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THE VISUAL DETECTION AND STEERING OF MEDICAL AUTONOMOUS VEHICLES

The paper presents initial research on method, which improves precise indoor localization and steering of autonomous mobile devices that can be used for medical applications like: patient's state monitoring, medicine distribution or environmental data collection before medical intervention (in case of biohazard or fire). The localization of object is based on optical codes, which are modified to be easily identified from distance in low light. Multiple codes modification was tested to find optimal ones. The visual recognition system is using Hough transform and Canny edge detection to read values from code. The novelty of the proposed method is reading values directly from image, without scaling and rotation. Moreover, the steering algorithm for identified device is proposed. It takes distance and decision uncertainty under consideration. The proposed method was verified against state-of-the-art optical codes in real-world indoor environment. Finally, the further research directions are discussed.

1. INTRODUCTION

The advancements of wireless, visual detection, mobile computing technologies and the diffusion of healthcare technologies are changing the way healthcare can be administered. There are several concepts, how the Smart Hospital should look like using newest technologies [4]. The key feature of this system is integration of different positioning systems. Various techniques are used to localize mobile devices within a hospital. The most popular solution is Wi-Fi localization. The Wi-Fi signal strength from multiple sources is used to estimate position of Wi-Fi enabled devices like computers, mobile phones or robots. The previous research shows [2] that despite popularity of solution the precision of localisation can vary from one to several meters. Additionally, the number of communications significantly influences energy in mobile devices [13]. In [12] authors show, that using optical codes attached at known and fixed locations such as signs and posters it is possible to increase the objects localization accuracy. The paper proposes to extent this concept for direct localization.

Data-matrix and QR-codes are often used in healthcare to exchange laboratory results or to secure data exchange between units [5]. In the scheme proposed in [15], the medical image is not subjected to degradations due to watermarking. The codes provide large amount of information, however its recognition and detection from distance by camera is not a simple issue in contradiction to glyphs (optical glyphs) [8]. Optical glyphs are successfully used in wide range of different areas like simple localization and orientation of an object in augmented reality. Another area of optical glyphs' application is robotics [14], where glyphs can be used to

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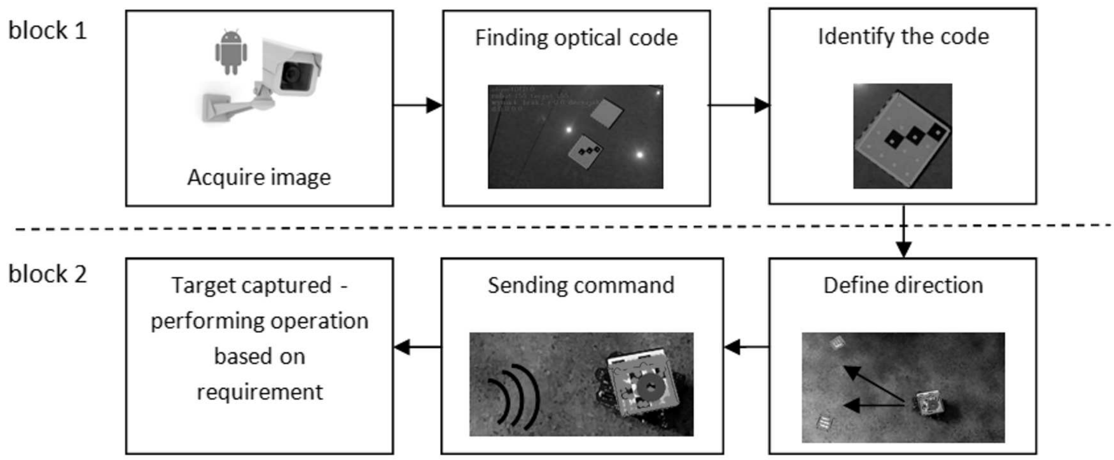

Fig. 1. Block scheme of automatic image analysis method.

give commands to a robot or help robot to navigate within some environment. The disadvantage of glyphs is its simplicity - small amount of data provided.

In some cases, the mobile devices are required to get to the patients to obtain information about their health status or to administer medicines. Therefore, in this paper proposes the initial research considering visual localization and steering of mobile devices that can be used for this purpose. The tangible application, where that system could be applied is wheel chair localization system in hospitals [18] or mobile medicaments distribution system [7].

The rest of this paper is organized as follows: Section 2 presents the proposed merger of optical glyphs with the QR-codes and data matrixes as well as proposition of steering algorithm. In Section 3 simulation results are presented and discussed. Finally, conclusions are given in Section 4.

