Low-cost sensor data processing of autonomous mobile robot guide

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Abstract

This paper describe algorithms for low-cost sensors data analyzing and processing for localization problem which are used in robot-guide project. Experiments were carried out for the simulation world model.

1. Introduction

Nowadays in the world are implementing a robotic tour guide developed by the largest corporations (Sony, Hitachi, Toshiba, General Motors, Siemens and others). Their design successfully used in cinemas (ED Corporation), the Seoul Museum of Natural History (South Korea), in the Madrid office center Santander's Group City, Regional Archaeological Museum of Agrigento, the Institute for Manufacturing Engineering and Automation of the Fraunhofer Stuttgart, at International Technical Fair (CES2010), forums, and corporate offices (Kaikan Exhibition Hall in Toyota City). The main disadvantages of these systems are high cost and proprietary source code. This makes economically disadvantageous to use one of the existing platform for creating robotic exhibition.

Belarus will host a world hockey championship in 2014 year. Within championship exhibitions would have a keen interest and many people will come. Exhibitions will need technical innovations to increase number of visitors. This can be a robot guide. The idea of robot guide creating was supported and project of robot breadboard constructing is in progress.

Main feature of the robot guide is intersection with people and exhibits in the indoor environment. The room is located a predetermined number of exhibits. Robot has information about map of the room, coordinates of the exhibits and his start position (Fig. 1).

Touch-screen display will be used for robot control. Each visitor may choose for what type of the tour he want. After activation robot paves the way to exhibits. It plays media information about exhibition at the time of driving and explains about exhibits on arrival.

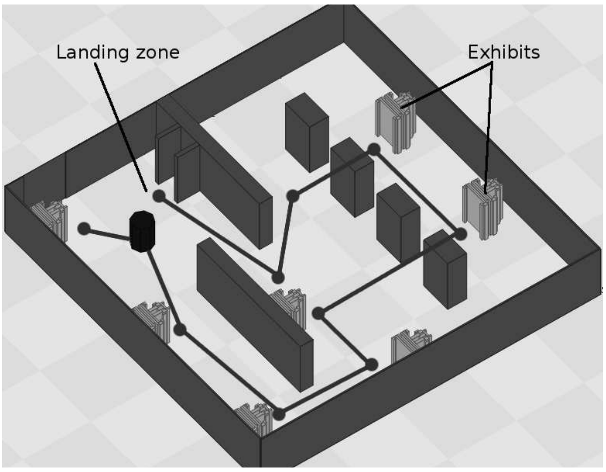

Fig.1. World model with exhibits and robot guide.

Dictated by financing of the project we are using only low-cost sensors. We implement ultrasonic and infrared sensors based on previous developments of the BrSTU Robotics group for this project. Obstacle detection, localization and mapping tasks need unusual solutions for those types of sensors. Existing algorithms for localization are based on laser scanners and are not applicable to our problems. We are using odometers and gyroscope to solve localization problem. The SLAM algorithm implementation developed for our purposes.

Low-cost sensors data should be process to reduce the error to acceptable parameters. These conditions were laid down in platform developing and in navigation system algorithms.

Working on the robot guide project we divide it on 3 subtasks:

1. Creating robot model and simulation;
2. Developing algorithms and software for the robot model;
3. Development hardware for the robot and algorithms adaptation.

In this article we use the results of the first two tasks.

2. Previously works

Low-cost sensors systems always have been in demand. Developers replace the expensive sensors and reduce the price of the product by using software processing algorithms.

Using of ultrasonic arrays is very common for localization and map building problem. Lindsay Kleeman and Roman Kuc examined in detail the approach based on ultrasonic sensors [1]. Chong and Kleeman work added accuracy odometers and various variant of Kalman filter for navigation and mapping problems [2].

Their approaches have a number of problems associated with the shortcomings of ultrasonic detection of obstacles. Researchers successfully solve problem for static environment. Developed algorithms are require improvement to implement it for the dynamic environment. Because ambient noise makes ultrasonic sensor unacceptable for navigation, as there is a lot of mistakes. It should be noted that sonars are a good tool for detection of dynamic obstacles, even in a noisy room.

