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Open-source Localization Device for Indoor Mobile Robots

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Abstract

Determining own location in indoor environment forms the basis for the majority of tasks performed by mobile robots. Various approaches to this problem have been proposed over the last few decades, differing in the type of perceived data. The most reliable and accurate methods are based on detection of artificial markers placed in the environment. Surprisingly there are very few products available on the market, which would offer the functionality of determining mobile robot's position using artificial markers. Therefore we decided to design and build an affordable, robust and extensible localization device, which could be used in various robotics applications. The created device uses an ARM-based microcomputer and a dedicated camera to autonomously capture and process images of the environment in order to calculate its location. It is resistant to changing light conditions and offers the performance of more than 30 frames per second with average positioning error of less than 5cm. In this paper we present details concerning the hardware and software architecture of the device together with experimental results.

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1. Introduction

Finding robot's position and orientation in indoor environment is one of the most crucial tasks in the domain of mobile robotics. Therefore the problem has received significant attention over the last few decades. Existing approaches to the problem can be classified according to the requirements concerning available infrastructure into three basic groups: external localization and autonomous localization with or without infrastructure in the environment. In this work we are focusing on autonomous localization based on dedicated markers located in the environment. The review of existing solutions in this area, which is presented in the next section, shows that many approaches have been tested, giving significantly varying results. Although the need for localization is obvious and some solutions are very promising, the range of localization devices for robots available on the market is very narrow. Moreover, offered devices are closed-source products, which suffer from various issues and tend to fail in specific situations. Typically, a user cannot extend, correct or even adjust localization algorithms to particular environment features.

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This fact was the main motivation for the development of the device presented in this paper. After several months of testing existing solutions we decided to build a new localization device, which will overcome the problems with the off-the-shelf products. The work resulted in building an autonomous device capable of finding own location in indoor environment. The most crucial features of the developed device are:

- high speed – more than 30 measurements per second,
- a few centimeters localization accuracy,
- small size – the device can be fit into a cuboid of $58mm \times 28mm \times 40mm$,
- extensibility, thanks to open-source software and general-purpose hardware,
- relatively low price – all parts cost about 300 USD.

The device is based on a single board computer equipped with an ARM Cortex-A8 CPU and a dedicated camera. The mode of operation is similar to other approaches – the device detects markers mounted in a ceiling. The detection is based on infra-red light. The device is equipped with infra-red LEDs with adjustable light power, which makes it resistant to changing light conditions. The software is based on OpenCV (http://opencv.org/) library, however, crucial elements are written directly in C and C++ for best performance. In this paper we present details on how to build such a device and how to develop proper image processing software. We also describe the experiments conducted to measure accuracy and demonstrate robustness of the developed solution.

2. Mobile Robots Localization

As mentioned before, existing global methods can be classified according to required environment infrastructure into three basic groups. Among the approaches which do not require any alterations in the environment the most widespread solutions are based on probabilistic localization algorithms, like particle filters[1]. Randomly selected poses of a robot are evaluated according to current sensor readings, which eventually leads to finding the most probable pose of the robot. The algorithm requires a rather strong computer. The greatest drawback is the lack of guarantees for finding location in particular time. The problem may become significant when the environment has many similar fragments. Another approach to the problem of indoor localization is utilization of 2.4GHz radio signals[2]. Measured signal strength and proper attenuation models allow estimation of location without dedicated infrastructure and without complex computations. Unfortunately, the accuracy of this approach is too low for most robotics applications.

In most scientific and industrial applications it is possible to modify the environment in order to make it more suitable for mobile robots. There are two basic approaches in this area: remote localization which detects robots in the observed environment and autonomous localization which detects markers located in the environment. Highest accuracy, robustness and performance can be achieved using a remote localization systems. Typically, these solutions are based on a camera (or several cameras) mounted above the workspace of robots. The image is processed by a dedicated server, therefore the approach can provide high efficiency. The system described in[3] provided 60 measurements per second, while detecting pose of 10 soccer-playing robots. This impressive result is possible only at a very limited space and in particular lighting conditions. Use of camera-based remote localization in larger spaces is also possible, as demonstrated in[4]. The solution allows locating fork lifters in a large warehouse, using several cameras, which detect unique markers mounted on the lifters.

To avoid centralized processing which reduces autonomy of robots and cost of required infrastructure, many solutions propose inverted approach. The robots are equipped with cameras for observing the environment, which is enriched with detectable markers. Moving image processing to robot's on-board computer makes localization fully autonomous and significantly reduces costs of building large robot-friendly environments. On the other hand it increases required computational power of the robots.

The markers do not necessarily have to be physical objects – robot's vision system can observe projected shapes, displayed by active devices located in the environment[5]. In general, these solutions can provide good accuracy and efficiency, however, it is hard to deploy the projectors system in large environments properly. Physical markers attached to walls and ceilings are much cheaper and can cover far bigger areas. A very low-cost system of this kind[6] is based on a simple webcam which detected black shapes printed on white paper (figure 1a.). The solution does not perform very well, reporting 4%-8% of incorrect detections; the webcams often behaved poorly in changing light conditions and caused significant motion blur. Similar conclusions are presented in[7], where the authors describe a method for using QR codes as markers (figure 1b.), which simplifies image recognition algorithms development.