Optical glyphs based localization and identification system

Grzegorz Redlarski, Aleksander Pałkowski, Dominik Ambroziak

Faculty of Electrical and Control Engineering, Gdańsk University of Technology

Abstract: Optical glyphs are non-complex graphic signs that contain encoded information. By utilizing techniques of image processing and pattern recognition, it is possible to implement an effective global system for autonomous vehicle navigation. The simplicity of the system allows it to be easily implemented, without having to rebuild monitoring equipment. It also provides the possibility to use, during the design process, of widely available *open source* software. This paper presents an algorithm, whose task is to find the symbols of objects contained in the database and determine their position and orientation in the global coordinate system of the camera. The speed and reliability of the system has been demonstrated on the basis of experimental studies using real mobile robots.

Keywords: camera-based tracking, image processing, mobile robot navigation, optical glyphs, pattern recognition

1. Introduction

Ensuring continuously provided information on the location of the robot is a key element of any navigation system because it allows maintaining control of the movement of the vehicle. Location of the robot is specified as the possibility to obtain information about its position and orientation in the given coordinate system (fig. 1). Approach to this problem depends on the type of localization procedure that applies to the system being developed.

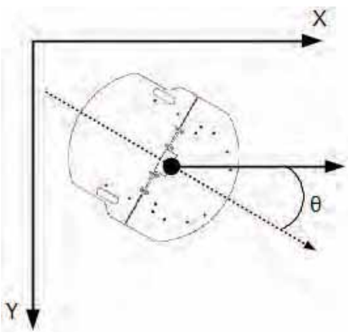

Fig. 1. Position (x, y) and (θ) orientation of a robot in the global coordinate system

Rys. 1. Pozycja (x, y) i orientacja (θ) robota w globalnym układzie współrzędnych

There are two types of the issue: local and global. Local navigation is often not a sufficient solution, mainly due to the accumulated position errors. Therefore, as a parent localization control mechanism, global navigation methods are applied. Because of the location of the navigation process, two approaches are specified: indoor and outdoor.

Amongst many global techniques used indoors [2], due to its accuracy and versatility, the most attention is drawn on the vision-based positioning systems. Their primary function is to extract specific characteristics of the tested environment, which will further allow determining the required vehicle data.

A widely used method of object localization is placing some kind of unique marker on its surface [5, 6, 9–10]. The vision system by means of appropriate methods of image processing and analysis performs operations leading to separation of the shape from the environment and determines the coordinates and orientation in the global reference system. The process of designing a system that executes said procedures is composed of: choosing a marker whose attributes will distinguish it from the environment and developing a computer algorithm used for its identification.

One of the simplest solutions is graphic markers whose color or shape ensures their good detection. Relying on color of the marker [6], however, does not guarantee versatility of the solution because the camera color perception changes significantly due to changes in lighting conditions, elements of the environment or the use of low performance cameras (effect of measurement noise). The absence of mentioned disadvantages can be gain by using a black-and-white signs representing certain symbols called glyphs. This concept is known to robotics, but is mostly used for land markers allowing robot self-localization [3].

Therefore, the article proposes a solution based on identification and localization of glyphs located on a mobile robot. The main determinant of the quality of this solution is the simplicity of the system, which implies the ease of its implementation and speed, as well as accuracy of positioning of the vehicles.

2. Optical glyphs

Optical glyphs are two-dimensional graphic signs with square grid structure, used in the so-called augmented reality systems [1, 11]. Their appearance and purpose resembles the popular QR codes (Quick Response), from which distinguishes them primarily the size, amount of information and principles, according to which markers are designed.

These symbols are divided into an equal number of columns and rows of black or white fields (fig. 2). During the design process, a number of features, that will differentiate them from similar, potentially occurring within the same environment shapes, should be established. Namely, it is assumed that the external fields of a glyph must remain black, forming a distinct, black border, and each column and row (without the circumference) must have at least one white square. The whole, in order to facilitate separation of the symbol from the environment, should be surrounded by a white background.