2. PROPOSED METHOD

The proposed method was divided into two blocks. First block is used to identify device (object) position, while second block finds a direction and leads a mobile device to a target. The method scheme was presented in Fig. 1.

The research was performed using mobile device based on Arduino and camera with Android operating system (mobile phone). The devices are communicating via Bluetooth. In the first step, the image acquired by camera is analyzed to find optical codes or glyphs. Shape modification of glyphs was proposed to increase distance of detection. Additionally, the orientation of optical code is also recognized. Finally, the code is identified. Based on visual code the connection via Bluetooth is made. Finally, the sequence of vehicle position is used to find the target and direct mobile vehicle toward it. Each step of the algorithm is thoroughly described in next subsections.

2.1. QR CODE SELECTION AND ANALYSIS

Initial survey was conducted using QR-code, data-matrix and optical glyphs to measure its usefulness for localization and steering. Their visual representation was presented in Fig. 2. Both QR-code (Fig. 2a) and data matrix (Fig. 2b) have the ability to store information as binary data or sequence of characters [15]. E. g. ”data” text is represented as a 21x21 pixels size QR code. 30 % of data is redundant and can be used to correct reading errors. In case

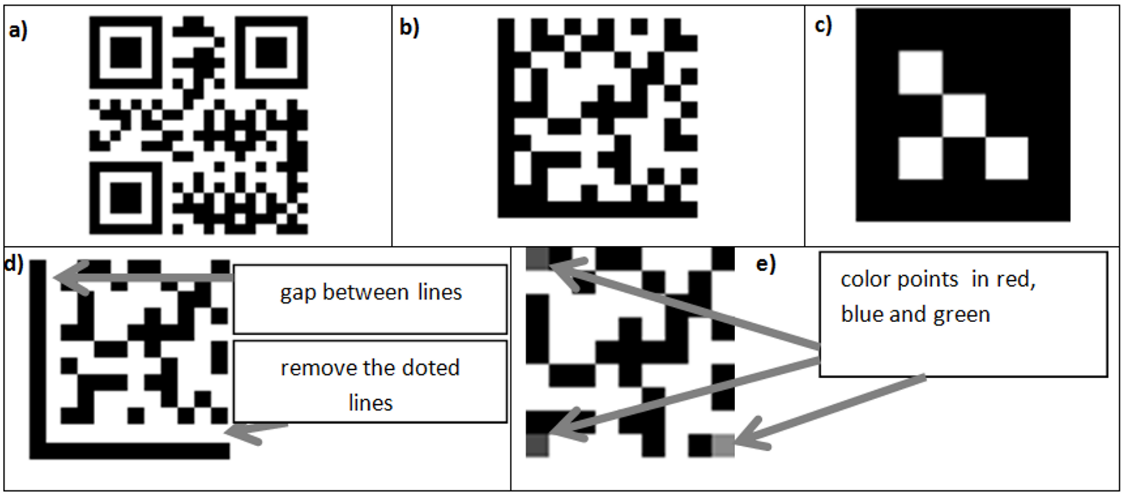

Fig. 2. The various graphical code representation: a) QR-code, b) data-code, c) glyph, d) gray code modification, e) modification based on color codes.

of data matrix it is smaller(14x14) pixels, thus only a border is used for identification of code. The third considered standard is optical glyph, which is easy to detect. Unfortunately, its biggest drawback is inability to detect direction (black square border), therefore the amount of information provided is inferior to two presented codes.

Considering small codes (up to 30x30 pixels), data matrixes are easier to identify from distance than QR-code (larger size of pixel). Therefore, data matrix was selected as a template for modifications. Additional research shows, that a border is easier to detect if its contrast is significant, therefore the detected border was moved from data by thickness of a border. Further research shows that if the distance from camera is significant the codes are barely visible (1x1 to 2x2 image pixels per optical code pixel) the border is hard to detect, thus additional color markers were introduced (Fig. 2e). In this case the code can be found from a far distance, providing the color camera is available. This simplification allows decreasing the amount of localization pixels to minimum and therefore allowing providing detection from maximal distance. The drawback of proposed codes is fixed number of pixels in row and in column.

