Vision Based Localization for Multiple Mobile Robots Using Low-cost Vision Sensor

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***Abstract*-This paper presents an efficient approach for a vision based localization of multiple mobile robots in an indoor environment by using a low cost vision sensor. The proposed vision sensor system that uses a single camera mounted over the mobile robots field takes advantages of small size, low energy consumption, and high flexibility to play an important role in the field of robotics. The nRF24L01 RF transceiver is connected to the vision system to enable wireless communication with multiple devices through 6 different data pipes. The downward-facing camera provides excellent performance that has the ability to identify a number of objects based on color codes, which form colored landmarks that provide mobile robots with useful image information for localization in the image view, which is then transformed to real world coordinates. Experimental results are given to show that the proposed method can obtain good localization performance in multi-mobile robots setting.**

***Index Terms*— Multi-mobile robot localization, Vision Sensor, Color Code**

I. INTRODUCTION

An essential and one of the most challenging components of mobile robots is their localization and navigation system. All mobile robots must preferentially be able to estimate their position in a given environment in order to navigate autonomously. Since the early days of mobile robotics localization research vision-based method, among others, has been one of the techniques being explored by researchers. Vision sensors are one of the most versatile as they can be used in many environments such as indoor, outdoor and even in underwater applications [1]. They can provide useful image information about detected shape or color in their field of view. This information is particularly useful for helping the mobile robot localize. Therefore, the authors propose a localization method of identifying each mobile robot and obtaining its relative position and heading direction in the limited filed using vision sensor. Two important papers [2], [3] provide a good survey of various aspects of the progress made so far in vision based navigation and localization methods.

Unfortunately, vision based localization requires complex algorithms and high quality hardware resources when related to general environment features. However, using simple landmarks can reduce dramatically the cost and the complexity of the recognition system. We propose to use color code which is combination of two or more color tags placed close together as a simple landmark to differentiate multi-mobile robots. A camera so-called "Pixy" that implements a hue-based filtering algorithm is used to detect objects of a specified color. This camera is designed to be low cost, fully programmable, and found to be appropriate for real-time processing with enough flexibility to be connected directly to most microcontroller-based systems without any additional electronics. The advantages of small size and real-time performance make it possible to apply embedded vision to the robotics.

The image information in the ground is obtained by the downward-facing camera over the field and color codes are placed on the mobile robot as shown in Fig. 1 (A). The main advantage of the vision system in this paper is that the vision sensor can be incorporated directly with an inexpensive microcontroller, which results in compact and light weight vision system. The proposed vision sensor is used to identify and track the mobile robots that move within the field of view of the camera. The built in image processing unit in the vision system provides the identified object color code's id, its x and y coordinates of the center of color code, its height, and width, and angle from the vision sensor. This information can be read to a microcontroller in real time used to estimate the real-world position of the mobile robot.

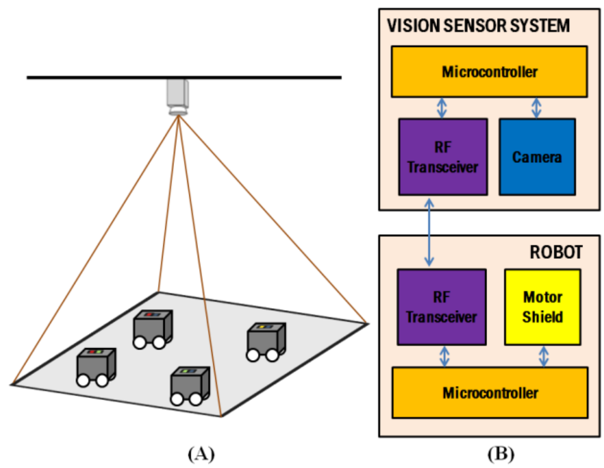

Fig. 1. (A) Illustration of how the camera should be placed in real environment. (B) Block diagram illustrating the system architecture. Vision sensor system provides actual positions and orientations to mobile robots through wireless communication.

The component layout, depicted in Fig. 1 (B) shows overall system implementation. Multiple nRF24l01 wireless transceivers are used to establish communication between vision sensor system and multi-mobile robots. These wireless transceivers make it easy, inexpensive and suitable implementation of our work because they allow point to multi-point communication. Therefore, robots can broadcast their own information to their teammates with the use of these wireless modules. They make effective alternative in multi-robot systems [4], [5] that require broadcast communication.