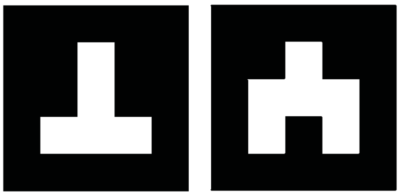

Fig. 2. Examples of optical glyphs with dimensions of 5 × 5 [10]
Rys. 2. Przykłady glifów optycznych o wymiarach 5 × 5 [10]

The main part of the glyph forms a unique pattern of white fields arranged to satisfy the condition of rotation invariance. That means that the pattern appearance must remain unique regardless of the orientation of the glyph. This is especially important for this reason, that for the glyphs that do not meet the above assumptions, it is impossible to determine the correct orientation and it is difficult to compare them with the patterns stored in the database of symbols.

The glyph size depends on the location of the camera and the image quality that it generates. The shape of the symbol must be distinct and the border fields (both black and white) should be at least two pixels wide. However, the simplicity of the representation of the symbol makes the requirements for image quality and size of the related glyph not particularly high – as is shown later in the article.

3. Absolute localization algorithm

Identification and global localization algorithm that uses optical glyphs [10] has been adapted to the above task on the basis of the solutions used in augmented reality visualization [11].

The objectives to be brought before the development process were primarily to enable correct identification of any number of objects and to accomplish high accuracy of their localization on the plane.

Subsequent steps of the proposed algorithm for localization and identification are as follows [10]:
1) Downloading new video frame.
2) Image pre-processing.
3) Detection of objects with quadrilateral shape.
4) Separation of dark objects surrounded by white background.
5) Transformation into a non-reversed quadrilateral.
6) Glyph fields binarization.
7) Additional validation tests.
8) Saving glyphs contained in the database.
9) Establishing the position and orientation of the glyphs by the CoPOSIT algorithm.

3.1. Image pre-processing

The purpose of the pre-processing of video frames obtained by the camera is to distinguish shapes that would probably be the optical glyphs located on the known mobile objects. In this regard, the edge detection techniques were used.

Therefore, the image pre-processing block performs the following three steps: conversion of image to a monochromatic scale, applying a differential edge detector and applying the Otsu thresholding method [8] (fig. 3).

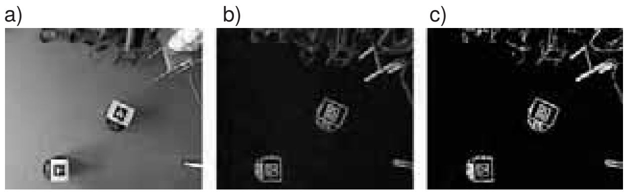

Fig. 3. Image pre-processing: a) a monochrome image; b) frame after applying differential edge detector; c) after applying Otsu thresholding [10]
Rys. 3. Wstępne przygotowanie obrazu: a) obraz monochromatyczny; b) klatka po zastosowaniu różnicowego detektora krawędzi; c) po zastosowaniu progowania metodą Otsu [10]

Through the research, it was found that a given sequence is a guarantee of effectiveness for the applied pattern recognition methods.

3.2. Identification of glyphs

The first step in identifying potential glyphs is locating in the prepared image separated objects surrounded by white background. For this purpose the Connected Components Labeling Algorithm [4] is used. With a list of featured objects, a filtering of those whose boundary points satisfy the condition of quadrilateral shape must be made.

After successfully qualifying the shape as a quadrilateral, an average difference of brightness between pixels located directly outside of the shape and inside must be calculated. If this value is greater than a specified minimum, this classifies an object as a potential glyph. Described test exploits the fact that the glyph is a sign with black boundary on a white background. An obvious statement is that the picture will contain rarely perfectly black pixels next to white ones (due camera interference), and therefore, in this case, the difference between the border pixels is examined.