2.2. THECODE ORIENTATION AND DATA AQUISITION

The localization of optical code with complex background or poor illumination is not an easy task. Donghong et al. [6] used Radon transform to locate data matrix by the L pattern. This algorithm however is not suitable for real time application. The border lines can also be detected by Hough transform [3], however the process can be time consuming if it is applied directly. Another approach [17] determines the 3 points of the L according to the convex of the edge points of the code. This algorithm is simple and fast but requires clean background to work correctly. Finally, there are other locating algorithms [9], [10] however they are not applicable for location and steering due to requirement of good illumination condition or non real real-time processing. Therefore, the modified algorithm, introduced for optical glyphs [11] was implemented, to find optical codes proposed in Fig. 2. All codes are represented by square grid divided equally into the same number of rows and columns. Each cell of the grid (with exception of Fig. 2e) is filled with either black or white color. In case of optical glyph, the task is to find all quadrilateral areas, which may look like a glyph. In other words, four corners of each glyph are searched. This operation is most difficult in the entire glyph search algorithm. In

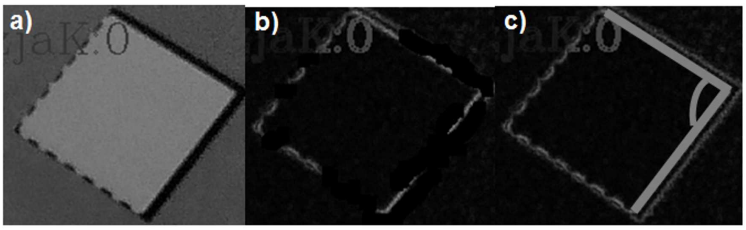

Fig. 3. Impact of illumination/environmental conditions on thresholding: a) image, b) Otsu enthropy, b) Canny detector.

the simplest approach, the color image is converted to grayscale. The binarization is performed by using the method based on Otsu entropy [11]. The main concept behind this method is to use the entropy as a measure of the amount of information contained in the resulting binary array. Therefore, a threshold value is selected which maximizes the entropy. Unfortunately, these methods proved to fail in some cases (Fig. 3b), therefore in research the direct Canny edge detector [1] and Hough transform were used (Fig. 3c).

In case of glyphs [16] the edges are analyzed to find a quadrilateral looking object. In proposed approach, the only two lines are detected therefore only their length and intersection is verified. The two lines detected in Fig. 4 have to be of the same length and one of its ends should be found in the same area. In practice, the distance between points should not be longer than thickness of detected line and length of lines should not be further than size of pixel in detected code. In this research, this value was set to 4 pixels. Further increase of this value did not influence detection accuracy.

Additional approach was proposed for codes, where additional three red, green and blue points are added. These points are additionally used to find a glyph on image and therefore allow localizing object easier. To find candidates, three filters are constructed based on RGB image. The filter counts how close the pixels are to required color. The filter is constructed for R, G, B matrixes. As result the color matrixes are constructed (Eq. 1-3).

$$CLR[x,y] = 2.0 * R[x,y] - G[x,y] - B[x,y] \tag{1}$$

$$CLG[x,y] = 2.0 * G[x,y] - R[x,y] - B[x,y] \tag{2}$$

$$CLB[x,y] = 2.0 * B[x,y] - R[x,y] - G[x,y] \tag{3}$$

Within the CLR, CLG and CLB matrixes the centers of color blobs are searched [1] and then treated as ends of lines (three points)

The fourth corner (Fig. 4) is obtained by calculating a vector from the point at the intersection of two intervals to the middle of interval situated between the other two points. The length of the vector will give the searched position. At this step the direction code is predefined, thus the optical codes don't have to be asymmetrical as in case of optical glyph.

2.3. CODES VALUES

The majority of proposed algorithms [12], [13], [14] rotate the image and then read its value. The area is divided into a mesh and dominant color is read. However rotation can add noise in case of small images, therefore in this paper values are read directly from the image. Based on the position and fixed number of rows and columns the values of centers are calculated. The introductory research shows that borders are the area containing the highest noise. To improve the recognition, the image was blurred using Gaussian filter, before the reading process. The result of reading is presented in Fig. 5.

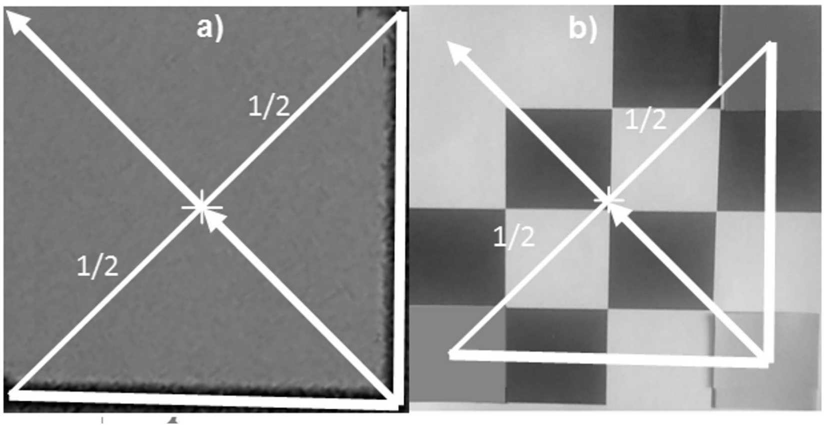

Fig. 4. Geometric operation to find 4-th corner.

