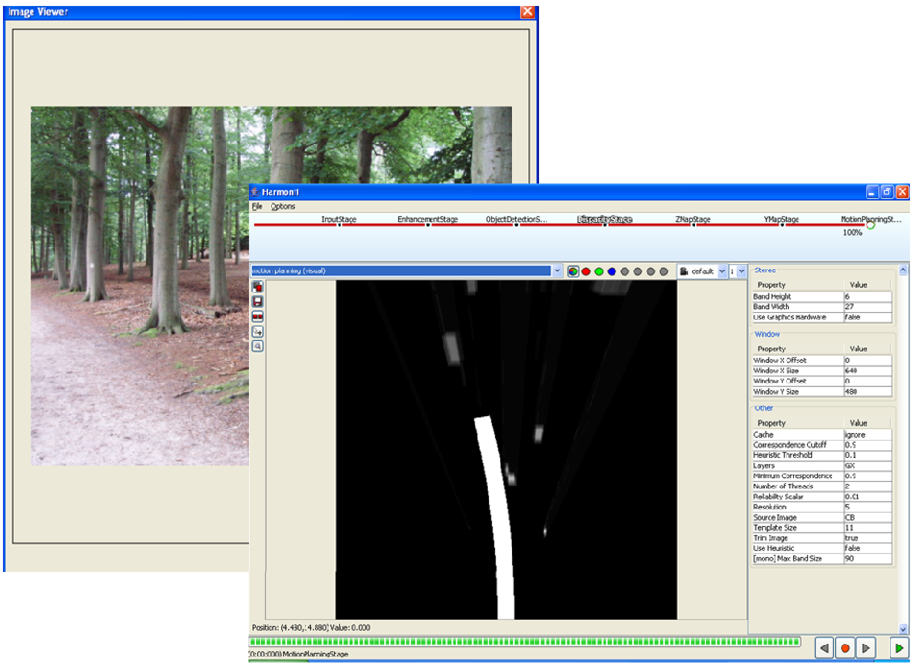
Kiminkii

the Harmonii Computer Vision Environment

Harmonii is a software environment for developing computer vision applications, primarily aimed at autonomous vehicles and Driver Support Systems (DSS). The software consists of a pipeline of image processing operations that progressively produce more and more sophisticated models of the image and of the outside world it captures. It integrates a number of powerful techniques for image understanding, including stereo (depth) vision, segmentation and linear feature discovery. Furthermore, it builds a 3D model of the visual features produced, and plans trajectories for mobile robots and autonomous vehicles based on the modelled obstacles.
The system contains a graphical user interface for experimenting with the different modules, finding the optimal settings for parameters in analysing in detail the effects of the processing. As such, it also serves as a test-bed for those interested in learning about important techniques in the Computer Vision field. Alternatively, the system can be integrated in real-time applications requiring a vision or motion planning component, through its Java-based API.



The Harmonii graphical user interface

Some of the implemented operations, notably stereo vision, require considerable computational resources. These operations have been

made efficient in two ways. First of all, key algorithms have been made multi-threaded in order to benefit from multi-processor or multi-core hardware. A typical run of the complete pipeline, leading to a planned path, can be perform up to twice a second, given the right parameter settings. A further improvement has been obtained by re-implementing some parts for computation on a Graphics Processing Unit (GPU). On a modestly-priced graphics card, this hardware-acceleration will result in a speed-up of 10 times.
The name Harmonii is inspired by the term harmony in music: the effects of notes sounding simultaneously. The software exploits the effects of combining multiple (stereo-) images captured simultaneously. Analogously, work continues on the Symphonii component, which adds to this the possibilities of combining successive images.

The following sections describe some of the main features of Harmonii. For detailed information and pricing, please contact {a dot knobbe at this domain}.

Image Processing

A number of basic operations is available for turning the original colour image(s) into a range of images suitable for further processing.

Original colour image

The pipeline starts by separating the original images into each of the three RGB components as well as a grey-scale component. Furthermore, channels for the hue, saturation and brightness (HSB) colour-model are added. Hue is a measure for the dominant colour in a pixel. Saturation is a measure for how strong a colour is. It can be used as a measure for the greyness of a pixel (for example to recognize road surface regardless of shadows).

Grey component

Saturation component

Each of these 7 channels can optionally be complemented with blurred versions. A range of kernel functions can be used to smooth the original image, for example to remove any noise in the image. Additionally, this blurring has the effect of gathering information about neighbouring pixels in each pixel, which is useful in subsequent steps. Also, a number of edge detection kernels can be applied in order to gather information about strong changes in intensity in the images. This can be used to detect lines or road markings in the image. Again this operation can be applied to all of the channels.