Given a list of potential glyphs, an attempt at identifying them preceded by additional tests should be made. Fields containing the said image are further extracted and converted into a rectangular image (fig. 4a). Due to the different conditions of illumination – after the processing, the contrast of certain markers might be mediocre, so additionally the slice is subjected to the Otsu thresholding. Thereby a binary image containing a clear sign (fig. 4b) where each pixel can be easily classified as black or white is obtained.

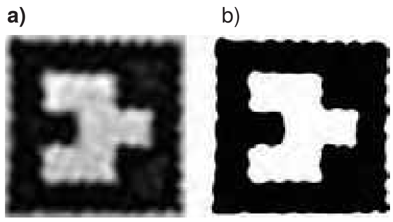

Fig. 4. Cut out glyph image: a) original slice; b) slice after applying Otsu thresholding

Rys. 4. Obraz wyciętego glifu: a) oryginalny wycinek; b) wycinek po obcięciu metodą Otsu

The glyph binarization step consists of creating a matrix (map) of binary values the size of the number of fields in the tested character. The matrix values indicate occurrence of a black (0) or white (1) field. To accomplish this, each section of the grid is examined separately in terms of the number and type of pixels presented in. In practical terms, it would be almost impossible to achieve a complete filling of one color in every field, because the process of selecting a glyph causes a lot of distortion. Therefore, during calculations, only the middle clippings of grid fields are considered (fig. 5), the fulfillment of which given color is compared with a fixed confidence level. This results in resistance to deformation and an increased certainty for choosing the correct color.

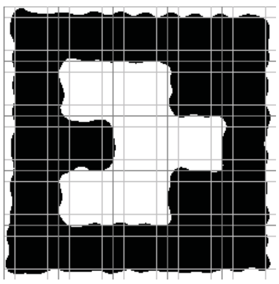

Fig. 5. Division of the glyph into basic grid (dark lines) and fields tested for the content of color (light lines)

Rys. 5. Podział glifu na podstawową siatkę (ciemne linie) i pola badane pod kątem zawartości koloru (jasne linie)

Additional tests eliminate shapes that are unrelated to the glyphs on operated vehicles, or accidentally approved objects with similar characteristics. Elements of this type are to be verified whether the matrix indicates the presence of a black boundary around the mark and at least one white box in each column and row (except the boundary fields).

After described series of operations the system has enough information to be able to include recorded signs as valid glyphs. Thus it is possible to compare stored binary maps with maps already added to the database.

3.3. Establishing the position and orientation

The requirement to calculate the position and orientation of the glyph in a rapid and reliable way forced the search for universal methods, which also will be able to offset any deformation of the camera image. The glyphs are symbols located only on one plane, therefore this amount of information must be sufficient to determine the location of the signs.

The algorithm that satisfies these conditions is the Coplanar POSIT [7]. Based on four points-features selected on the object (in this case – corners of the marks) the algorithm calculates the rotation matrix and translation vector needed to establish the exact coordinates and orientation of the glyphs.

In addition, the characteristics of the algorithm make it possible, to a limited extent, to detect objects in three dimensional space.

4. Experimental results

The problem taken in the article is related to the analysis of optical marker identification algorithm for reliability, speed and positioning accuracy. For this purpose the research process has been divided into two main parts: research on the reliability and speed of the algorithm and a study of its accuracy.

An application that supports the described algorithm was programmed using the C# language and the AForge.NET library functions [11]. The use of common image processing algorithms enables the implementation of the corresponding algorithm with the assistance of many other open source image processing libraries.

The study of proposed solutions have been carried out on a computer with an Intel Core 2 Duo P8400 processor clocked at 2.26 GHz. The source image was provided by a wide angle network camera Mobotix Q24M with a fisheye lens, located at a distance of 2.45 m from the objects.

4.1. The speed of the algorithm

The first part of the study is related to the verification of the speed of the application. As an indicator of the speed of the algorithm, the number of frames per second (FPS) was chosen. Research method that was mentioned for the above consist of comparing the reference values FPS_r with the values obtained during the test. Reference FPS was taken for a zero number of objects presented in the area of research and its value ranged from 7.02 to 5.99 FPS. Test FPS_i values were obtained by increasing by one the number of optical markers, up to the maximum value – ten.