The rest of the paper is organized as follows: in Section II, we begin with an overview of the related literature. After discussing related works, the main hardware components are discussed and the localization method for multi-mobile robots is detailed in Section III. Section IV demonstrates the performance result of the proposed localization method by using the NDI 3D Investigator optical instruments for performance evaluation. Section V presents concluding remarks and the possible future work ideas.

II. RELATED WORKS

We review in this section some research relevant to localization methods for multi-mobile robots. There have been various attempts to combine the experiences of individual robots in a group in order to increase the precision of localization of the group. One example extended the localization problem from one robot to multi-robots proposed by Fox et al. [6] is a collaborative localization algorithm based on the histogram filter and the particle filter (PF) to utilize the measurements of relative information between team robots.

A similar approach to what is proposed in this paper was presented by Baatar et al. [7] by detecting specific marker to identify multi-mobile robots using ceiling-mounted camera. They presented excellent results by adopting a localization method that combines odometry which is the use of collecting data from wheel encoder and vision-based localization. The fusion of the odometry and vision-based localization data is achieved with the use of the Extended Kalman Filter (EKF). This method, using a high quality camera and a mobile robot platform that offers odometry, was able to accomplish good localization results, with a maximum positioning error of 12 mm and maximum orientation error of 1.7^{o}. Our vision sensor is not only lighter, faster, less expensive and efficient, but also can differentiate many mobile robots due to use of the color code than their vision sensor.

There was another similar approach to that of our method that uses landmarks, proposed by Ahmed et al. [8]. Many artificial landmarks attached on mobile robots are used as tool for identification in the vision-based localization method to distinguish a number of mobile robots. In their experiment, the small robots were localized with an error ranging from 2.8 cm to 5.2 cm in the testing environment which has the dimensions of 150 cm long by 163 cm width. Recently, Hunsue Lee and Beom H. Lee [9] proposed the Rotating Triangles (RT) landmark for multi-robot localization that recognizes 2^9 distinct IDs using 9 triangles.

The proposed vision system in this paper can be used for the implementation of soccer game scenario where multiple robot tracking system for RoboCup (Robot World Cup) type soccer competition for mobile robot localization and classification are needed. Papers [10], [11] offer summary about the past, present and future of the robot soccer competition in small size league and middle size league competitions, respectively. Every operation conducted by soccer robots needs accurate location information in order to complete the task of robotic soccer player successfully. Many researchers have deeply researched in the field of soccer robots that propose methods that can be used for the competition. To perform autonomous movement to desired target position as expected and perform path planning for the movement, the soccer robots should essentially have the ability to localize their current position. In the intense environment and fast movement of soccer robots, the self-localization ability of the soccer robots to obtain its position and orientation using a variety of sensors plays an important role in the competition. Some groups [12]-[14] used omnidirectional camera to resolve multi-robot localization problem. It has been used in areas where large visual field coverage is needed because the rich information of the environment in the large area can be captured by the omnidirectional camera. Most of vision systems are more likely to be affected by lighting conditions around the environment. In order to minimize the problem, several researchers [15]-[18] have tried to improve the robustness of vision sensor by adjusting camera parameters in the image acquisition to adapt the output of vision system to varying lighting conditions.

III. IMPLEMENTATION DETAILS

For the algorithmic implementation and experimental setup of our proposed vision-based localization method for the multi-mobile robots, the detailed descriptions along with the hardware components are presented in this section.

A. Hardware Design

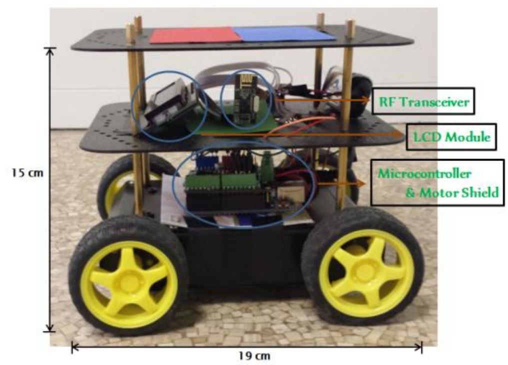

Fig. 2. The mobile robot platform used for experiment. It is composed of a chassis, microcontroller, motor shield, LCD module, and RF transceiver.

