Optical Flow Based Robot Navigation

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The Problem: The aim of this work is to develop algorithms that will be used for robust visual navigation of mobile autonomous agents. The input consists of a sequence of images that are continuously asked for by the navigation system while the agent is in motion. This image sequence can be provided by a monocular vision system for a real physical agent, or by a software simulator for a virtual agent. The agent then tries to understand its environment by extracting the important features from this image sequence and then uses this information as its guide for motion.

Currently, the main tool that we use for navigation decisions are optical flow fields. Optical flow is a vector field that shows the direction and magnitude of the intensity changes from one image to the next one in the sequence [1]. An example optical flow field is shown in figure 1.

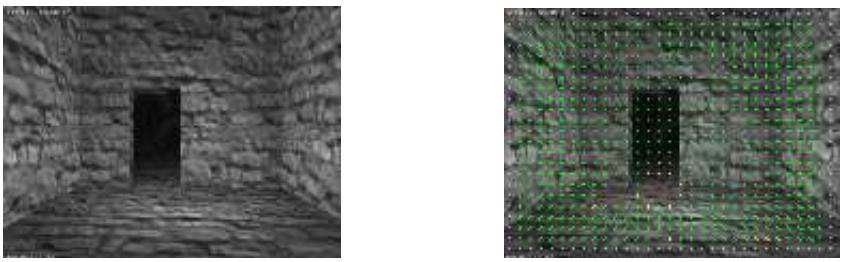

Figure 1: The picture on the left shows a scene from a simulated environment, where the agent has just moved one step forward from its initial starting position. The picture on the right shows the computed optical flow field that is the result of the motion of the agent, superimposed on the first picture.

We are computing the optical flow between each pair of images in a continuous input stream, and using these flow fields we aim to extract necessary information like the layout of the surfaces seen in the images, and the motion of the observation point [2].

Motivation: When we think about the most popular sensors in robotics research, we see that laser range finders, sonar sensors and infrared sensors are all widely used, and all of their strengths and weaknesses are very well known and documented. They basically provide a simple distance measurement within an error bound. One other sensor that is also gaining popularity is vision, which is potentially the most powerful sensor, because vision is also the primary sensor that human beings use for navigation, and we know that we do much better than any robot built until now. There is also not as much work done using vision for navigation as there is using other sensors. Therefore visual sensing seems to be still a mysterious area that is waiting to be uncovered, and that holds promise for robust navigation.

Another motivation for us is that vision seems to be very computationally challenging given the complexity of most of the algorithms developed by vision researchers. But when we consider the speed and ease in which human beings use vision for navigation, a natural confusion arises. This is also another reason for us to look for methods that have not been tried yet.

Approach: In order to compute the optical flow field, we make use of edges in the images [3]. Basically, a low pass filter is applied to the images for reducing the effect of noise, and then the edges are found by applying another (Laplacian) filter. We perform a patch matching operation to determine where the edges in one image moved to in the next image [4, 5].

After computing the optical flow, we use it for navigation decisions such as trying to balance the amount of left and right side flow to avoid obstacles, to trail moving targets, or to escape from approaching enemies [2]. We also use the optical flow to estimate the remaining time to contact with a surface, which can be found using the ratio of the distance of a point in the image plane from the focus of expansion to the rate of change in this distance (divergence from the focus of expansion) [1, 6]. An example time to contact estimation graph that we produced is shown in figure 2.

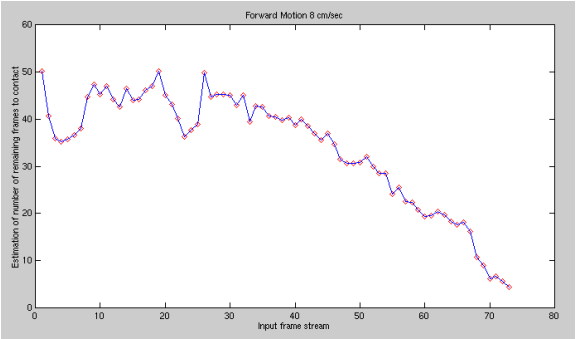

Figure 2: This graph shows the estimations of the number of remaining frames to contact as our robot is moving directly towards a wall.

Difficulty: There are three major difficulties with flow based navigation that we encountered. Since the patch matching algorithm that we use to compute the flow is computationally expensive, currently there is a trade-off between the time it takes to compute, and the quality of the flow field. The second difficulty is that the algorithm cannot produce flow fields for the parts in the images where there are no edges (not enough texture) to compare. And the last one is that there are a lot of parameters that can be used to fine-tune the algorithm to run better in different situations, and in order to be autonomous, the agent may have to learn how to adjust the parameters by itself, unless global satisfactory default values can be found.

Impact: Among the popular sensors, like laser, sonar, infrared and vision, we see that vision can be used for both indoor and outdoor applications, and we can use vision nearly in every environment that we can think of. Even when the amount of ambient light is not enough for a regular camera to function properly, there are night vision systems that can easily be used to provide high quality visual input to a navigation system. Therefore, implementation of a robust visual navigation system may lead to great applications like autonomous helpers for blind people, unmanned vehicles to accomplish a variety of things under various conditions that may possibly be dangerous for human beings, etc.

A powerful navigation system will also help many robotics researchers to abstract away the low level details and concentrate on other high level tasks that will eventually require autonomous motion.

Future Work: We are planning to enhance the reliability of the flow fields and the speed of computation by some methods like making use of the color information that the images carry, predicting the next flow field and maybe incorporating other sensor readings. We are also planning to develop methods for filling in the empty places in the flow field, where there were not enough textures for the algorithm to compute the flow.

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