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Autonomous mobile robots for outdoor tasks

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1. Introduction

The design, creation and programming of mobile robots is one of the key issues of mechatronics and makes an important part in mechatronics education. A lot of robot navigation systems only work indoors. Outdoor operation meets with more challenges: fewer resources are available, the environment features like lighting conditions are harder to control and modify, and operating conditions are more volatile [1]. But since outdoor robots are used in a lot of fields like demining or exploration and also offer the potential for new application areas, research and education dealing with them is very meaningful.

However, systems readily available on the market are usually very expensive. For educational, private and rapid prototyping purposes, cheaper platforms with more possibilities to develop and apply own algorithms are desirable. This paper presents an outdoor robot with the price of no more than 1500 Euro. It is based on a simple remote controlled vehicle and equipped with several low cost sensors: one global positioning system (GPS) module with a gyroscope, a miniature color camera, two shaft encoders, seven ultrasonic range modules and seven infrared sensors. The main control over the vehicle is done by the RCUBE system, which is a platform for intelligent autonomous robots developed at Brandenburg University of Applied Sciences.

For successful fulfilling of tasks, the localization and navigation are of vital importance. The robot needs to know where it is, where it wants to go and which path it will take. The use of a GPS module for navigation on the campus has been investigated and a GPS-map for this specific area was created. The results of the precision evaluations are presented. In the next step, various sensors, like shaft encoder, ultrasonic range modules, infrared distance sensors or robot vision and their role in localization are discussed along with the possibilities to fuse the acquired data and get the most possible precise information on the environment. The vision system has been evaluated in an object recognition task.

For researchers looking for a quick way to test their methods and for students, a well designed software approach is important. A Three-Layer-Architecture for the controlling unit is presented. The knowledge about the environment can be extended and completed if a network of mobile robots and sensors is created.

2. Hardware

To achieve the low price for the robot, the hardware components had to be chosen very carefully. The results are presented in this chapter and the components are described in terms of their function and precision.

Platform an outdoor monster truck type Tamiya Trail Master QD 1/14 was chosen to be the first platform for the outdoor robot. It costs about 100 Euro and is available in toy shops.

Fig. 1 Monster truck platform: left - original; right - rebuilt

Controller the RCUBE [2] system was developed in a project at Brandenburg University of Applied Sciences. It is a platform for intelligent autonomous mobile systems including vision, sensor/actuator and computing hard- and software. Its main features are low power consumption, a number of ports for sensors and actuators exceeding those of systems on the market, a high computing power and on board image processing capability. It consists of 4 modules which can be connected by the 1 Mbit controler area network (CAN) field bus.

A typical RCUBE system consists of four components. First, there is a CPU board with a 220 MHz Strong ARM processor running ARM Linux, supplying the computing power of the system. Second, the VIO board makes up the standalone image processing module which is able to connect up to 4 standard PAL cameras. Third, the AKSEN board provides connections to robot components like actuators and sensors. Finally, a Compact Flash module gives a greater storage capacity.

The motion control of the autonomous mobile robot is based on the RCUBE platform [3, 4]. Its components provide the capability to sample sensor data, to control DC motors, to sample and process vision information, to communicate via an internal CAN bus and via a serial interface. It is also a key component of the BOSPORUS system and will be used, for example, for fixed and stand alone sensors, cameras and GPS receivers.

GPS will be used for localization of the robot. In theory, GPS positioning can achieve an accuracy of position measurements with deviations of less than one centimeter. In practice, standard hardware with reasonable prices has position deviations of several meters.

The robot is equipped with a nonexpensive GPS receiver from the Swiss company u-blox [5] and costs less than 100 Euro. The characteristics of the board have been investigated with a series of measurements on a survey point on the roof of one of the university's buildings. In a period of 21 days, the GPS measurements of four receivers of four different points were sampled every 30 seconds. The statistics for two points measured over 24 hours are collected in Table. It should be noted, that the differences between the minimums and the maximums are about 33 m in the latitude (South-North-direction) and about 18 m in the longitude (West-East-direction), the deviations are about 4 m/2 m. More details on the measurements can be found in [6]. Concluding, it can be stated that an autonomous mobile robot can be localized on the map using average data of a GPS receiver. The precision of the localization can be estimated by a few meters while separate measurements can differ more than 15 m. Averaged GPS data can be used directly for global localization and navigation, but the positioning error is too large for direct motion control. In the field of motion control, the incoming GPS data should be tested on the base of the probability that they are correct.

