A Comprehensive Study of Using 2D Barcode for Multi Robot Labelling and Communication

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Abstract — **Multi robot is an emerging field in robotic research with surprisingly various open problems. Reports have been published stating the advantages of multi robot over conventional single robot, including reducing task completion time. One of the open problem as concentrated in this study is their communication. This study focuses on using a 2D QR barcode for robot labelling suitable for vision-based multi robot communication. The aim is to prove that QR barcode could be decoded in various distances as well as in different angles. Image sampling is done in controlled environment. A two-way ANOVA without repetition is used to analyze the image data in terms of successful QR decoding. ANOVA with significant level of critical α 0.05 is used and has justified that smallest variance at different distances and angular pose will give the best position in order to decode the respective QR barcode. Hence multi robot communication by means of labelling a QR label onto them has the possibilities for further research.**

Keywords — **Multi robot, communication, labelling, QR barcode**

I. INTRODUCTION

Multi robot, occasionally known as distributed robotics or coordinated robot, is an application of using more than one robot in solving typical daily problems. A research by [1] explain the practice of multi robot in exploring an unknown environment. Experiments has proved the time achieved to explore a new unknown environment is drastically reduce when using two or more robots compared to one robot.

It is certain that multi robot is an emerging new research area filled with various open problems. One of the major concerns is the communication among the robots and their labelling, or identification [2]. It is sensibly important as to avoid collision as well as job redundancy [3].

There are many approaches that have been taken in order to undertake this problem. The prominent approach is by using wireless radio communication by means of radio frequency, Wireless Sensor Network (WSN), specific frequency of communication such as WLAN, Bluetooth, infrared, and many more [4][5][6][7]. There are also new direction in multi robot communication by using sound processing, where languages only understood by the robots is being developed [8][9]. These researches were inspired by the legendary Star Wars movie character, the R2D2 and 3CPO.

However, very few studies on using vision-based identification have been conducted. A vision-based multi robot system is normally focused on the localization of each individual robot as presented by [10]. In order to identify the right robot in its colonial systemic order, this paper proposed using a 2D matrix barcode for each robot that could contain a great amount of information about each and every particular robot. This study in particular, will focus on justification of using a 2D QR barcode suitable for multi robot labelling and communication in general.
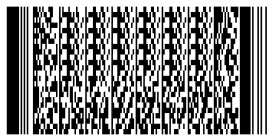
II. 2D BARCODE INTRODUCTION

Barcodes are widely known in today communities. Going back in history, barcode are used to store data in parallel lines in different widths, so called the 1D code. It was first used in the USA in the transportation system to track the delivered goods. Since then, barcodes were heavily used in every aspect; we could see them in shopping market, airport, and even in adverts. In addition, some of the most recent mobile phone was already embedded by barcode reader to alleviate barcode reading. This phenomenon proves how popular the barcode has been.

There are many kind of barcode. Table 1 illustrates the well-known barcode in the globe. Process of choosing

suitable one for multi robot research is fairly task. Literatures suggested that 2D Barcode has the ultimatum characteristic [11] and could be possibly used for multi robot labelling and communication.

Images	Classification; Barcode Name
	1D; UPC barcode
	1D; Code-128 barcode
	2D; PDF417 barcode
	2D; QR barcode
	2D; Data Matrix barcode
	2D; Aztec barcode

2D barcode symbology is chosen in this research due to the fact that it ability to store enormous information in one single code. Also, capabilities of encoding alphanumeric character are also a chosen factor. This is important as information required to store at the multi robot barcode is in various forms. It could be in alphabet label, numeric coordinates, etc.