1. Mobile Robot

DFRobot 4WD (four-wheel-drive), shown in Fig. 2, is the mobile platform used as the test-bed for the experiments of the localization of multi-mobile robots method developed in this paper. Overall, this is a great kit for research related projects because it is low cost and easy to control by a simple microcontroller such as the ATmega328. The dimensions of the robot and the accessories used in the experimental setup are also shown in the figure. The 2A motor shield [19] based on the DFRobot L298P chip allows the microcontroller to drive the mobile robot. The speed of the mobile robot is adjusted through PWM signal which can be generated from microcontroller's PWM output. The motor shield can be powered directly from microcontroller or from external power source. It is strongly recommended to use external power supply to give sufficient power to the motor shield. With the use of the LCD module [20], as shown in Fig. 3 (B), one can easily monitor the location of the mobile robot that is computed by the overhead vision system. This LCD module is hooked up to the microcontroller through the I^2C serial communication, and its operation is controlled by a program running in this microcontroller attached to the robot.

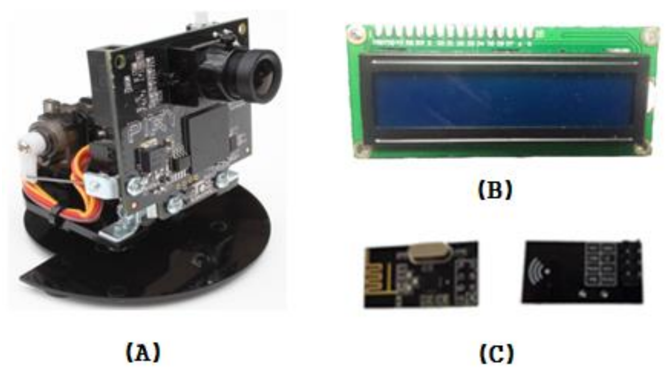

Fig. 3. From left to right, pictures of (A) Pixy camera based on CMUcam5, (B) LCD module, and (C) nRF24L01 wireless transceiver

2. Pixy Camera

Pixy which is based on CMUcam5, shown in Fig. 3 (A), is a fast and cost effective image sensor that is significantly better than previous versions of the CMUcam [21]. It is capable to find unique colors and return their image information to the same microcontroller used for controlling the mobile robot. The Pixy's on-board processor, which controls the camera and performs the vision processing, can be easily accessed through a simple serial communication interface from external controllers such as Arduino, Raspberry Pi, or Beaglebone black boards. The camera provides the microcontroller with accurate pixel image value of the center position and size information of the recognized objects in the image field of view. This information, obtained based on image pixel value from the camera, can then be used to transform it into the real world position of the mobile robot. Also, when color code uses as a landmark, the vision sensor can give angle value to the mobile robot. All of this useful information is available through one of several interfaces: SPI, I^2C and UART, digital or analog output at 50 frames per second. The native resolution the Pixy's image sensor is 1280 x 800, but for higher frame rate of up to 50 frames/sec, and lower CPU and memory requirements the vision system actually uses 320 x 200 pixels resolution. Ref. [22] offers detailed information about the pixy camera.

3. nRF24L01 Transceiver

The nRF24L01 wireless transceiver is suitable for low power and low cost communication that is designed for operation in the 2.4 GHz ISM band. Fig. 3 (C) shows a view of this wireless transceiver. A total of seven wireless transceivers are used to allow wireless communication between six mobile robots and the vision sensor system. One wireless transceiver is attached to the microcontroller that is connected to the vision system and the rest of wireless transceivers are mounted on the microcontrollers that are controlling the mobile robots. These wireless modules can be easily connected to the microcontrollers through Serial Peripheral Interface (SPI). Ref. [23] provides the specification and in-depth information about the nRF24L01 transceiver. Each data pipe has its own physical address decoding in the nRF24L01 and can be configured for individual behavior. The wireless transceiver can receive packets designated to six different data pipes in one frequency channel. Fig. 4 depicts a simple description for communicating multi-mobile robots configured as slaves with vision sensor system configured as one server. Each mobile robot exchanges some commands with vision sensor system to achieve the more appropriate and smooth communication.