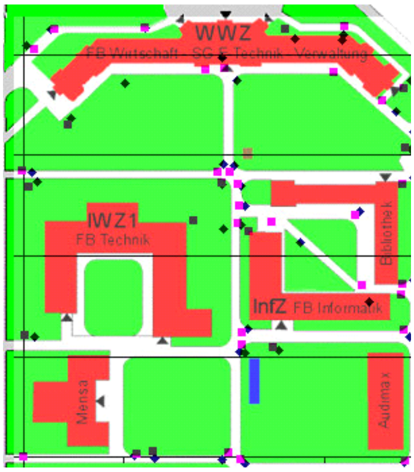

Fig. 2 Map of the campus (blue – measured, pink – known points)

About 40 characteristic points of the campus were surveyed using the u-blox receivers, calculating the average of data sampled every second over two to five minutes. The coordinates of these points were determined according to a reference point and compared with the well-known coordinates of approximately the same points (Fig. 2). The obtained deviations are less than 5 m for most of the points.

To improve the results of the GPS receivers, two main methods were pursued and tested. The first one is the usage of Differential GPS (DGPS), where the fact that two receivers close to each other are subject to the same error sources is utilized. The described methods have significantly improved accuracy achievable with GPS. The precision reaches up to 1.3 m in 2D and 2.3 m in 3D (with 95% probability). Detailed descriptions and analyses can be found in [7].

Table

Statistics of the data of two points and of their distance

	Receiver 1		Receiver 2		Difference		Distance
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	
Average:	5224.6281	1232.2275	5224.6274	1232.2268	1.37	0.60	2.33
Deviation	0.00216	0.00178	0.0017	0.00167			
m	4.00	2.01	3.15	1.89	1.77	1.08	1.05
Minimum	5224.621	1232.222	5224.623	1232.219	-3.86	-2.00	0.29
Maximum	5224.638	1232.238	5224.636	1232.232	5.28	3.17	5.28
Max-Min	0.0178	0.01571	0.01331	0.01325	9.14	5.18	4.99
m	32.98	17.77	24.66	14.99	9.14	5.18	4.99

The second implemented method of improving GPS measurements uses carrier phase information of the GPS signal. Usually, the position of a receiver is calculated with help of a code based measurement of so called pseudo-distances. More accurate algorithms observe the phase of the carrier signal, where accuracy in the scope of millimeters is possible [8].

Sensors the mobile robot positioning by the GPS receiver is supported by the fused data of various sensors (see Fig. 3). Different problems can be addressed with different types of sensors:

- global positioning and orientation: GPS receivers, gyroscopes;
- relative positioning with reference to known objects: image processing;
- relative positioning with regard to initial point: odometry;
- obstacle detection: ultrasonic, infrared or laser based sensors.

One mobile robot is equipped with 7 ultrasonic range modules, 7 infrared distance sensors and 2 shaft encoders, the other additionally with one GPS receiver connected to a gyroscope, one CCD camera.

GPS data helps to locate approximately the robot on a map of the campus. After knowing the area the robot is in, vision capabilities can be used to determine well known landmarks which are defined in advance.

