if the program is stopped then restarted, the file count will restart at 0 and therefore be overwritten. To save the files, simply copy them to a different directory, or change the name of the file.

The Calibrate ground plane button allows the user to select corresponding points in a similar fashion to the Select points button. Instead of remapping the points to three-dimensional coordinates, these coordinates will be used to determine the position of the ground plane with respect to the cameras. The current implementation of the ground plane subtraction assumes that the ground is perfectly perpendicular or parallel to the camera axis. In future implementations of the program, a least square estimation will be employed to approximate the orientation of the ground plane.

The Save results check box forces the program to save the unwarped image and the chosen
intermediate processing image, with the overlays drawn on. These are saved into the \texttt{sequences} directory.

The radio buttons at the bottom right corner of the window allow the user to view the different intermediate processing images. These are created when detecting obstacles using the V-disparity algorithm.

The various algorithm parameters may be changed online. These can be found in three tabs on the \texttt{Results} window. They are as follows:

1. \textbf{V-disparity Parameters} - (Figure 15) This tab contains the parameters for searching for the ground plane and obstacles in the v-disparity image. These may need to be tuned to improve obstacle detection results, which will be discussed further in Section

2. \textbf{Depth Map Filters} - (Figure 16) The parameters in this tab are set for viewing
the optimal V-disparity results. However, the user may toggle variables to see how
this effects the results, online.

3. **Depth Map** - (Figure 17) This tab allows the user to toggle between using the Sum
of Absolute Differences (SAD) and Normalised Cross Correlation (NCC) algorithms
for calculating the depth map. Again the parameters are currently set for viewing
the optimal V-disparity results.

4. **Kalman Filter** - (Figure 18) The parameters kept in this tab are for filtering the
output for the Ground Plane Subtraction method for obstacle detection. The filter
is only active when the *Subtract ground plane* check box is selected in the *Depth map
filters* tab.

### 3.3.4 Theoretical Depth Map

This window displays the theoretical depth map used in ground plane subtraction (Figure
19). It serves as an aid to the user to ensure that the depth map calculated is oriented
the same way as the sensor. This parameter is set in the *Results* window, in the *Depth*
Figure 15: V-disparity parameters in the *Results* window.

Figure 16: The controls for the depth map filters in the *Results* window.
Figure 17: The controls for modifying the depth map and V-disparity parameters.

Figure 18: Kalman filter controls.

map tab (See Figure 17). The ground plane can be set by changing the Rotate theoretical ground parameter.
3.3.5 Graphical Display

This window is used to display results of the ground plane subtraction algorithm. Once the depth map has been processed, the image is segregated into a number of sections in the horizontal direction. The program determines the closest object in each region, and calculates the objects position in three-dimensional space. In the Graphical Display window, the point is plotted out in a scaled, top view diagram of the scene behind the car (Figure 20). Each section is represented by a line from the origin to the closest object in that section. The graph represents an area that is two metres long, and four metres wide. The origin of the coordinate system is at the bottom of the white area, in the centre.

3.4 System Calibration

3.4.1 Camera Calibration

It is necessary to calibrate the video cameras to determine the internal parameters used in the range calculations. The cameras have been calibrated already for their current zoom setting. However, if the user chooses to change the zoom on the cameras, they will need to recalibrate the cameras to determine the new focal lengths.

Complete the following steps to calibrate the cameras:
Figure 20: A scaled, top view diagram of the area viewed by the panoramic sensor.

1. Remove the mirrors if they are attached to the cameras. Place them so that the user can be seen in the field of view of the cameras.

2. Hold the calibration grid in front of the camera. Save 10 to 20 images from each camera using the GUI, with the grid in different orientations. Some example images can be seen in Figure 21. Try to place the grid in a position that takes up the most space in the image. Copy the calibration images to a floppy disk. Reboot the computer, and load up the Windows operating system.

Figure 21: Examples of camera calibration images.
3. Using the saved images, complete the calibration with the Matlab camera calibration toolbox. This can be downloaded at:
http://www.vision.caltech.edu/bouguetj/calib_doc/
Follow the method used in the example, which can be found at:
http://www.vision.caltech.edu/bouguetj/calib_doc/htmls/example.html

4. Change the values of the default focal lengths in the constants.h file, and recompile the program.

3.4.2 Unwarping Parameters

Before the software can function properly, it is necessary to calibrate several parameters using the GUI. The calibration method is as follows:

1. Select the Unwarping Parameters tab in the Raw Images window, as shown in Figure 22. Change the coordinates of the left and right image centres until the pink cross is in the middle of mirrors. Change the inner radius parameter so that it the light blue circle lies around the outside of the black aluminium collar. The outer radius should be set to a value that puts the dark blue circle at the edge of the mirrors.

