MOBILE ROBOT NAVIGATION ALGORITHMS BASED ON STEREOVISION

Szymon Szomiński
AGH University of Science and Technology
Al. A. Mickiewicza 30, 30-059 Kraków, Poland
E-mail: szsz@agh.edu.pl

Anna Plichta
Cracow University of Technology, Department of Computer Science
ul. Warszawska 24, 31-422 Kraków, Poland
E-mail: aplichta@pk.edu.pl

KEYWORDS

ABSTRACT
This paper regards the application of stereovision for navigating a mobile robot in an unknown environment. The robot, provided with two cameras, moves inside a building. Thanks the analysis of the streams of data the distance between the robot and the other objects (walls, obstacles, dynamic obstacles, other robots) is provided in real time and the robot trajectory is set. The paper presents the navigation algorithm for the experimental robot designed and built for the conditions specified above. However, the algorithm can be easily applied in open spaces.

INTRODUCTION
In mobile robotics it is uncommon that the system has the certain a priori knowledge regarding the state of its environment vast enough to act by itself. It is because the environment is dynamic and changes too rapidly and independent for the robot or the place for storing data is limited.

The sensors registering the changes in the environment provides it with current data necessary for autonomic activity and responding to the unpredictable situations. The data can be used in various manners. There are mainly two approaches: individual approach and fusing the sensoric signals together.

Types of mobile robots
There are several categories of mobile robots according to their various driving platforms: These are:

- pacing robots,
- wheeled robots,
- crouching robots,
- flying robots,
- swimming robots.

In practical use, the wheeled robots prevail. They find application in transporting goods, inspecting the places unavailable for people, or patrolling the terrain.

AVOIDING OBSTACLES
The robot is fully autonomous when it meets the following criteria. It should be provided with the logical system which enables it for avoiding obstacles and heading the given goal. There are some types of sensors which seek the environment to provide the robot with the information about the obstacles in its route. The most popular are infrared sensors, laser rangefinders or ultraviolet sensors.

Sensors which make use of waves of light belong to the active sensors emitting the energy (the light) in environment. These elements use the infrared light, invisible for human eye, and are resistant to any disturbance, that comes from illumination. There are two subcategories in that group:

- touch free sensors - simpler subcategory which uses the light waves; the change of initial state follows the detection of an object.
- optical rangefinders - they measure how far the object is and the change of state follows the subtle interpretation of the received energy.

Some sensors uses the acoustic wave to detect the obstacle. In such sensors one uses the supersonic waves which are emitted as the light band and after the reflection from the obstacle are caught with the receiver. However, it works in slightly different manner than the light-using sensors. The light using-sensors usually measure the intensity of reflected wave whereas those based on acoustic waves typically measure time the wave needs to reflect from the obstacle and return to the receiver.
Both types of sensors provide the robot with information on the environment and obstacles ahead. The range and other parameters of those sensors are, however, limited. Because all of them measure the distance from the obstacle within the range of the sensor, it is necessary to use as many sensors as possible to avoid the collision with obstacles.

In another approach one uses the video recorders provided with some algorithms instead of the sensors. Video recorders can do more than just measuring the distance. The acquisition of the distance from digital images must be real-time and fully automated process, which is possible by means of some methods of such automation.

**AUTOMATION OF MEASUREMENTS IN THE DIGITAL IMAGES**

One of the most important processes in photogrammetry is the identification and measurement of the homologous points in two or more images. The function of such measure is to choose the object in one image and to find its equivalent in the second image. In analogue and analytical photogrammetry the operator carries out the measurement manually. In digital photogrammetry the measurement should be automated. That process is called image matching automatic stereo matching or just correlation. Matching several images is called multiple image matching. It has some applications in aerotriangulation or in sequential images matching (the images acquired with video recorders).

The word "matching" usually stands for the matching the fragments of two or more images, finding their counterpart or recognizing the similar feature. Many things can undergo matching, for instance the area of pixels registered in the Area Based Matching array, based mainly on analysis of the shades of grey in the given fragment of the image. If the image is colorful one carry out the analysis of the one of its constituents or the weighted combination of the constituents. Whenever the above-mentioned process is undergone by some feature of the image, it is called Feature Based Matching (FBM). The feature can be local (f.ex. point or edge of an object) or global (polygonal objects).