QR barcode is chosen in this study primary because of its module [12]. Each module corresponds to a black module and white modules represent '1' and '0', respectively. Fig. 1 illustrates the structure of the QR code. There are three finder patterns located at the corners. The finder pattern is a crucial reason of its selection. It is indeed the very first blobs that the vision system sees and important for detection. The

QR structure is divided into three area allocation; the error correction area, the data area and the reserved area [12].
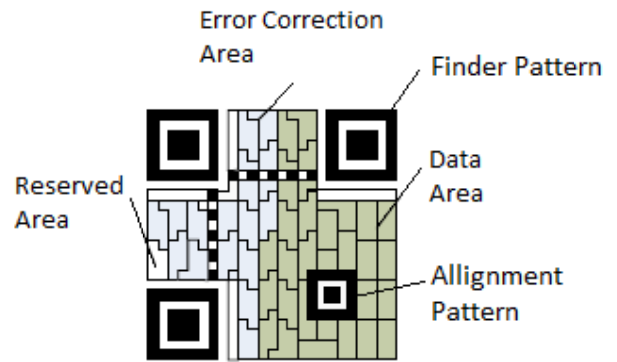

Fig. 1: QR barcode structure

In order to justify whether a QR barcode could or could not be used for multi robot identification, a deep study must be done, considering these factors:

1. Encoding, decoding, and scanning program which developed based on 2D barcode symbology [11],
2. 2D barcode generation and management technologies [11],
3. Capability of decoding at distances, and
4. Capability of decoding at different angle.

In summary, the criteria number (i) and (ii) is fulfilled by the 2D symbology as suggested by [11]. Therefore, this study is highly intended to cater the last two criteria, which are the decoding capabilities at different distances and angles. These two criteria are undoubtedly important as the barcode is somewhat decoded in unknown distance and angle.

Fig. 2 dramatise the paradigm of using barcodes in multi robots environment. It could be seen that if robot A is able to see the barcode of robot B in an angular of θ and at distance d, the robot communication and perhaps localization could be easier, and of course it could be only applicable in the sense of using robotic vision system.
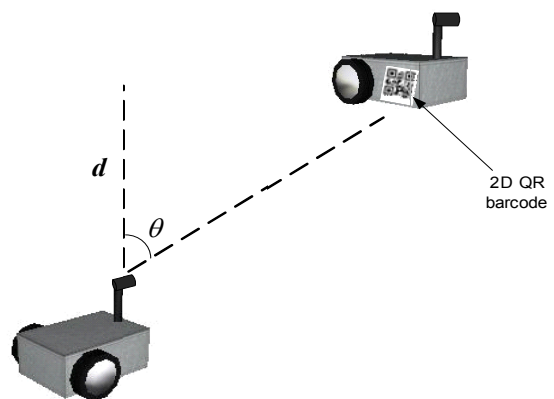

Fig. 2: An illustration of using 2D barcode in multi robot communication and labelling.

III. EXPERIMENT METHODOLOGY

This study focuses on experimental procedure to prove the use of QR barcode in multi robot environment in the sense of statistical analysis of decoding the barcodes at different angles and distances. Fig. 3 depicted the flow chart of methods taken in this study. An image processing approach is done through sampling, filtering and decoding algorithm, as suggested by [12]. Successful sample decoding is calculated, and tabulated and compiled in a table for further analysis and validation.
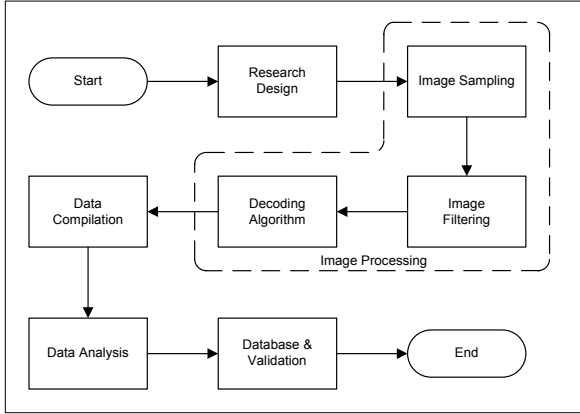

Fig. 3: Methodology Flow Chart

The study concentrated on the suitability of the QR barcode for multi robot labelling and communication. Hence, the research design is planned such a way that to prove the criteria discussed earlier, including concrete statistical analysis. The robot hardware is prepared with embedded vision system consists of basic control system and actuators. However, since the study focus on hypotheses validation, the hardware part will not be discussed in this paper.