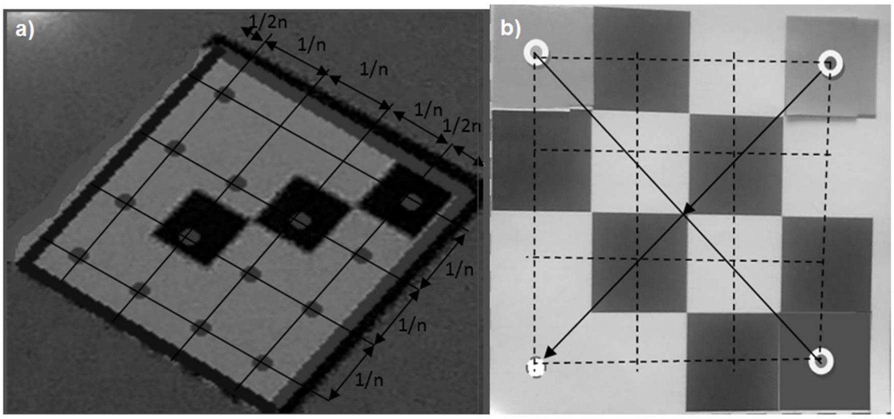

Fig. 5. Reading values from codes: a) black-white code, b) color code.

The values are directly obtained as a matrix, where "0" and "1" elements correspond to black and white cells of a code image. Providing, that optical glyphs can't be symmetrical, major values are discarded. In case of presented codes 2^{16} different values can be read in case of first shape modification (Fig. 5a) and 2^{13} in case of second Fig. 5b. The obtained value is used to identify a device and perform secure connection. At this stage of research, codes are used as identifiers only.

2.4. THE TARGET TRACKING

The obtained coordinates are used, to find the object and its target. In this case the extended algorithm introduced by an author in [13] was used. The modification takes the direction of a mobile device into consideration. Additionally, the data is updated, when needed. If the object is far from the target, the updates are less frequent than in case when the target is close. The decision procedure was presented in Fig. 6.

The steering algorithm (alg. 1) was defined as pseudocode:

1) Calculate the angle α_1 and α_2 for the vector $v_1 = [x, y]$ and $v_2 = [x, y]$ of the mobile

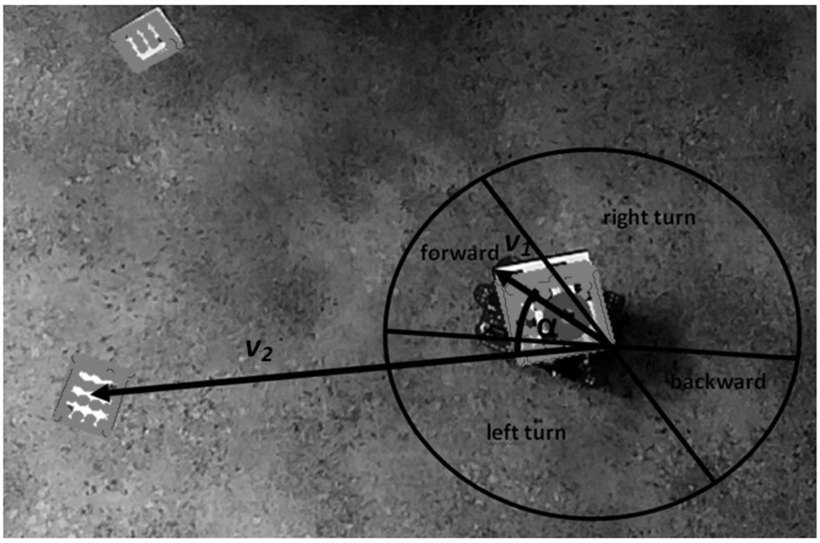

Fig. 6. The decision scheme according to angle and distance.