We add infrared ranges to solve navigation problem. They are less susceptible to noise and well-defined static obstacles, thus complementing the sonar. Kam, Xiaoxun Zhu and Kalata use in their researches infrared scanner with sonar for building sensor fusion model [3]. It is good for static environment. But infrared scanner will skip over many obstacles in dynamic environment. It happens because the rate of the robot and obstacles in the aggregate rate impose severe restrictions on the reading speed sensors.

Developed platform is a symbiosis of several approaches for robot building and sensor models. Developed model has not been used previously for robot guides.

3. Robot platform

Robot guide breadboard platform is building in laboratory of BrSTU Robotics group. It is 46 cm diameter platform with odometers, gyroscope, sonar sensors, infrared sensors and two web cameras as Wi-Fi sensors. The platform has four wheels, that two of them are omni. It have maximum speed 1,5 m/s. Robot appearance illustrate as computer model on figure 2.

Optical odometers have 64 sectors accuracy. Each wheel has length of 31 cm. Thus odometers have 1 cm/m average positioning error without calibration. Gyroscope is using for measure heading angle. Without calibration it have 1 degree average error in turn maneuver.

We are using two sensors models jointly for obstacle detection. There are infrared sensor model illustrate on the figure 3 and ultrasonic sensors model illustrated on figure 4. Each of the models have their own advantages and disadvantages. Combining data of models we obtain model that have more advanced precision and reliability.

Fig.2. Model of the robot guide.

Working on the simulation subtask we create detailed robot guide model for the Player/Stage simulator. This model has all sensors and actuators of the real robot. We establish an error to the sensors for conformance to the real world.

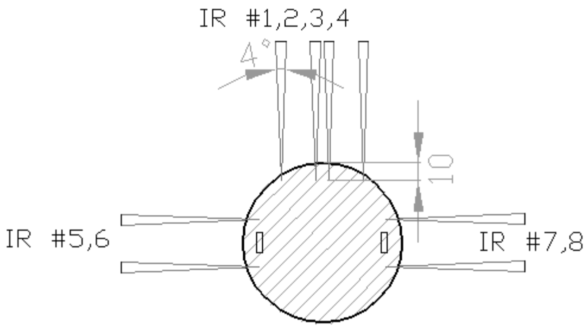

Fig.3. Infrared sensor model.

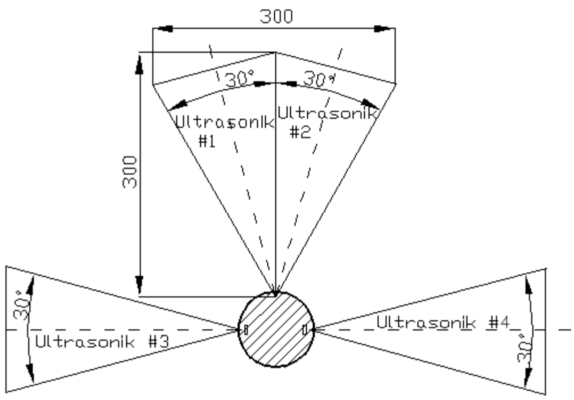

Fig.4. Ultrasonic sensor model.

Robot software write as common three layer architecture which consist from reactive behavior, execution level, planning level [4,5] (Fig. 5).

Reactive behavior – low level control logic, sensor data processing;

Execution level – middle level control logic, ensure the implementation and execution of a chosen robot behavior, performance reflexes in emergency situations;

Planning level – high level logic, choosing how to deal with high-level goals using data about the environment, the robot determines robot behavior.

