Aesthetic Marker Design for Home Robot Localization

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***Abstract:* A new and aesthetic marker technique for indoor robot localization is presented in this paper. The marker, as a visual landmark, is designed to fit human inhabited indoor environments, where aesthetic considerations are as much important as efficiency of the visual localization. Design development was performed using color filtration and shape detection of the marker image. HSV color space was used for color separation, then hue component values of the highest geometric distance were selected for contrast decisions. This method allows the extraction of contrasting color information, where contrast values were lowered until machine visual detection was efficient enough whilst marker image aesthetics were still enjoyable for the human viewer. Separated colors were examined by shape detection for geometry, size and orientation to introduce the marker elements. Results of the aesthetic marker feature tracking illustrate marker information retrieval. In conclusion, aesthetic markers, when harmonized with color preference, can be integrated unobtrusively into home environments and are efficient for robot localization.**

***Keywords:* aesthetic marker design, indoor robot localization, color harmony, HSV color separation, shape detection**

I. Introduction

In the near future mobile robots will appear in our homes. Currently one of the biggest problems is robot self-positioning; thus estimating orientation and self-localization based on visual landmarks to be able to avoid obstacles and follow desired paths within home environment. We will encounter mobile service robots in our daily lives in our homes, offices, schools and medical or rehabilitation institutes, where well designed markers will enable fast and prompt robot localization. Markers are efficient if detection, recognition and localization are achieved [1], but existing markers are only practical, not decorative in present days and people do not want to see these non-aesthetic, industrial style marker images in their homes.

Marker based localization has been researched and various approaches have been introduced in the recent years, among them barcode style artificial landmarks [2], pentagon shaped code [3], pictograph [4], fiducial marker [5] or seamless pattern recognition [6].

In this paper we introduce a theory for possible code system requirements, where attractive and decorative robot marker system could be invited into our homes. We setup a hypothesis for aesthetics and measure different marker images from various directions to determine positioning possibilities, where contrast values are reduced and aesthetic harmony is maintained until machine visual detection is still efficient enough for accurate localization and information exchange.

II. Robot Localization

Autonomous robots carry out a wide range of tasks, and to achieve the appropriate physical movement, the robot must be able to acquire accurate information about its location in relation to the environment. There are various models for orientation possibilities using various camera systems [7], sensors and equipments from IR, radio or sonar transmitter and receiver to manipulation in intelligent space [8], [9]. The most widely used methods for autonomous robot self-localization are different kinds of visual localization systems using cameras [10], [11].

Visual localization determines robot position by visual analysis of recorded camera images. Methods differ mainly in the basis point information of the recorded images. There are systems that use robust image databases for comparison, others manage to generate a map while localizing (SLAM) and there are faster systems that are looking at markers for orientation.

Markers can be neutral or artificial, neutral markers are predetermined and still items in a specific environment (e.g. door, standing lamp, picture on a wall) but they are difficult to recognize, while artificial markers can be detected more accurately. Their disadvantage compared to previous methods is that they require more site preparation, given that artificial markers should be planned and placed properly. However, the advantage of identifying safer and more accurate positioning and simpler algorithms for detection and recognition, artificial markers are much faster and less resource-intensive when the robot needs position information in real time. The global map describes marker coordinates (see Fig. 1), thus the robot can determine his relative position and orientation based on the camera image in relation to the marker position and information in the given environment [10].

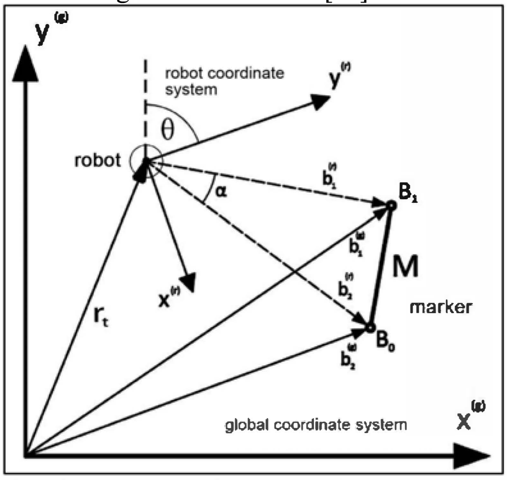

Fig. 1. Relation between robot coordinate system and marker global coordinate system

III. INDUSTRIAL MARKERS

There are specific markers that are used in industrial and laboratory environments, but their aesthetics, ergonomics or size in terms of living areas are not enjoyable for the human viewer. Industrial markers were designed for fast and efficient localization of autonomous robots in cases where they need to localize themselves in the working environment.

Nevertheless when such markers are used, they have high black and white contrast mainly square or circle like matrix elements, 2D or 3D code systems, where geometric elements have certain mathematically described distortion as a result of various distance and viewing angle of the camera, position can be calculated via triangulation (see Fig. 2).

