Vision-Based Localization for Mobile Robots

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Turtlebots

The Turtlebot is a mobile robotics platform for researchers and hobbyists, designed by Willow Garage. The use of off-the-shelf components makes the platform affordable and extensible. We use Turtlebots, driven by Willow Garage's ROS software framework, in our research on navigation and localization.

Turtlebots consist of the following parts:

- iRobot Create
- Microsoft Kinect
- Asus EEE PC
- IMU

ROS

ROS, or the Robot Operating System, is developed by Willow Garage for use with their flagship pseudo-humanoid robot, the PR2, and it also works with Turtlebots. ROS is an all-encompassing software framework for robot programming, based on the model of many different "nodes" running concurrently and communication by message passing. ROS is fully network transparent, so the nodes can be on different computers. When using ROS, the hardware drivers are generally abstracted away in their own nodes, so the nodes we write are purely developing the robot perception and control algorithms.

OpenCV

OpenCV, or Open Source Computer Vision, is a large library of useful computer vision algorithms. It has facilities for fast matrix math operations, general image processing, dealing with camera idiosyncrasies, object detection, machine learning, and more. It also includes a rudimentary GUI (graphical user interface) toolkit for quickly visualizing algorithms. We apply it to the video stream from the Turtlebot's Kinect, to see things in front of the robot, as well as to the images captured by the upward facing camera, for use in Ceiling Cat.

Our Robots

Patient Zero

Yertle

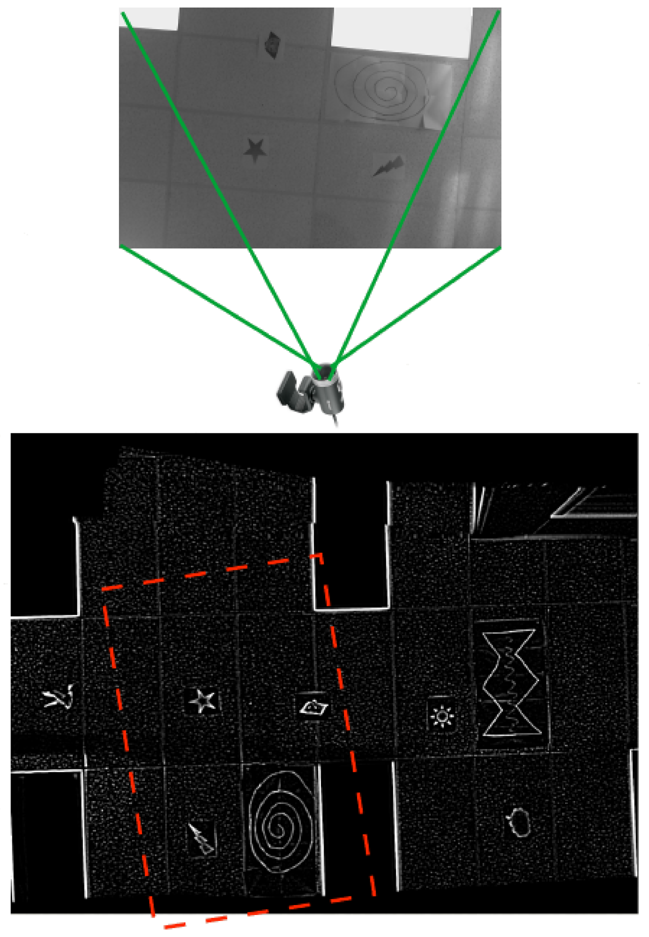
Squirtle

Development was performed using one official Turtlebot from Willow Garage, and two robots of our own manufacture, constructed from the same electronic parts, but scaffolded in wood to allow for rapid prototyping.

Software Projects

Ceiling Cat

One of the most important capabilities for a mobile robot exploring its environment is accurate localization. Most tasks, such as map-making and navigation, are aided by knowledge of the robot's current position. Ceiling Cat implements a technique for absolute localization analogous to a sailor navigating by the stars. We modify both the robot (by adding an upward-facing webcam) and the environment (by placing markers on the laboratory ceiling to make it less homogeneous). Given a map of the entire ceiling, the robot takes pictures as it drives around, and incrementally aligns them using image stitching, in order to determine the path taken around the lab.



This shows an example of the goal of the localization process. The large image is the map of the entire ceiling (actually, the Laplacian of the ceiling, for normalization purposes). Then, our localization procedure should give the coordinates of the red dotted rectangle, in terms of a *warp*. Our warp incorporates a translation and a rotation:

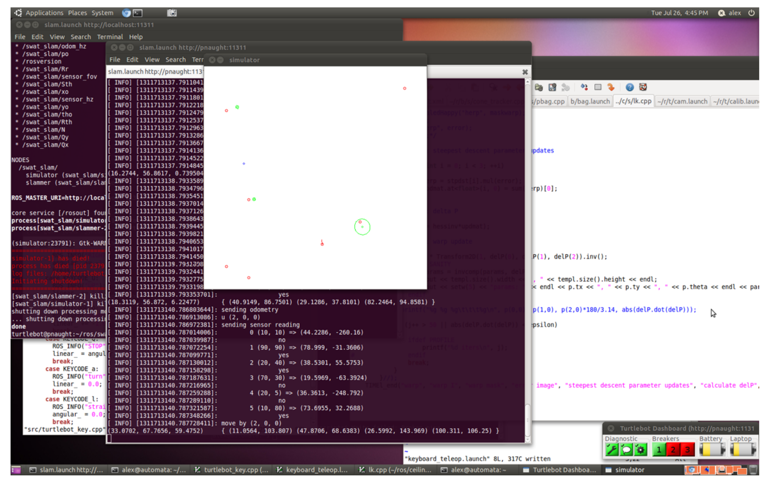
$$W = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & t_x \\ \sin(\theta) & \cos(\theta) & t_y \\ 0 & 0 & 1 \end{bmatrix}$$

We use the Lucas-Kanade algorithm for finding the relationship (translation and rotation, in our case) between two images. Specifically, the inverse compositional variant is the most efficient method.