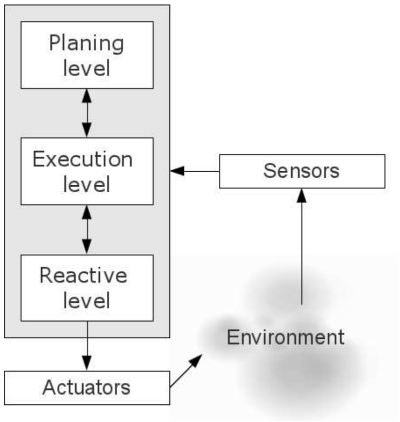

Fig.5. Robot guide software architecture.

Such tiered systems allow us to divide low-level code from high-level. It is very important for easy migration of the software to other platforms.

4. Sensors data processing

In order to process the data is necessary to get representation of the robot world view. It get information about environment appearance from obstacle detection sensors. Visible world of the robot is shown on figure 6 from IR sensors and on figure 7 from Ultrasonic. Left images are show how it looks in simulation and right images are robot view of the environment. Thus, we can find many points where the sensor readings are identical in the environment. This makes it essential to use precise localization. For this goals we use local positioning sensors, Wi-Fi camera sensor and localization algorithms.

4.1 Infrared sensors

One type of the obstacle sensors is infrared rangefinders. For the project we use SHARP GP2Y0A21 infrared sensors 10-80 cm detection zone. The angle of reflection depends on the distance to the object. Received reflected pulses are collected and transmitted high-quality lens on the linear CCD sensor. Illumination on a certain area of CCD matrix is defined by the angle of reflection and calculated the distance to the object.

This method is more protected from interference effects of radiation and different reflectivity of surfaces made of different materials and painted in different colors. For example, it became possible to define a black wall in bright light.

We used spreadsheet or normalization to obtain the linear characteristic method. Normalization after the conversion formula:

$$R = \frac{m'}{V + b'} - k \qquad (1)$$

After selection of the constants for GP2Y0A21 formula would look like:

$$R = \frac{2914}{V + 5} - 1 \qquad (2)$$

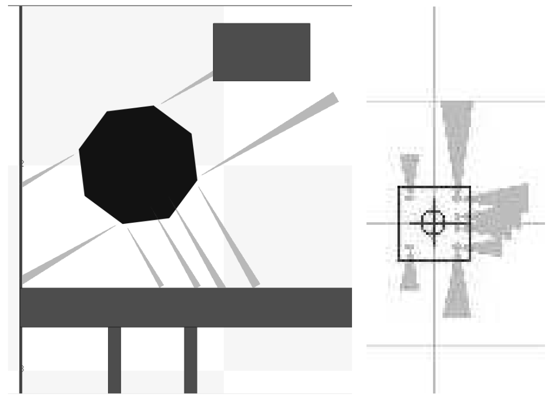

Fig.6. Robot guide visible from IR sensors.

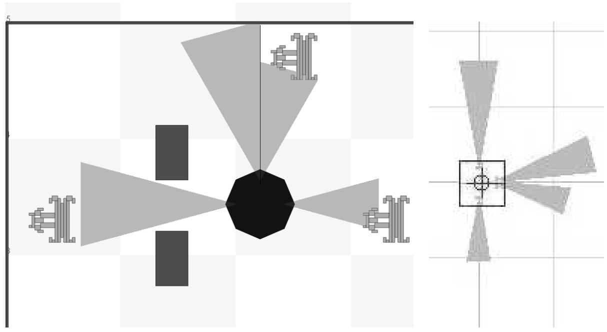

Fig.7. Robot guide visible from Ultrasonic sensors.

If the distance is less than the minimum measured (figure 8, this 10 cm) characteristic falls very quickly and gives the impression that the long distance is measured.

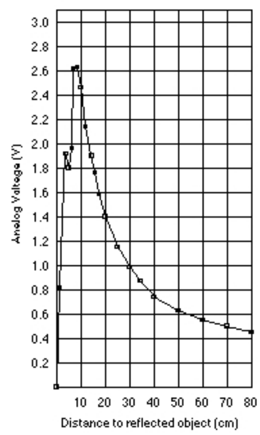

Fig.8. Nonlinear characteristics obtained from infrared rangefinders.