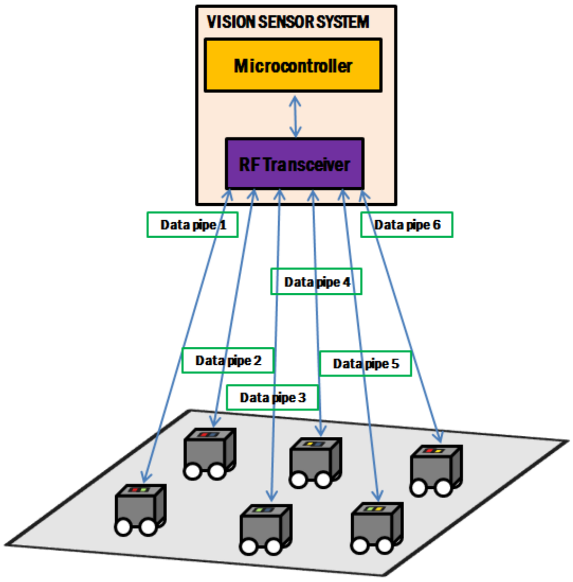

Fig. 4. The simple system architecture to communicate between vision sensor system and multi-mobile robots.

B. *Landmarks Based on Color Codes*

The Pixy camera has the unique ability to identify objects of specified color or color codes. Color codes are used to improve detection accuracy by decreasing false detections.

That is to say, there exists a lower probability that specific colors will occur both in a specific order and close together. Also, the use of color codes allows the camera to provide respective mobile robot with angle estimate and id number, in addition to coordinate information. The angle information is useful value that is used as heading direction to measure the turning motion of the mobile robot within its range between 0^o and 359^o. The id serves as an identification number of the mobile robot. The combination of two colors forming color code landmarks, assigned for example as red and blue or red and green or red and orange combination etc., are shown in Fig. 5 (A) and this can give each color code a number for identification from the camera. Two mobile robots should not be allowed to use the same color assignment. Six color codes produced by four color tags are used as a landmark in our work. Color codes with more different color tags can allow for distinguishing many more mobile robots at the same time. The camera can detect up to 7 different color signatures that it can remember. These color signatures can be designated and managed using “PixyMon”, an open source application for the camera. It allows users to change configuration parameters such as the average brightness of the camera and data out port according to serial communication etc.

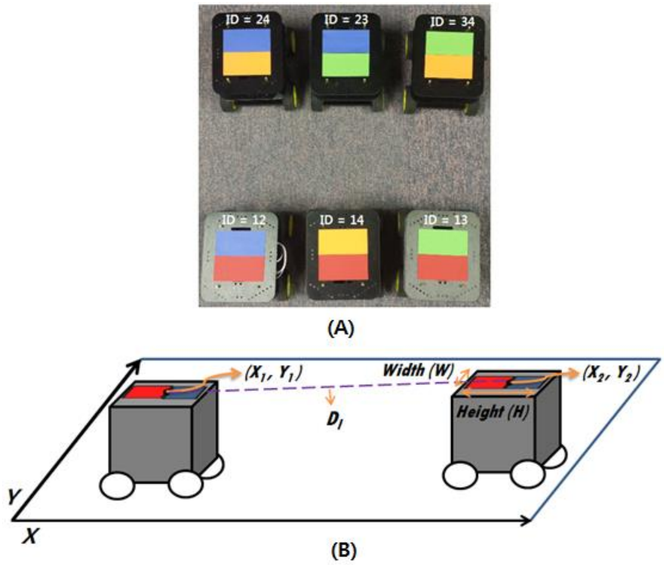

Fig. 5. (A) Image of landmarks based on color code attached on the top of mobile robots. (B) Dimension estimation of the landmark in image frame.

C. Vision-Based Localization Method

The camera is connected to the microcontroller through one of the serial interfaces. However, because the RF transceiver exclusively uses the SPI interface to communicate with the microcontroller, the data out port parameter has to be configured to 1 for I^2C interface in the application. Six different color codes have to be placed on the top of the six mobile robots. The camera mounted in an overhead position is then ready to collect the useful information to localize multi-mobile robots. When the camera detects color codes, it collects image information of color codes that the camera has detected. Fig. 6 shows what the collected image information looks like, such as id, x, y coordinates of the center, height, width, and angle of the detected landmark is returned to one array member. Occasionally, there is a difference of values between previous angle and current angle. To overcome this problem, we calculated the average value between two angle values obtained by the camera, as given by the equation (1).