Results obtained for the first three glyphs fall within the range of 7.01 to 5.97 FPS, while increasing the number of samples up to ten changed the frames per second indicator to range between 7.01 and 5.95 FPS. Figure 6 illustrates the correct identification of ten markers at once. The application interface allows viewing next to the selected glyphs: a unique object name, position and orientation in the camera global coordinate system (according to fig. 1).

It should be noted that, despite the unfavorable lighting conditions in each of the studied cases, the algorithm correctly identified all tags. Monitoring of the object in its normal operating environment is often associated with the frequent changes of light, however concluded – the algorithm delivers full functionality in real conditions.

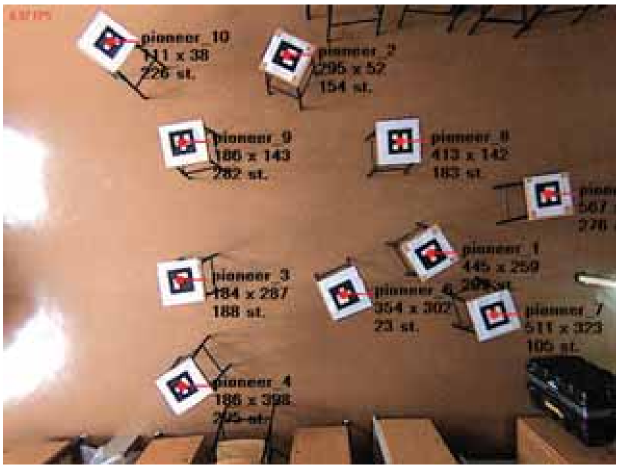

Fig. 6. Identification of ten objects at once

Rys. 6. Identyfikacja dziesięciu obiektów jednocześnie

In addition, according to the study, the effect of the number of markers in the space affects the speed of carrying out the identification process only to a very limited extent. The difference of 0.04 FPS (caused by interferences of the video camera) is unnoticeable and allows monitoring of multiple objects at once in real time.

4.2. Accuracy of the system

The second part is devoted to test the accuracy of the positioning of the algorithm. For this purpose one optical glyph was used, the location of which was determined by the designed system. In order to transition from the coordinate system defined in the pixels to the coordinates in the room (in centimetres), a constant factor $k = 0.6875$ was set.

A series of four studies was performed by getting the coordinates in video frame pixels and comparing that position to actual coordinates of the glyph. Figure 7 shows a diagram of the study with marked pixel coordinates calculated by the software and the actual location in the research area.

In some cases, the figure stated a range of pixel values between which the algorithm calculated the position of objects in the course of the program. Table 1 presents the results of the study described above along with the statistical data describing the algorithm's performance.

Based on the results presented in tab. 1, it can be stated that the positioning error of the tested algorithm is equal to about 2 %. Despite a poor image quality, the algorithm locates the glyphs with an error up to 0.7 cm locally (in the frame) and 1.72 cm in comparison with their actual positions. Therefore, it can be said that the algorithm in a correct manner determines the object position. In addition, any deviations and errors in the process are mainly due to the imperfection of the camera (especially from the effect of barrel distortion) and unfavourable lighting conditions.

The application has been also tested in combination with real robot navigation system. Navigation was based on continuous measurements of the position and orientation of the robot in a test room, which task was to eventually navigate the vehicle to a point selected by the user. The example result of the operation is illustrated in fig 8.