2. When the parameters are set correctly, these can be made the default values for every time the program is run. Choose an initialisation file and open it. For example live.ini. Look for the unwarping parameters variable names. Modify the default values as necessary. It is possible to save different default values for each mirror type, and camera configuration.

3. The default value for all parameters, including the initial settings of the tick boxes can also be changed to suit the user.

4. It is not necessary to remake the program. Just save the initialisation file, and run the program.

3.4.3 V-disparity Parameters

Before the obstacle detection algorithm will perform correctly, the search windows for the ground plane and obstacles in the v-disparity image must be set correctly. These parameters are set using the tab in Figure 15. This can be done as follows:
Figure 22: Calibrating the unwarping parameters.

1. Set the window for searching for the ground plane in the v-disparity image. The window must be wide enough to allow variation in orientation of the ground plane, but small enough to maximise the computational efficiency. The lines to be searched for have been parameterised as shown in Figure 23.

2. The search window for the obstacles should exclude the left most obstacle, as this is the background, which we are not interested in detecting. The obstacles should be mostly vertical. However, it is also possible to search for obstacles with negative rho.
Figure 23: Definition of the v-disparity parameters. Lines in the v-disparity image are defined using the perpendicular distance from the origin \( \rho \), and angle \( \theta \).

Figure 24: In the v-disparity image, the ground plane appears as a downward sloping line. The obstacles are the near vertical lines.

3.5 Example Parameters

3.5.1 Raw Images Window

Display controls:
• Num frames skipped = 0
• Save video sequence = unticked

Camera controls:

• Zoom = 3200
• Iris = 17
• Focus = 37593
• Shutter = 4 (indoors) or 13 (outside)
• Gain = 0

Unwarping parameters:

• Image centres - Should coincide with the centres of the mirrors.
• Unwarp section - Area of interest. The both cameras should have the same End angle. The Start angle can differ to compensate for rotation about the image centre.
• Capture area - Can use this to cut out any unwanted areas in the centre and edges of the mirror.
• Draw unwarp parameters - ticked
• Inverse - ticked (can be changed to suite particular setup, to ensure unwarped image is oriented correctly)
• Flip - unticked (can be changed to suite particular setup, to ensure unwarped image is oriented correctly)

Resize parameters:

• Resize - ticked
• Leave other parameters as is

Panoramic sensor parameters:

• *Camera focal length* = 1050 (Don’t change this unless the zoom changes. If the zoom is changed, the cameras must be recalibrated to determine the new focal lengths.)

• *Distance from focus to mirror* = 102mm (Don’t change unless zoom changes. Will then need to recalculate this value.)

• *Distance between cameras* = 300 mm

3.5.2 Unwarped Images

• Update top/bottom display = unticked (this will help to speed up the algorithm)

• *optical flow* = none

3.5.3 Results

V-disparity parameters:

• *Ground plane* - this is the search window for an angled line. The red overlay in the v-disparity image should coincide with the angled line of the ground plane as in Figure 23.
  
  – *Start Theta* = 110
  – *End Theta* = 115
  – *Start Rho* = 50
  – *End Rho* = 100

• *Object plane* - Search window for obstacles. Want to find all near vertical lines, which are the obstacles. However, we do not want to include the background, so *Start Rho* should be set high enough to skip over the background shown in Figure 24.

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- Start Theta = 0
- End Theta = 2
- Start Rho = 20
- End Rho = 180

- **Negative plane** - This will segment object planes that are angled in the opposite direction to those above. Should generally not need to use this, unless the above parameters fail to capture all obstacles.

Depth Map Filters:

- Thresholds are just for interest. It segments the disparity map by intensity, into red and blue regions.
- **Blur unwarped images** - ticked
- **Gaussian** - unticked
- **Median** - ticked
- **Subtract ground plane** - unticked

Depth Map:

- **Update disparity map** - ticked
- **Disparity Algorithm** - Can choose between SAD and NCC. Use SAD unless the disparity map is particularly low quality, as the NCC algorithm has no left-right checking, or sub-pixel interpolation.

Kalman Filter:

- Kalman filter is used for ground plane subtraction only. However since this method was found to be much less accurate than v-disparity, these parameters should not be necessary.