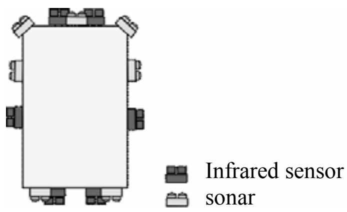

Fig. 3 Positions of sonars and infrared sensors

The shaft encoders inside the wheels at the rear axis count rotations of the wheel and support dead-reckoning. Very small ultrasonic sensors measure distances to all objects that reflect the sent ultrasonic waves. Ideally, a range from 3 cm to 6 m can be measured, but in practice, the analogue gain of the sonar's had to be reduced for not catching unwanted signals from the floor. Right now, a distance up to 3.50 m can be determined. Infrared sensors work after the same principle as sonar's, but with infrared waves instead of ultrasonic. Sharp GP2Y0A02YK are used to measure distances in a range from 20 cm up to 150 cm.

Image processing the RCUBE platform provides sufficient performance to manage even the more complex tasks in the field of digital image processing in real time. An important role for navigation of the mobile robot plays image processing for landmark detection.

The implemented landmark detection system [9] works with the OpenCV library, which is optimized for real time computer vision and includes a collection of low-overhead, high performance operations to be performed on images. The challenge of image recognition for the embedded RCUBE system, which is of course not as powerful as an ordinary computer, was to find a good ratio between performance and robustness of the used algorithms.

First, the edges of a reference picture of the landmark are analysed. The best result from several investigated performant edge-detectors achieved a self-developed algorithm based on gray value differences. It outperformed the edge detection algorithm implemented in OpenCV as well as edge detection based on the SUSAN principle in processing time, the number of correct detections and robustness.

Recognized edges are described using a gradient based descriptor in the next step. The edges are then analyzed and marked in the input picture, in which the object has to be found. Corresponding edges in both pictures are furthermore determined with a matching algorithm and then submitted to a Hough Transformation to eliminate false positives and to recognize the object. The time for a complete image recognition cycle is approximately three seconds.

3. Software concept

Taking into account that very different sources of information from the environment have the advantage that the weaknesses of one source can be the strength of another, the reliability of the system is increased. But this comes with the price of a rising complexity of software design for such systems – building the hardware is just one part, using it productively is another important issue.

A robot navigating outdoors has to deal with an incomplete, inaccurate and approximate environment and the resulting “ubiquitous presence of uncertainty” which can not easily be modeled [10]. The idea of trying to model a complete environment has long been outdated by more modular approaches. One way are Three-Layered-Architectures based on three separate computational processes presented in [11]. The first proposed process is a reactive feedback control mechanism (“skill layer”), the second is a reactive plan execution mechanism (“sequencing layer”), and the last one is a mechanism for performing time-consuming computations (“planning layer”). Another way is to leave any kind of hierarchical approach and work exclusively with behaviors, a set of small independent units [12]. Each behavior is then alone responsible for fulfilling one specific task like following a line or detecting a landmark, some of which are suitable to be solved with fuzzy logic controllers.

In the Three-Layered-Architecture, higher level layers do not suppress the results of lower level layers, but provide input or advice. It is now applied to the different RCUBE modules.

Skill layer or the controller is written in C language and is located on the AKSEN board. It is taking sensor input and computes direct commands for the actuators. Simple behaviors are implemented on this layer, like avoiding obstacles or following a wall. Knowledge about the world model is rarely necessary here.

Sequencing layer knows a world model and thus the state of the mobile robot. It is written in C++ and runs on the CPU board of the RCUBE. It gives advice to the controller, in terms of which behavior is to use to what extent and to which time. Among others, it works with GPS input and a local representation of the campus. The computations of the sequencing layer can be more complex than those of the skill layer, but should be able to cope with bigger environmental changes.

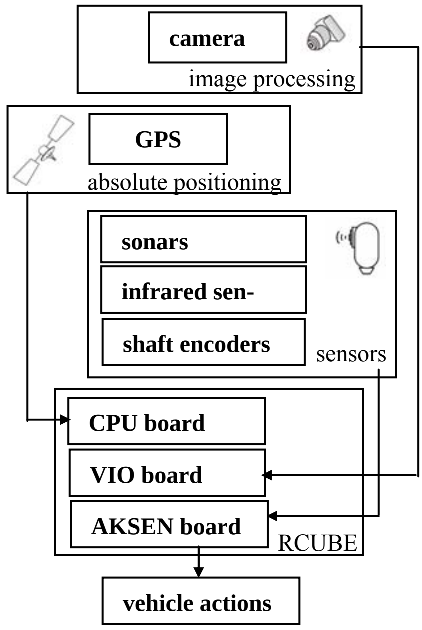

Fig. 4 Matching of environment input to RCUBE modules

Planning layer carries out time consuming computations. In this work, this layer is essentially used for image processing work for landmark detection and the process of smoothing carrier phase GPS data. It gives input to the sequencer by providing plans or it can answer queries from it. This layer is written in C++ and is located on the CPU board, taking its image data from the VIO board.