Image sampling is done by using experimental setup shown in Fig. 4 (side view) and Fig. 5 (top view). 50 images are captured in similar angles and distances in a controlled environment. The lighting condition is controlled by using a light meter; yield the reading in the range of 180-220 lux. The distance experimented are 50cm, 100cm, 150cm, and 200cm while the angles as shown in Fig. 5 are 0˚ in the middle, 15˚, 30˚, 45˚, 60˚, and 70˚ in the right camera point of view, -15˚, -30˚,-45˚, -60˚, and -70˚ in the left camera point of view. The image sampling has yield a total of 2200 images, adequate enough for statistical analysis later.
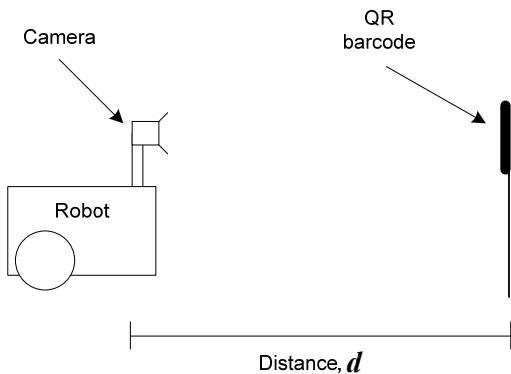

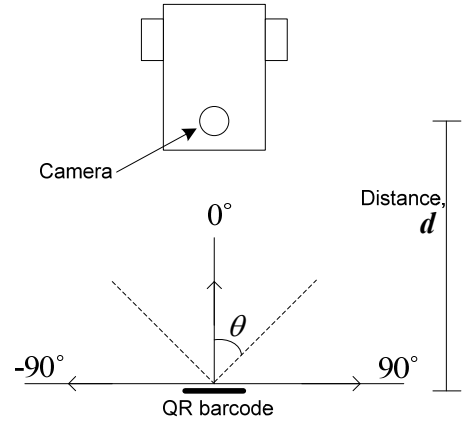Fig. 4: Side view of image sampling

Fig. 5: Top view of image sampling

The image which successfully decoded by means of image processing are vectorized and tabulated for hypothesis validation. The tabulation process also helps with database making and useful for further research.

The statistical analysis is done by using the two-way Analysis of variance (ANOVA) without repetition. It is used to test hypotheses about the differences between the means of variable distance and angle. ANOVA is also used in this study in order to test for samples mean and variance as well as to identify the data trustworthiness in the critical significant value α 0.05. The α is set to 0.05 to verify that the robot is able to recognize other robot with 95% confident level. The experiment is done without repetitions means that there is one reading for every case. The results for two-way ANOVA without repetition is slightly different in that there is no interaction effect measured and the within row is replaced with a similar but not equal error row.

IV. SAMPLING RESULT

The camera captures the image in RGB color space and it is processed to output in binary images. The conversion is done by applying commonly used weighted of R, G, and B component to obtain grayscale image and binarized by using automatic threshold algorithm proposed by [13]. The equation for commonly used weighted sum of R, G, and B component is given as (1):

$$I_{gs} = \begin{bmatrix} 0.2989 & 0.5870 & 0.1140 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

Table 2 below tabulated the image sampling result and the processed output. We could see that there are a large variance of the captured image depending on the distance and angle during sampling. Therefore, ANOVA analysis suits the requirement in order to justify the data trustworthiness and to achieve the specific objectives.

TABLE II
SOME OF THE IMAGE RESULT

Type: Distance, Angle	RGB Image	Binary Image
50cm, 0°		
50cm, 75°		
100cm, 45°		
100cm, -60°		
150cm, -75°		
200cm, 75°		

V. STATISTICAL ANALYSIS

In this study, two hypotheses are to be studied. The first hypothesis is about decoding the QR barcode in different distances, while the second hypothesis is decoding in various angle. As stated in the experiment design earlier, image sampling has been made to occupy with this study yielding in 2,200 digital images, sampled to use for the statistical analysis. Statements below stated the null hypotheses in this study;

H_o (1): There will be no difference between all the angles, and

H_o (2): There will be no difference between all the distances.

Table 3 tabulated the result data. At middle camera view or 0°, all 50 image of QR barcode is successfully decoded regardless the distance. Only at intense cases of angle such as 75° and -75°, some of the images are unsuccessfully decoded. This is perhaps due to the decoding algorithm that failed to find three finder patterns in the respective images, or perhaps due to the bad resulting image as the impact from extreme angle and distance.