object and the target using f function:

$$f(x,y) = \begin{cases} atan(y/x) & : \; x > 0 \wedge y \geq 0 \\ atan(y/x) + 2\pi & : \; x > 0 \wedge y < 0 \\ atan(y/x) + \pi & : \; x < 0 \\ \pi/2 & : \; x = 0 \wedge y > 0 \\ 3\pi & : \; x = 0 \wedge y < 0 \\ 0 & : \; else \end{cases} \tag{4}$$

2) Calculate the relative angle α_r=α_2 - α_1. If $\alpha_r > 2\pi$ then α_r = α_r - 2π.
3) Define movement direction:
   a) if $|\alpha_r| < \pi/6$ then go forward else
   b) if $|\alpha_r| > 5/6\pi$ then go backward else
   c) if $\alpha_r \leq 0$ then turn left,
   d) if $\alpha_r \geq 0$ then turn right.
4) If the command is go forward or back set a time of movement based on the distance as:

$$step = p\frac{\|v_2\|}{\|v_1\|}vel \tag{5}$$

where: p - the distance and vel - average velocity in vehicle lengths per second.

3. OBTAINED RESULTS

The proposed method was verified against the classical glyph approach and QR codes recognition system. The research was performed to analyze the vulnerability of method to bad lighting conditions and ability to recognize proposed codes form distance. Five types of QR codes and glyphs were analyzed. The comparison was presented in Table 1 for codes of the same size and amount of information stored.

QR codes and data matrices were read using algorithms described in [17] and [11]. The poor performance of the glyphs is a result of a higher number of columns and rows needed to store the same amount of information. The proposed modification proved to give a better

Table 1. The comparison of codes against two propositionse.

Distance [cm]	QR-code	Data Matrix	Glyph	First modification	Second modification
good light 90^o	170	210	90	230	250
weak light 90^o	140	180	60	190	200
good light angle 75^o	160	200	90	210	230
good light angle 60^o	120	150	80	150	160

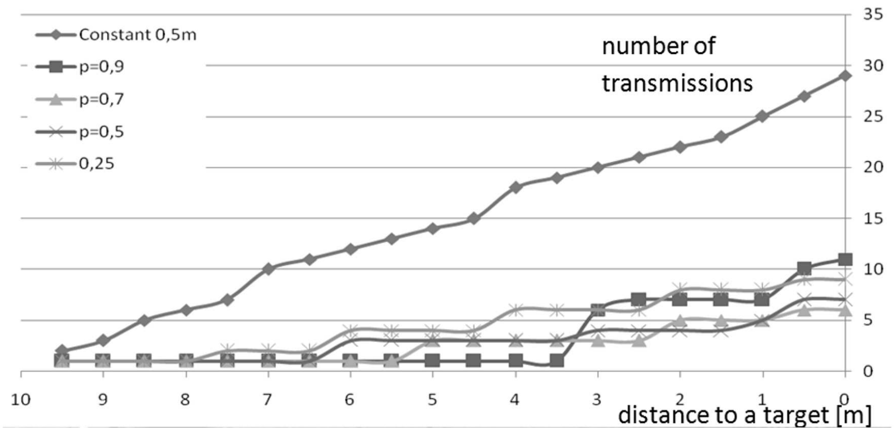

Fig. 7. The transmission using constant step value, the step according to distance needed.

performance in case of first and second modification. Using 3 color RGB border allows to recognize and identify really small objects. It is worth to note that in case of modification the fixed size of codes are set. Additional research was performed to analyze the transmission number using proposed algorithm. The comparison of number of transmissions needed to reach the target is presented in Fig. 7.

The implementation of various length of time step based on uncertainty, connected with distance, allowed to decrease the transmissions number. The lowest value was achieved for p=0.7.

4. CONCLUSIONS

The paper proposes two modifications of the optical code that allows simpler code positioning on the image, which represent stationary or mobile medical object. The introductory research shows that proposed codes are easy to identify and at the same time can provide more information. The size of code can be decreased by using color cameras. Moreover, the steering algorithm was proposed, that allows to reach a target (patient or other medical equipment). The research shows that it is possible to decrease number of transmissions by 60% by using steering with steps of various lengths. The initial research shows that it is possible to localize and direct object to target using indoors visual navigation. This introductory research can be used to send vehicle to areas where the first aid is needed and to measure the basic environmental parameters or to check the state of a patient. Further research will focus on securing codes and allowing avoiding obstacles on the way to the target. Finally, the solution will be integrated with Wi-Fi based localization to increase precision of navigation in required location, e. g. while distributing medicine to a patient.

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