**The characteristics of the particular methods**

Area Based Matching is based on the analysis of the area of the group of pixels and subsequent comparison of their shades of grey. If the image is colorful, one can use one channel for correlation. In that method tiny image fragments, so called image patches, are compared one another. Then, their mutual similarities are measured by means of correlation or by virtue of least square method. Image matching which makes use of correlation is often called "image correlation". Otherwise, it is called LSM (Least Squares Matching). Feature-Based Matching is used in computer graphics. Edges or other objects taken from the original images are compared to the proper homologous objects taken from the other images. Probability is usually represented as the cost function.

Recently, another method has been widely adopted: Symbolic Matching That method involves the comparison of the symbolic descriptions and usage of cost function. The symbolic description can pertain to the grey scale or to the objects in the image. They can be implemented into the system as charts, trees or semantic networks. Contrary to the previously enumerated methods symbolic matching is not based on the geometrical similarity. Instead, it compares the topological features of the objects.

Pixel to pixel stereo matching algorithm detecting deep stereo-discrepancies between pairs of images. That algorithm matches the single pixels into mutually corresponding scan pairs. However, closed/solid pixels are not matched. Then, by means of fast postprocessor, the information from both scans is fused together. The algorithm manipulates large areas lacking textures, measures the pixel discrepancy (which is independent on the image sampling) and cuts the incorrectly found data in order to accelerate the dynamic programming. The calculations are fast (about 600 nanoseconds per pixel for oddness). Approximate maps of discrepancies and precise infinities in horizontal and vertical limits are displayed for several stereo image pairs containing textured, non-textured, convergent or diagonal objects photographed inside and outside.

**STEREO MATCHING ALGORITHM**

Stereo matching algorithm is for determining depth discrepancy in the image. In other words, it is for acquiring the image of the depth out of two images. These images should be acquired with two cameras which are calibrated in the stereo-visual system (system provided with two identical cameras set at different angles). Images of the environment are recorded at certain angle which may be determined with specific algorithms for stereo-vision system calibration.

In the image of depth one determined the distance between objects from two 2D images and other objects. Such image is provided with information on its location in the space. In our case closer objects are brighter and more remote are darker.
The so called discrepancies of the depth in the image are important also for people. Human eye is stereo-visual and we all know it very well, because that function enables us to determine the distance between objects in the environment and is the milestone of space-orientation.

The algorithm was used to make up the autonomous robot provided with two cameras and neural network in order to avoid obstacles in unknown environment. The stereo-visual system consists of two (almost) identical web cameras. The algorithm is called pixel to pixel because it calculates the difference between the pixel corresponding to one another. Determination of the location of the point in space is possible only for those areas where pixels overlap one another. The formula for determining the difference between pixels.

\[
d = x_l - x_r
\]

where \( d \) stands for the distance between pixels

\[x_l\] - coordinate \( x \) from the left image

\[x_r\] - coordinate \( x \) from the right image

The main process consists of two stages In the first stage the map of discrepancies (depths) takes place. The second stage is so called post-processing. The acquired data can be applied for controlling of the mobile robot.

One can create the restrictive algorithm limiting the robot movement fully. However, that solution is not flexible and it is typical of such robot to have problems with choosing the direction of its movement. Here, much better solution is using neural networks.

NEURAL NETWORK

Neural network is an appliance or algorithm which reflects (at least partially) the functioning of biological neural system. It typically consists of the network of elements connected to one another; each element has one output and several inputs. Each output is connected with some inputs of the other element. The relationship between outputs and inputs is modified for each element separately in so called network-teaching process. The taught network processes the information via its modification on the border between elements, synthesis in the particular elements and sending signals to one another. The relationship between input signal and output signal of all network is interpreted as the solution of the problem. Provided with the information on the distance and using neural networks we can teach our system how to avoid obstacles autonomously.

In the project we used multi-layer neural network with initial error propagation which had been taught to avoid obstacles.