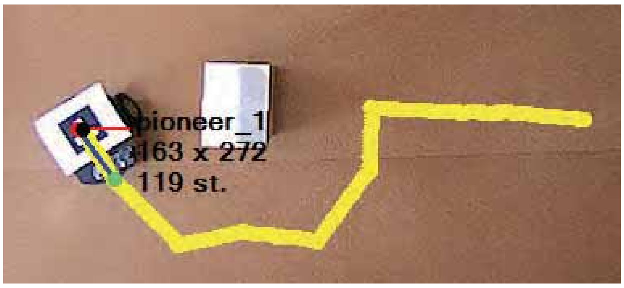

Fig. 7. Diagram of the second test showing the coordinates of the examined objects in pixels (in parentheses) and their real positions

Rys. 7. Schemat drugiego badania przedstawiający współrzędne badanych obiektów w pikselach (w nawiasach) i ich rzeczywiste pozycje

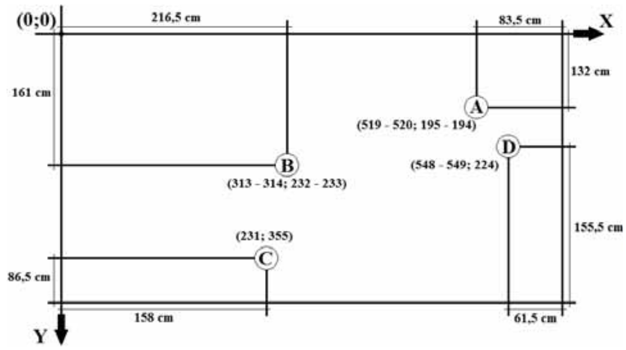

Fig. 8. Result of mobile robot navigation using the glyph positioning system [10]

Rys. 8. Wynik nawigacji robota mobilnego z wykorzystaniem systemu lokalizacji glifów [10]

Tab. 1. Research results of the algorithm for proper positioning

Tab. 1. Wyniki badań algorytmu pod kątem poprawności pozycjonowania

Number of sample	Position [px]	Average position [cm]	Real position [cm]	Absolute error [cm]	Relative error [%]
A	(519–520; 194–195)	(82.84; 133.72)	(83.5; 132)	(0.66; 1.72)	(0.79; 1.3)
B	(313–314; 232–233)	(215.53; 159.84)	(216.5; 161)	(0.97; 1.16)	(0.45; 0.72)
C	(231; 355)	(158.81; 85.94)	(158; 86.5)	(0.81; 0.56)	(0.51; 0.65)
D	(548–549; 224)	(62.91; 154)	(61.5; 155.5)	(1.41; 1.5)	(2.29; 0.96)

The robot has been properly positioned to the target point (red dot – fig. 8) with a small error of about 4 pixels in the image, which, according to the transformation coefficient, is equal to 2.75 cm.

It should be also noted that the accuracy of orientation of the objects obtained by the application was exceptionally good – with only 1° of uncertainty in the measurement.

5. Conclusion

This paper proposes a new algorithm for the indoor identification and positioning of mobile robots based on localization of graphic characters called optical glyphs.

In addition to the thorough characteristic of the symbol, of which the features allow to identify him with ease from most of the environments, a very precise description of the localization and identification algorithm was presented. The simplicity of the process allows it to be easily implemented for monitoring systems in factories or offices without unnecessary costs of purchasing additional hardware.

The accuracy of the localization of 2.75 cm made in indirect lighting conditions with a typical monitoring system camera is very satisfactory. Upon eliminating distortions of the video image, such as large effect of the barrel distortion, the accuracy could be increased several times.