$$Angle_{avg} = \frac{\theta_1 + \theta_2}{2} \quad (1)$$

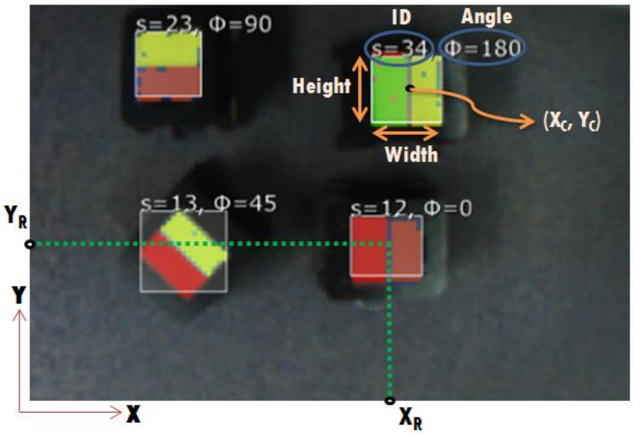

Fig. 6. Example captured image by the camera and relevant information.

The average angle value and the center of the color code are defined as heading direction and the position of the mobile robot, respectively. The position of the mobile robot can be calculated relative to the world coordinates of the landmark by matching the center of the image frame to current position of the camera. There is another severe problem that the fluctuation of value of height and width in image frame occur greatly while rotating the mobile robot. Therefore, the value of height and width is recalculated in advance. The width (W) and height (H) in Fig. 5 (B) are calculated by the following equations:

$$W = (M_X \times L_c) / D_I$$
$$H = (M_Y \times L_c) / D_I \quad (2)$$

where M_X and M_Y are actual moving distance of the mobile robot to the x axis and y axis, respectively. L_c is actual dimension of the landmark. D_I in Fig. 5 (B) is distance between previous position and current position of the mobile robot in image frame. It is defined by equation (3).

$$D_I = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \quad (3)$$

The marked position (X_R, Y_R) in Fig. 6 is the current position of the mobile robot in real-world domain. The conversion of the x and y coordinates of the mobile robot position from the image domain to the real-world domain is given by Equation (4) below.

$$X_R = (X_C \times L_c) / W$$
$$Y_R = (Y_C \times L_c) / H \qquad (4)$$

where (X_C, Y_C) is the coordinate of the center of the mobile robot in image frame.

IV. Result

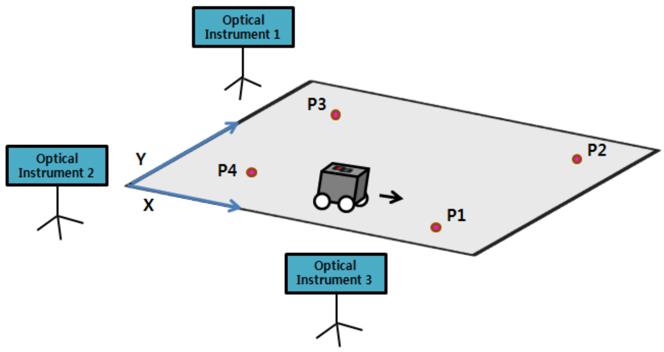

Fig. 7. The experimental environment for the accuacy measurement using thr NDI optical tracking instrument.

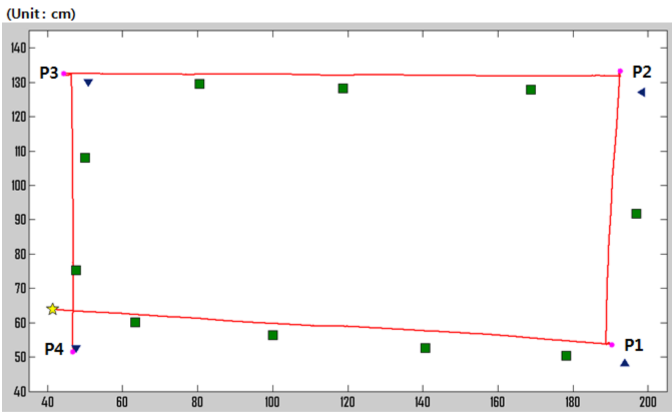

Fig. 8. Experimental results obtained from NDI 3D Investigator optical instrument. (Red line indicates actual trajectory of the mobile robot acquired by the optical instrument. Green rectangles and blue triangles are estimated by the Pixy camera and the yellow star indicates the starting point of the mobile robot.)

The proposed vision-based localization method has been tested in the real world environment. The test environment for the Pixy based localization of mobile robots is approximately 290cm long by 155 cm wide. The camera is attached to a bar of approximately 180 cm above the testing surface. The dimension of each color tag is 10 cm by 5 cm. When combing two color tags, the dimensions of the actual color codes are 10 cm by 10 cm.