Different sources of information about the world and their interface to the RCUBE are shown in Fig. 4.

4. Conclusion

This work describes a low-cost outdoor robot for educational and research prototyping use. The robot is controlled by the RCUBE platform with three main modules, providing actuator/sensor control, computing power and image processing capabilities.

The choice of nonexpensive components is presented. Aside from sensors like sonar’s, shaft encoders and infrared sensors, a GPS board is used for navigation. Its characteristics have been evaluated and methods to improve the accuracy have been discussed. The navigation system is furthermore supported by landmarks recognized by an image processing system.

A three layer software concept has been applied the RCUBE architecture, allowing parallel and highly reactive computations on the robot. The robot was also integrated in a Bosporus network, allowing creating an intelligent network with other robots, cameras, PCs or PDAs.

5. Acknowledgement

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H. Loose

AUTONOMINIAI MOBILIEJI ROBOTAI IŠORĖS DARBAMS

R e z i u m ė

Pristatoma nebrangi techninė sistema išorės robotams, tinkama mokymui, pramonei ir asmeninėms reikmėms. Analizuojamas sistemos, jutiklių, valdiklio, GPS ir vaizdų apdorojimo techninių komponentų parinkimas, pasiūlyta programinė įranga, leidžianti studentams ar tyrėjams pritaikyti savo algoritmus vietos nustatymo, navigacinėms ir kitoms užduotims atlikti. Galima integruoti kelis robotus sujungiant skirtingas technines sistemas į vadinamąjį BOSPORUS tinklą. Taip sukuriamas tinklas jutiklių bei vaizdų apdorojimo duomenims surinkti, kaupti, mobilių sistemų navigacijai ir valdymui. Tokios sistemos architektūra pristatyta ir įvertinta Brandenburgo taikomųjų mokslų universitete.

H. Loose

AUTONOMOUS MOBILE ROBOTS FOR OUTDOOR TASKS

S u m m a r y

This paper presents a low-cost hardware platform for outdoor robots, being suitable for education, industrial prototyping and private use. The choice of components is discussed, including platform, sensors and controller as well as GPS and image processing hardware. Furthermore, a software approach is proposed, allowing students and researchers to easily implement own algorithms for localization, navigation and the tasks to fulfill. Several robots can be integrated in a framework which connects various different hardware platforms, called the BOSPORUS network. Together with other components, they form an intelligent network for gathering sensor and image data, sensor data fusion, navigation and control of mobile platforms. The architecture of a reference platform on the campus of the Brandenburg University of Applied Sciences is presented and evaluated.

Н. Лоосе

АВТОНОМНЫЕ МОБИЛЬНЫЕ РОБОТЫ ДЛЯ НАРУЖНЫХ РАБОТ

Р е з ю м е

Представленная недорогая техническая система для роботов наружного применения может использоваться в учебном процессе, в промышленности и для личных целей. Обсужден подбор системы, датчиков, контроллера, ГСП и технических компонентов обработки изображений. Предложено программное обеспечение, позволяющее студентам или исследователям легко адаптировать свои алгоритмы для решения задач локации, навигации и др. Возможно интегрирование нескольких роботов соединением разных систем в так называемую BOSPORUS сеть. Так реализована интеллектуальная сеть по сбору и накоплению данных с датчиков и системы обработки изображений, навигации и управления мобильных систем. Архитектура такой системы представлена и прошла испытания в Брандербургском университете прикладных наук.

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