E-PUCK VISION: DETECTING KEY FEATURES WITH LIMITED RESOURCES

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Preface

This master thesis describes the research of visual feature detection on a robotic platform with very limited resources, especially on the well-known e-puck robot. The research was done at the Swarmlab of the Department of Knowledge Engineering at Maastricht University.

First of all, I would like to thank my supervisors Sjriek Alers, Bijan Ranjbar-Sahraei and Dr. Karl Tuyls. Sjriek Alers was my daily supervisor from the very beginning of my thesis and helped me through a lot of difficult times. He also helped me developing the theme of this thesis. With Bijan Ranjbar-Sahraei I had a lot of interesting discussions about glowing trails as replacement for pheromones, as well as he helped me improving this report.

Additionally, I want to thank Judith Sticker, who motivated me and helped me with the report. Finally I would like to thank my family, which supported me during this thesis and the whole study.

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Abstract

Swarm animals can achieve amazing intelligent results if they work together. E.g. ants and bees can explore an environment and find the optimal path between a start and a goal location, although each animal has only restricted knowledge. This swarm intelligence can be adapted by very small robots, also called swarm robots. They also have only restricted knowledge of their environment due to the fact, that swarm robots have only very limited resources, as they should be small, cheap and available in large amount.

To gain as much information as possible of the environment, one possibility for robots is to use visual feature detection. Currently visual feature detection for devices with very limited resources is still a highly unexplored domain, though there exist many algorithms for devices with high computational power.

This thesis focuses on some visual feature detection algorithms which can be used on very limited resources. Considering this constraint many common vision feature detection algorithms (e.g. machine learning) cannot be used. As it is not possible to detect every feature, only a world with predefined parameters is allowed. The features which have to be detected are colored rectangles, light sources, information markers and visual replacements for pheromones.

In the first step, general image processing algorithms with low resource requirements are evaluated and implemented to run on a small robot platform. These consist of pre-processing filters for grayscaling, halftoning, hue detection and blurring as well as algorithms to get a histogram, detect groups of nearly same color and find specific patterns. Although only a slow cpu is used, the images are processed fast enough to do real time image processing. This is due to the small memory, which limits the resolution of the image.

The low resolution also restricts the level of details which can be processed from a certain distance. On the used robot platform small parts of 2 mm size can be recognized in a distance of maximum 20 cm only. To process features with those small details the robot first needs to process an overall image and detect the area of possible features. This can be done by searching for a more simple feature, e.g. a specific color. Then it zooms at the found area and tries to detect and evaluate the detailed feature.

By combining the different feature detection algorithms it is possible for the small robot platform to drive autonomously in a small environment. This consists of distinguishing between different landmarks and drive to them in a given order, detecting the angle and distance in which another robot is located to itself and therefore driving to a specific point relative to the other robot. In a last step it reads complex information from a bar code printed on the wall.

Hence, visual feature detection is possible even if only very limited resources are available. Comparing the results with what modern image processing with high computational power is capable of the possibilities are very limited, for simple tasks like color detection and bar code reading even very limited resources are sufficient.

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Chapter 1

Introduction

Numerous phenomena in nature are fascinating to scientists - and not only biologists, but scientists of a variety of sectors. Often science can reveal coherences through exploring phenomena in nature, which become essential for the development of new products or solutions to scientific problems. For instance, the well-known lotus effect, in which the very high water repellence of the lotus flower concluded to new water repelling sealings for cars.

Another interesting phenomena in the nature is the behavior of ants in exploring resources and searching for food (known as foraging): When exploring unknown areas they have evolved an efficient method to find new food sources and paths to them [1]. Some of the ants continuously explore the environment around their anthill randomly. If they have found a food source they follow their trails back to their anthill, leaving a trail of pheromones. Other ants which cross the trail can follow it to the food source. They leave a trail of pheromones of their own when they are on their way to the anthill. By this behavior they are intensifying the already existing trail. At random some of the ants try other paths in order to find shorter ways. If another path is found and both paths are followed by the same amount of ants the shorter path will be traveled more often in the same time and the trail will be intensified. If most ants follow the path with the strongest pheromone trail they will find the shortest possible path.

Another foraging behavior used in the nature, which can be transferred to swarm robots, is the one of honeybees. Instead of using pheromones, they make use of a mechanism called Path Integration for navigation, and the mechanism of direct communication for recruitment[2]. The foraging process is split into two phases. In the first phase, the bees are exploring the environment. As soon as a bee finds a food source the bee returns to the hive, loaded with food. It then communicates the location of the food source to the other bees and by doing so recruit other bees. When the new recruited bees have collected food and returned to the hive, they will again communicate the location of the food source to other bees, so that the knowledge will spread.

This so-called Swarm Intelligence (SI) can also be applied to robots. Several small robots with limited resources each can explore an area and find the optimal path between a randomly chosen start and goal position.

1.1 Problem Statement

In order to apply SI-based techniques to swarms of small robots with limited resources, detection of environment feature is a key task [3]. Therefore, in this thesis the focus is put on using the robot vision for detecting important features of an environment. Features are "interesting" parts of the image and can be nearly everything, ranging from an uni color simple shape (e.g. a purple rectangle) to a multi color complex one (e.g. a robot).