Back propagation algorithm determines the policy of choosing weights in multi-layer network making use of gradient-based optimization methods. Teaching the network one provides it with some teaching sets (input vectors and corresponding vectors of model signals) To teach is to determine the weight of neurons at such level that the error made by the network is less than desired. The name "back propagation" stemmed from the method of calculating errors in the particular layers of the network. The errors in the last layer are calculated as the first on the basis of input and model signals. For the neurons set in any previous layer the error is calculated as a specific function of the errors of neurons of the previous layer. The error signal spread backwards: from the last layer to the input layer.

The above-mentioned system can be copied and become the core of the groups of autonomous robots able to collaborate and do some task. Fig 1. presents the list of operations performed by the algorithm.

THE DESCRIPTION OF THE SOFTWARE

The application dedicated to communication was written in the Visual Studio 2008 Express Edition. It is free programming environment by Microsoft in which one can write, among others, in C#, C++, Visual Basic.NET. We chose C# 2.0 because it is a fast and object-oriented programming language. The environment has embedded compilers of the above-mentioned languages, debugger and virtual designer. From library .NET we took necessary components to create USB communication application. Programming code consists of some projects which together make "the Solution". The created code is fully object-oriented. Its core is Device class including SerialPort component of the namespace System.IO. It encapsulates API functions of Windows system when it comes to the serial data transmission. We could have referred to that functions as well, but the SerialPort class was perfect for our project.

The Device class includes the object of the Serial Port class and is responsible for the proper communication with our microcontroller; the methods included in the Device class are sufficient to provide it. For instance, when we call device.Send(Port.RC, OpType.Write, 255) method, that object allows for the establishment of the connection, for setting the correct port as the output and it enables the proper value to reach its port destination. Each task, however simple, has some
complexity i.e. one must choose proper message,

transform it into a sequence of ASCII characters, load
into buffer and send.

For the sake of comparison, device.Receive(Port.RB is
much more intricate due to the fact, that the application
must monitor the potential responses of the device.
Apart from that function its code is actually connected
with the user's interface which should display its
current task in a clear manner.

THE RESULTS OF THE EXPERIMENT

It is not easy to control autonomous robot. Control
systems for autonomous robots should be functional,
scalable, efficient and easy to expand.

One should also take into account whether to provide
the robot with manual control, too. It is useful, because
it enables the user for monitoring the whole system and
making corrections, if necessary. The navigation is
intuitive because the machine describes the
environment from the human perspective (Figures 3).
Images form cameras enable us to check the real
conditions prevailing in the environment the robot is
currently in. It would be not so, if the robot was
provided only with radar or infrared sensors. However,
it has some disadvantages. The robot cannot move
inside very dark rooms. In the darkness it is as blind as
any man. That problem can be solved easily: infrared
cameras are cheap and commonly used.

In the autonomous mode the robot is able to avoid 90%
of the obstacles like walls, pillars or furniture. It
cannot detect smaller obstacles. To solve that problem
one should use better cameras and more efficient
computer hardware, able to cope with more data
acquired with the cameras. The better the cameras and
hardware, the more efficient the robot is in recognizing
the obstacle.

SUMMARY

The main assumption in the conducted experiment was
to make up a fully autonomous, mobile and intelligent
robot. Thanks to providing the robot with the set of
web cameras for observing the environment and with
the specific control algorithm we fulfilled the task.
(Figures 3) Making use of the acquired data the robot
can estimate the distance between itself and the
obstacle and can subsequently change the direction of
its movement to avoid the obstacle. Cameras enable us
also for examining the problems connected with the
movement in enclosed places. Cordless communication
is crucial for controlling the robot. It is also important
for understanding the problems affecting such systems
in statu nascendi and for coping with them. The project
actually pertains to many branches of knowledge and
scientific disciplines - electronics, robotics, mechanics
and computer science. All these disciplines are
mutually bound and overlap one another.

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AUTHOR BIOGRAPHIES

SZYMON SZOMIŃSKI He studied computer science at the Cracow University of Technology and obtained his degree in 2010. Currently, he study computer science at the AGH University of Science and Technology. His e-mail address is: szsz@agh.edu.pl

ANNA PŁICTA She studied comparative literature at the Jagiellonian University and obtained her degree in 2007. She also studied computer science at Cracow University of Technology and obtained her degree in 2010. Currently, she works as a teaching fellow at Cracow University of Technology. Her e-mail address is: aplicta@pk.edu.pl