In order to evaluate the suitability of the Pixy camera to solve localization problem of multi-mobile robots, we used a high quality NDI 3D Investigator optical motion tracking instruments [24]. This system employs an advanced motion capture technology. Three optical instruments are properly placed on the testing environment to track the movement of the mobile robot as shown in Fig. 7. Smart markers, attached to target objects such as a robot in this paper, emit infrared light that are tracked by the optical instruments. The optical instrument not only obtains accurate coordinate information and heading direction of the object, but also tracks the position of the mobile robot consistently as long as the markers stay within the fields of view of the camera system. Some components such as wireless strobe, battery, smart markers have to be placed on the mobile robot for the use of the NDI optical instrument. However, the small mobile robot that we are using does not have enough space. So, the experiment for accuracy measurement has been conducted on a relatively bigger mobile robot based on the iRobot Create base [25] and a landmark is put on it at the similar height of the small mobile robot, as mentioned above.

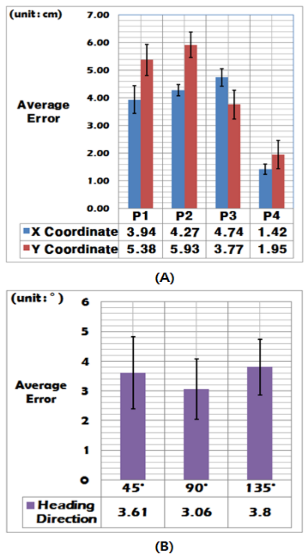

Fig. 9. The statistical evaluation of mobile robot localization average errors along with standard deviation. (A) X & Y coordinates (B) Heading direction.

The localization results are compared against the tracking information obtained from the NDI 3D Investigator optical instruments. For our experimental evaluation, we consider the location and heading data obtained from the NDI optical tracking instrument to be the true coordinate and heading values. Red line and four points, depicted in Fig. 8, indicate actual route of mobile robot and each corner of the rectangular shape for the test path, respectively. The collected position information of each point by the NDI 3D Investigator optical instruments is compared with that from the Pixy camera. In order to demonstrate accuracy of the heading direction measured by the camera, an encoder equipped with iRobot create is used. After rotating the mobile robot by using the encoder, the comparison of the value of the heading direction between the Pixy camera and the optical instruments is evaluated. To obtain better estimates of the average measure of the localization accuracy, the test runs were repeated 10 times. In Fig. 9, the average errors in each point estimates for the x, y coordinates and heading direction of the mobile robot location is presented when it arrives within view of each point and the standard deviation also is marked on the graph.

In Fig. 7, the range of the ground corresponds to the approximate range of the Pixy camera. Also, it is observed that the more the mobile robot gradually approaches to the edge points such as P2 in the camera view, the higher the error gets. Strong lighting and light reflection are reasons for causing the landmarks on the mobile robot to show white effects from the image of the camera. One possible method to solve this problem is to adjust the brightness of the camera to adapt the lighting of the surrounding environment.

V. CONCLUSION

In this paper, the proposed localization method for multi-mobile robots is demonstrated to properly identify the estimated position and heading direction of the mobile robots. However, in some areas of the field where the lighting is very strong, the camera sometimes cannot detect the robot position due to the light reflection. The setup of the Pixy camera is very simple and the camera is optimized for localization of multi-mobile robots. It offers useful information to localize and tracks several objects at the same time. To differentiate the mobile robots, we identify each mobile robot with color code. As demonstrated in the paper, the Pixy camera is found to be an effective tool for accurate localization of multi-mobile robots. It well qualifies to be a fast (with up to 50 frames per second), cost-effective and lightweight vision system by taking advantage of the capability and power of the Pixy camera. In repeated experimental tests, the proposed method was able to achieve average localization accuracy with errors in the range 1.42 cm to 5.93 cm, compared with the optical tracking instruments, from P1 to P4 locations, and heading errors in the range 3.06^{o} to 3.8^{o} at 45^{o}, 90^{o}, and 135^{o}. Thus, we concluded that the proposed color-codes based vision method using the Pixy is effective, efficient, practical, acceptable, as well as relatively easy for mobile robot localization in real-world environment. In the future work, we plan to design and develop operations for robot soccer games type scenario.

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