TABLE III
RESULT DATA AT DIFFERENT DISTANCE AND ANGLE

Position (Robot view)	Distance (cm) / Angle(°)	50cm	100cm	150cm	200cm
Right	75	42	39	30	23
Right	60	40	38	32	27
Right	45	50	50	50	50
Right	30	50	50	50	50
Right	15	50	50	50	50
Middle	0	50	50	50	50
Left	-15	50	50	50	50
Left	-30	50	50	50	50
Left	-45	50	50	50	50
Left	-60	38	35	26	23
Left	-75	42	38	30	27

A randomized block design and two-way ANOVA without replication was conducted. The distance variable measured in four levels; which are 50 cm, 100 cm, 150 cm and 200 cm. In the other hand, the angle variable is measured with eleven levels; from -90° to 90° as shown in Table 3 earlier. This angle variable is treated as blocks are selected for statistical treatment, in the manner analogous to that of the one-way ANOVA. The treatments within each block stretch across the different distance, and the blocks spread down the angle. By using a randomized block design and a two-way ANOVA without replication, the variability can be partitioned into variability due to treatment and variability due to angle. In this case all effects were statistically significant at the 0.05 significance level.

TABLE IV
RESULT OF THE RANDOMIZED BLOCK ANOVA TEST

Variation Source	Sum of Squares	Degree of Freedom	Mean Square	F
Treatments	222.0909	3	74.0303	5.478193
Blocks	2937.682	10	293.7682	21.73865
Error	405.4091	30	13.51364	
Total	3565.182	43		

Table 4 illustrate the result of the randomized block ANOVA test. The treatments is calculated at their own block

using the function of sum of squares, or $n\sum_{j=1}^{t}\left(\bar{x}_j - \bar{\bar{x}}\right)^2$

where *n* represent the size of each treatment or block while *j* is the each component in the treatment or block. The mean square is then calculated from the treatment or block, where *between-treatment* is used for treatments or block, while *within-treatment* is used as sampling error. The DOF for treatment is n-1 or 4-1 = 3 or whilst for blocks is 11-1 = 10.

From the result, we found that the main effect of the between subjects variable distance is significant using a critical α of 0.05, the critical *F* is (F (3,30) = 2,92, $p < 0.05$). The calculated value (F (3,30) = 5.48) exceeds the critical value, and, at the 0.05 level, we are able to reject the null hypothesis that will be no difference between the all angles. At this level of significance, our conclusion is that the overall distances are significantly differences. For the second hypothesis, the main effect of the within subject variable type of angle is significant using a critical of α 0.05, the critical *F* is (F (10,30) = 2.16, $p < 0.05$). In this case, the calculated *F* (21.74) is greater than the critical value (2.16) and therefore $H_0(2)$ is rejected. Hence, the overall angles are significantly difference. Our conclusion is then is made such a way that both hypotheses are significantly differences. The result also showed that with significant level of 0.05, or equivalent to 95% confident level, we are 95% corroborate that the robot may recognized other robots in the sense of using QR barcode with at least 95% credibility.

In examining the Excel printout, our purpose in this randomized block ANOVA was not to examine the impact of the blocking variable (angle category) as an independent variable. Also, our model does not include any consideration of possible interaction between blocks and treatments, as will the two-way ANOVA with replication.

From the values in Table 3, we can see that the smallest variances at different angles and distances will give the best position in order to decode the 2D QR barcode.

VI. CONCLUSIONS

This comprehensive study is a stepping stone for vision-based multi robot communication. It is important as this type of communication does not imply frequency-based communication, and therefore will avoid communication channeling errors and redundancy.

The QR barcode is not only innovative for marketing purposes, but it could be useful for labeling, creatively for the robot. The study has proven that the QR barcode could be use for this purpose at undeniably high confident level, which is at 95% confident level. The null hypotheses in this study are rejected, which mean that there are significant differences between distance and angle, proven that it is not a barrier. This statistical data has agreed with our main idea where QR barcodes could be used for multi robot labeling and communication.

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