Most algorithms used to analyze complex features need a high computation ability and a high amount of memory to store the information about different types of a feature. However, robots which are used in swarms often have low computational ability and low memory, as they should be cheap in production. Therefore, all algorithms which can be used on swarm robots have to be of low resource requirements. That prohibits many common techniques in feature detection (e.g. image based machine learning).

Parallel to modifying the common image processing techniques to be computationally less expensive, another problem is that the features in the environment have to be as simple as possible, but still be distinguishable from each other. Moreover, particular features are required which can be detected from very far or very close distances.

Also, the surrounding environment presents problems in feature detection. Light conditions and other objects influence the vision with noise or false detection of features. In a dark environment the noise density in an image is much higher than in an appropriate bright environment. Other objects have to be filtered, even if they seem to match parts of a feature.

This leads to the following objective:

Using a simple robot camera for detection of the environment key features with respect to the limited available resources.

1.2 Research Questions

In pursuing the thesis objective, the following complementary general research questions are addressed.

As described before basically, the features can be anything. However it is not possible to detect any kind of feature with very limited resources. The limited resources are defined as a 16 bit CPU of 60 MHz and a memory of 8 KByte RAM. The size of the program file cannot exceed a limit of 144 KByte. Therefore, special features should be found which are detectable by simple image processing algorithms and limited storage memory.

Research Question RQ1:
What type of features in the image can be detected by a simple robot with limited resources?

Objects in the environment should be detectable from a distance, but some also need to provide information about their identity. Therefore the features have to be split into two groups, features which can be seen from a far distance but provide almost no information and those which provide much information, but can not been detected if the robot is not close to their front.

Since with a small memory resource it is not possible to save images in high resolution the question has to be solved from which distance the features are recognizable and distinguishable.

Research Question RQ2:
Which detail level can be recognized and what is the maximum distance to distinguish between different features of the same kind?

Another problem which is a result of the small memory is that it is only possible to save either a small detailed part or a general view with low details. Therefore, it should be figured out if and how it is possible to process several parts of the image after each other, e.g. getting an overall image and zoom at specific interesting parts.

Research Question RQ3:
How to split an image into subsections for independent processing and memory saving?

In addition to the first three general research questions, more specific questions should be solved. There exist many algorithms which provide help in image processing and feature detection, e.g. image blurring and edge detection, but not all of them can be used due to the limited resources. Some algorithms need much memory, others have a long run-time. In addition, the maximal usable memory of the robot should be determined.

Research Question RQ4:
Which image processing algorithms can be used with limited resources?

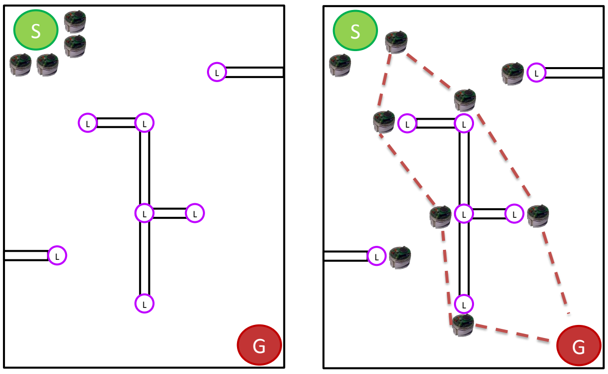
Due to different environmental conditions, the feature detection probability should be computed. It gives a clear overview how good the feature detection work and if it can be used in a real world environment.

Research Question RQ5:
What are the probability of correct detection of a feature and wrong detections?

1.3 Methodology

In order to answer the research questions in the previous section, an environment exploration scenario with specific features is defined (as shown in Figure 1.1(a)) in which the task is, to find the best path between a start (green circle) and a goal (red circle) location. In the environment several obstacles (i.e. walls) and landmarks exist. Landmarks are points in the environment which the robot can use to orientate itself and contain at least one detectable feature.

The robot that is used in this thesis is e-puck, which has a small camera onboard [4].



(a) (b)

Figure 1.1: Designed scenario: (a) unexplored environment (b) analyzed environment with best path

When the image is captured by the robot, it should be filtered for being more processable to applying feature detection algorithms:

Task T1:
Applying filters on the captured image.

In the next step the features which can be detected have to be defined. Each feature has to be either added to or be part of an object (e.g. e-puck, landmark, start and goal position) in the environment. The features should contain specific colors and simple shapes. Also the size of each feature has to be regarded.

Task T2:
Defining possible visual features, detectable by the e-puck camera.

With a clear defined feature the search algorithms for it can be implemented, where the search algorithm is an image processing technique which extracts features from the image.

Task T3:
Developing image processing algorithms for detecting specific features.

As soon as all partial algorithms work they can be combined to explore the environment. Therefore the e-puck has to be able to detect all of the features at the same time:

Task T4:
Combining feature detection algorithms, to explore the environment simultaneously with e-puck vision.

To evaluate for which scenarios the algorithms and filters are appliable the cpu time has to be measured. Dependend on how fast the results of the environment analysis have to be available the visual feature detection algorithms can be used. Also the memory requirements have to be computed to decide which algorithms can be used by which image size.

Task T5:
Computing the required memory and measuring the computational speed.