Blurred grey

Edge detected grey (Sobel)

Stereo Vision

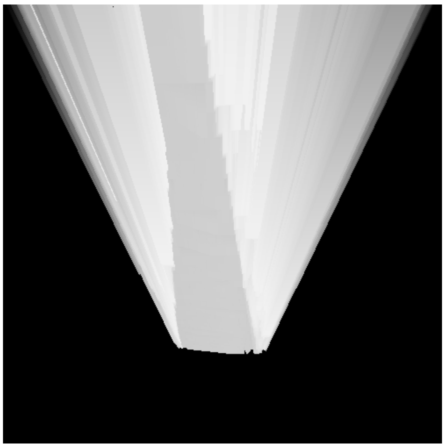
The most important technique for image understanding in Harmonii is the stereo vision module. By comparing two images taken by two identical cameras situated next to one another, it is possible to gage the depth of objects appearing in the two images. For each pixel in the left image, a corresponding pixel in the right image is determined. The so-called *disparity* between these pixels is a measure for the distance of the object from the camera-pair. Finding the correct corresponding pixel is done by comparing the neighbourhood of the pixel. This can be done based on any subset of the channels available, although typically just grey (and/or green) is a reasonable and efficient choice. Optionally the blurred and edge detected images may provide additional information that can help improve the estimated depth, especially in areas where neighbouring pixels are similar.

Original image (left version)

Depth map (dark = deep)

By measuring the depth of each pixel, the outside world can now be modelled using a cloud of dots in 3D. This cloud can arbitrarily be translated and rotated to compensate for unusual mounting or tilting of the cameras on the robot. By bounding the cloud, objects that are not relevant to navigation (such as ground or overhead obstacles) can be filtered out. The cloud can be visualised in a number of ways. A density map projects all dots on a horizontal surface, thus showing where obstacles appear in the area in front of the cameras. A height map shows the height of obstacles for this same area.

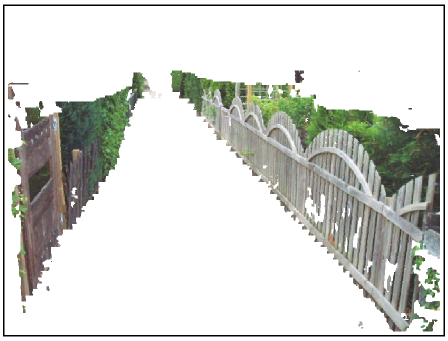
Density map 15m ahead



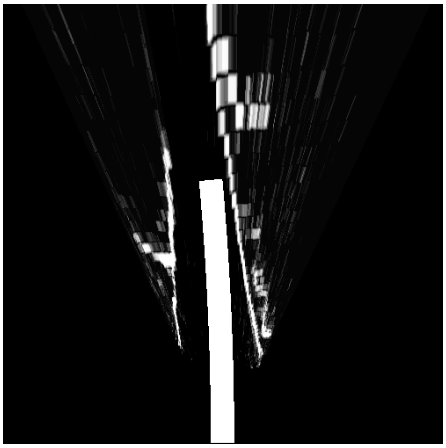
Height map for the same area

Motion Planning

The 3D model of the outside world can be used to plan paths for the mobile robot the cameras are attached to. Harmonii considers a number of possible paths and selects the path with the lowest risk, based either on density or height of the obstacles. A range of parameters can be used to model the properties of the robot, such as its size and maximum steering angle, and the planning distance.