Advantages:

- accurate measurements;
- determines the points of the obstacle in the environment (can building a map of the area).

Disadvantages:

- Crashes in the reflection from the black surfaces (reflected in 19% of the beam);

- Narrow beam take chance to miss an obstacle.

4.2 Ultrasonic sensors

The other type of obstacle detectors is ultrasonic sensors. In project we use Seeedstudio Ultrasonic SEN136B5B measurement module 3-300cm detecting range. Module works in diffuse mode. In this mode the same ultrasound transducer emits sound waves and then picks up the scattered wave that is reflected from the object.

For estimating the error of IR sensors we use directional diagram build by manufacturer (figure 9). Working beam width is 30 degrees.

Advantages:

- Accurate measurements;
- Long range detection;
- Easily identify coming nearer obstacle.

Disadvantages:

- Wide beam – it is impossible to determine exactly where the barriers are located;
- High probability pass obstacles at an angle.

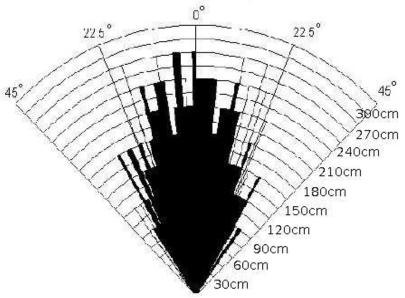

Fig.9. Directional diagram for Seedstudio Ultrasonic range measurement module.

4.3 Odometers and gyroscope

Using odometers and gyroscope we create accurate localization system that is solving robot navigation problem. Odometers and gyroscope are using for correcting trajectory of the robot by PID regulator on multilayer neural network (figure 10).

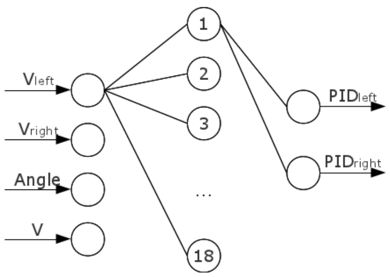

Fig 10. Architecture of PID regulator neural network.

V_{left} and V_{right} are speed of left and right wheels calculated from odometers. Angle is calculated from gyroscope sensor data. V is wishful robot speed. PID_{left} and PID_{right} are value is setting to the motor driver. Training set was obtained using a computer model.

It make easy to manipulate of the robot motors. This approach allowed reducing the error of the motors.

4.3 Sensor fusion

For sensor fusion we use occupancy grid map. Each cell has the dimensions of a square centimeter and the state from 0 to 255. Main stages of the algorithm:

1. Initialize the map (put a real map of the area to the occupancy grid map).
2. Read ultrasonic sensors data. Reducing map values on beam covered area before obstacle.
3. Read infrared sensors data. Increasing map values on detecting line.
4. If calibration initialized change position of the robot to obtained coordinates.

These approaches have transfer calculation to robot hardware level and allow evaluating the resulting data with higher probability.

4.4 Simulation results

Robot-guide localization requirements for the one-minute work. For speed 1,5 m/s it means 90 meters movement. Allowable error is forty centimeters.

We set error for all settings and get two type of experiments: with and without data processing. Our algorithms allow reducing the error falling from 96 to 99%.

5. Conclusions and future work

The main task of processing sensors for this project was to prepare data for using in SLAM algorithm. This algorithm is in development phase and has 3 stages:

- Starting position the robot calibration;
- Robot calibration with respect to the map;
- The robot calibration with respect to the exhibits.

This approach would solve the problem of robot navigation. Within localization problem was considered 5 problems:

- Systematic error of all sensors;
- Choosing of dimensions and the type of the maps;
- Comparisons sensors and map data;
- dynamism of the map;
- Map as a convenient way for path planning.

Thirst three problems are not hard for simulation model as show in our experiments. The main reason is that the model cannot pass all noise of the real environment and the mechanics of the robot. Therefore, the purpose of our further work is upgrades and implementation of developed algorithms to apply them to the real robot guide.

Acknowledgments

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