References

1. Banu S. M., *Augmented Reality system based on sketches for geometry education*, International Conference on e-Learning and e-Technologies in Education (ICEEE), 2012, 166–170.
2. Borenstein J., Everett H. R., Feng L., *Where am I? Sensors and Methods for Mobile Robot Positioning*, The University of Michigan, Ann Arbor 1996.
3. Bosnak M., Matko D., Blazic S., *Quadrocopter Hovering Using Position-estimation Information from Inertial Sensors and a High-delay Video System*, "Journal of Intelligent and Robotic Systems", Vol. 67, 1/2012, 43–60.
4. Di Stefano L., Bulgarelli A., *A simple and efficient connected components labeling algorithm*, Proceedings of the International Conference on Image Analysis and Processing, 322–327, 1999.
5. Loaiza M., Raposo A., Gattass M., *A Novel Optical Tracking Algorithm for Point-Based Projective Invariant Marker Patterns*, [in:] Bebis G. et al., *Advances in Visual Computing*, Springer, Berlin Heidelberg 2007, 160–169.
6. Jallouli M., Amouri L., Derbel N., *An Effective Localization Method for Robot Navigation through Combined Encoders Positioning and Retiming Visual Control*, "Journal of Automation, Mobile Robotics and Intelligent Systems", Vol. 3, 2/2009, 15–23.
7. Oberkampf D., DeMenthon D. F., Davis L. S., *Iterative pose estimation using coplanar points*, Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 1993, 626–627.
8. Otsu N., *A Threshold Selection Method from Gray-Level Histograms*, IEEE Transactions on Systems, Man and Cybernetics, Vol. 9, 1/1979, 62–66.
9. Pallos T., Sziebig G., Korondi P., Solvang B., *Multiple-camera optical glyph tracking*, "Advanced Materials Research", Vol. 222, 2011, 367–371.
10. Pałkowski A., *Use of swarm intelligence methods in mobile robot navigation* [in Polish: *Wykorzystanie metod inteligencji rojowej w nawigacji robotów mobilnych*], MSc thesis, Gdańsk University of Technology, Gdańsk, 2012.
11. [www.aforgenet.com] – AForge.NET Framework (01.11.2012).

System lokalizacji i identyfikacji oparty na glifach optycznych

Streszczenie: Glify optyczne są nieskomplikowanymi znakami graficznymi zawierającymi zakodowaną informację. Dzięki wykorzystaniu technik przetwarzania obrazu i rozpoznawania wzorców możliwa jest implementacja skutecznego systemu globalnego wspomagającego nawigację autonomicznych pojazdów. Prostota systemu pozwala na łatwe jego wdrożenie, bez konieczności przebudowy aparatury monitorującej. Zapewnia również możliwość skorzystania w procesie projektowania z powszechnie dostępnego oprogramowania open source. W artykule przedstawiono algorytm, którego zadaniem jest wyszukanie wprowadzonych do bazy symboli obiektów oraz ustalenie ich pozycji i orientacji w globalnym układzie współrzędnych kamery. Szybkość i niezawodność systemu wykazano na podstawie badań eksperymentalnych z użyciem rzeczywistych robotów mobilnych.

Słowa kluczowe: glify optyczne, nawigacja robotów mobilnych, przetwarzanie obrazu, rozpoznawanie wzorców, śledzenie kamerą

Grzegorz Redlarski, DSc Eng

Headmaster of the Department of Mechatronics and High Voltage Engineering at the Electrical and Control Engineering Faculty at Gdansk University of Technology. He received his MSc in 2000 within the specialization of control engineering and advanced in the specialization of electrical engineering. As a result, he received his PhD in 2003 and DSc in 2011. From 2011 he is also employed as an Associate Professor at the Faculty of Technical Sciences at the University of Warmia and Mazury in Olsztyn. His main fields of interest are power electronics, power engineering and, recently, biomedical engineering.

e-mail: g.redlarski@ely.pg.gda.pl

Aleksander Pałkowski, MSc Eng

Employee of the Department of Mechatronics and High Voltage Engineering in the Faculty of Electrical and Control Engineering at Gdańsk University of Technology. He graduated in Control Engineering and Robotics (2012) with a specialization in Information Technology in Control Systems. His main areas of interest are artificial intelligence, mobile robotics and application of robotic systems in biomedical engineering.

e-mail: a.palkowski@ely.pg.gda.pl

Dominik Ambroziak, MSc Eng

Currently employed as a senior technician at the Gdańsk University of Technology in the Department of Mechatronics and High Voltage Engineering. He graduated in Control Engineering and Robotics (2011) at the Gdańsk University of Technology. Involved in research in the field of energy, environmental and economic efficiency of selected objects and issues related to thermal improvement of residential buildings.

e-mail: dambroziak@ely.pg.gda.pl