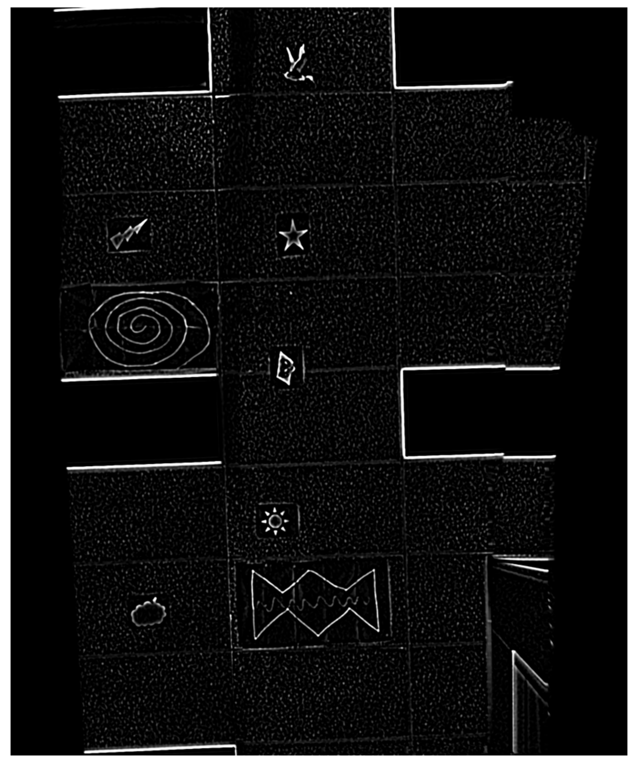
Procedure Lucas_Kanade(image, template, p)
begin
- Precompute gradient of template image ∇T
- Precompute Jacobian $\frac{\delta W}{\delta p}\big|_{x;0}$
- Precompute steepest descent images $\nabla T \frac{\delta W}{\delta p}$
- Precompute Hessian matrix and its inverse
- **while** $||\Delta p|| > \epsilon$ **do**
  - Warp the image $w = I(W(x;p))$
  - Compute the error image $E = w - T(x)$
  - Follow the gradient $\Delta p = H^{-1} \sum_x (\nabla T \frac{\delta W}{\delta p})^T E$
  - Update the warp $W(x;p) = W(x;p) \circ W(x;\Delta p)^{-1}$
- **return** $W(x;p)$

end

Results

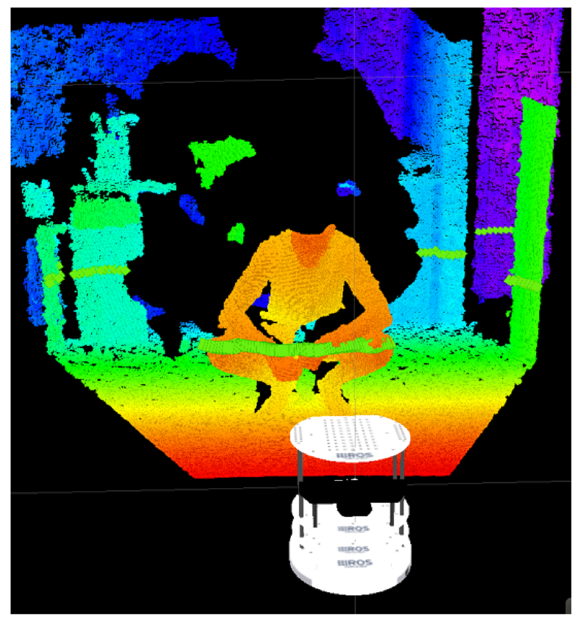


MATLAB and C++ simulations of several mapping/navigation algorithms were developed. The picture shows a visualization of SLAM using a Rao-Blackwellized particle filter, applied to a mobile robot locating beacons with a sonar-like sensor.



Patient Zero and Yertle, with their upward-facing cameras, gained the ability to localize very accurately within the robot lab by using the instrumented ceiling. Shown at left is a complete map of the ceiling. This map was made autonomously by the robot, using wheel odometry and image stitching.

Future Work



- Integrate Ceiling Cat with particle/Kalman filter
  - More accurate and robust localization
  - Fully automated map-making
- SLAM with the Kinect
  - Features from point cloud data
  - 3-D planar surface detection for robust features

Acknowledgements

Many thanks to:

- Prof. Matt Zucker, Ph.D.
- Surdna Summer Research Grant
- Edmond Jaoudi
- Willow Garage

References

[1] Simon Baker and Iain Matthews. Lucas-kanade 20 years on: A unifying framework. *International Journal of Computer Vision*, 56:221–255, 2004. 10.1023/B:VISI.0000011205.11775.fd.