Relevant obstacles



Minimum risk path based on density

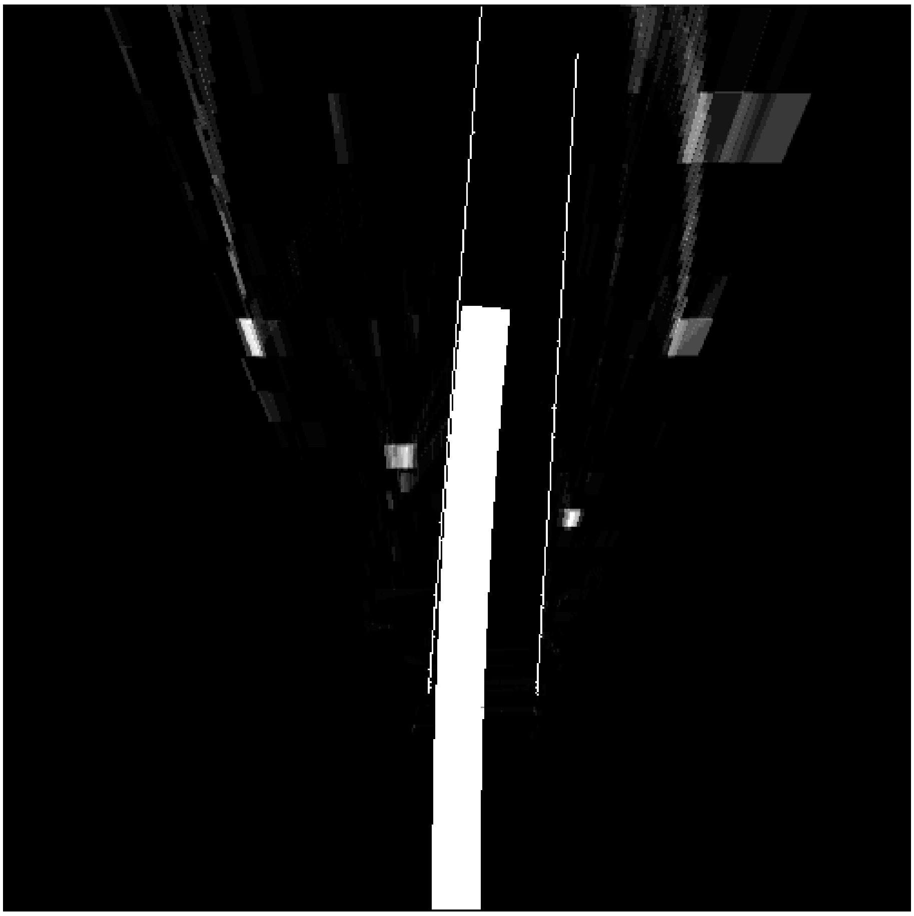
The system contains minimal facilities for interfacing with electronic interface cards that drive external motors. It assumes that steering is done differentially, that is by controlling the difference in speed between the left and right wheels. Using the API, the vision and motion planning functionality can of course be integrated in operational systems of any complexity.

Discovering linear features

In many applications, planning a path requires more than simply avoiding obstacles. For example on a highway, it can be more important to keep to the current lane, than to avoid obstacles. Harmonii provides facilities for recognizing linear features such as the side of the road and road markings (even interrupted). A so-called *Hough transform* produces these linear features (see figure). The horizontal line indicates the location of the horizon. Its width indicates that only lines will be found that point roughly in the viewing direction. There is a further limit on the slope of the line in the 2D image.

Two lines discovered in the horizontal plane

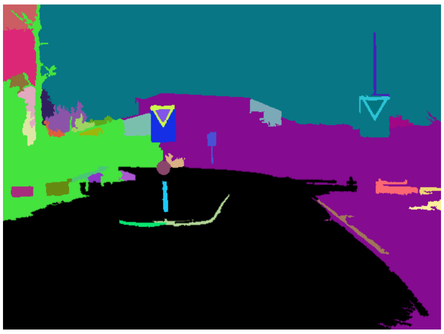
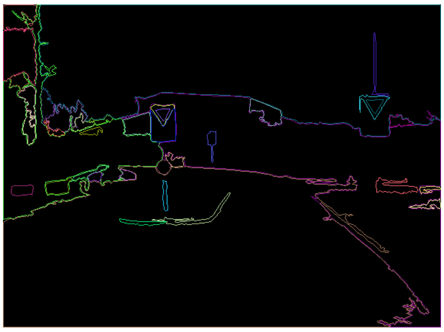
Using the 3D model of the scene that was created from the stereo images, the 2D lines can be translated to lines in the outside world. Any lines that do not turn out to be straight in 3D, or do not lie in the horizontal plane (within limits) are discarded.
The motion planning module can benefit from this additional information by combining obstacles and lines into a single map of the outside world. The figure below shows how the optimal path falls between the two parallel lines discovered. The positions of the two poles and the tree are indicated, as well as the two lines. Clearly, just navigating based on obstacles would result in a less attractive path.



Path that respects both density and lines

Segmenting images

Smooth surfaces, such as paved roads, present some challenges to stereo vision, as it is harder to determine corresponding pixels when all pixels are equal. Small imperfections and dirt will help to resolve some of these. The smoothness of flat areas however can also be exploited. A simple way of recognizing how the road continues ahead (when straight lines are not present), is to assume that the area directly in front of the robot is safe. By extending this area to include all similar pixels, it is possible to determine where the road continues to. Harmonii offers techniques for segmenting images and thus determining areas with similar properties. For the recognition of road and flat, smooth surfaces, using saturation as a means of determining similar areas is useful, because it is not sensitive to variation in lighting and shadows (see figure below). The system however allows you to pick any of the available channels.

Segmented image with polygons. The black area corresponds to road surface.