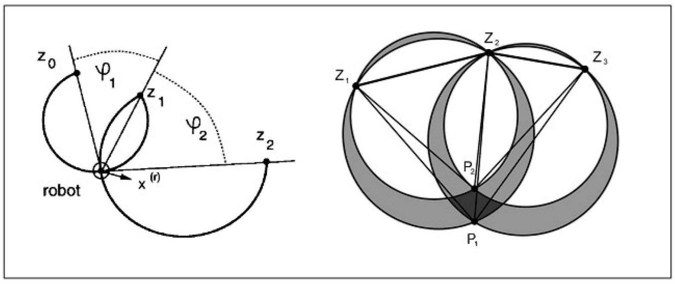

Fig. 2. Optical triangulation schema, with trigonometric measurement error on right side [12]

For purchasing, marketing and entertainment purposes there are new marker systems evolved from industrial markers as well, namely bar code, qr code, ms code, ar code and other marker systems. In lab experiments circular ceiling markers are frequently used, so as to equally detect position from all directions. We can make an exception for the sake of aesthetics, but we must state that localization is dependent on direction. Circular markers are robust in detection but actual data recognition requires higher CPU time (than markers with straight lines), which is not a favorable option. In home environments people need to feel comfortable when using them, so markers need more ergonomic and decorative design considerations.

IV. AESTHETICS

In product and environment design engineering objects or equipments have to fulfill their function and be also unobtrusively integrated into the environment. When designing location markers for service robots that enter our homes we do not what them to be superficial or ugly. We need markers to help in navigation but to fit into our carefully built living environment as well. Giving color information to markers enhances detection, yet being distinguished from the environment they are still decorative.

Color theories - especially the Coloroid harmony system by Antal Nemcsics [13] - introduce an aesthetic point of view where color contrasts are calculated to provide sufficient contrast and pleasurable view as seen in Fig. 3.

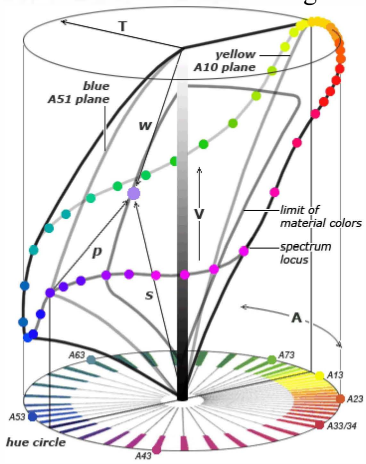

Fig. 3. Coloroid color space (A denotes hue, T - saturation and V - brightness of a color)

We used the CIE XYZ and RGB gamut triangle for starting point, where the highest geometric distance between color values present the best contrast values. As a result beyond the black and white contrast of industrial makers, and beyond the red, green and blue differences we were able determine harmonic changes in the Coloroid color space, by manipulating the hue, saturation and brightness values. Here we would like to note that it was very useful that the cylindrical Coloroid color space (Standard MSZ 7300) was easy to map into the CIE color space and had great similarities with the HSV color space, thus our color filtration algorithms of the used OpenCV environment fit well.

Since Coloroid aims to be a uniform perceptual color space, we designed harmonic marker images based on the following harmony rules of Coloroid:

Harmonious colors were selected, by choosing the same hue and saturation and changing the brightness in steps of equal perceptual differences (arithmetical) or in steps of increasing perceptual differences (geometrical) [13]. Another way to achieve harmony was by having the same hue and brightness, and variance in chroma in either an arithmetical or geometrical series, or changing chroma and brightness simultaneously (this latter results in monochromatic harmony). There are several variations beyond these, during the research we mainly focused on these, while keeping in mind the possible usage of grayscale colors, moreover color proportion and complementary contrast issues of basic color theories.

Fig. 4 shows some examples we designed with Coloroid Color Plan Designer software [14], via selecting harmonic color pairs.

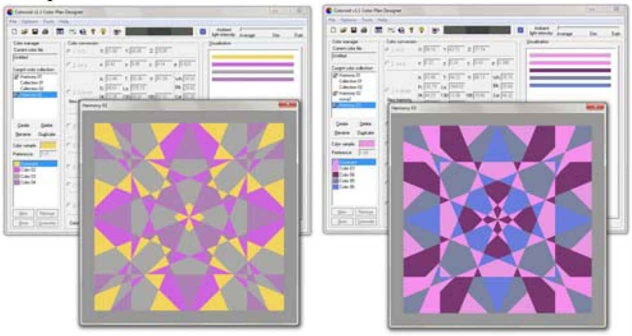

Fig. 4. Color harmonies selected by the rules of Coloroid theory

V. METHOD

The experiments were conducted as follows: marker images were generated manually on the basis of the research by Dániel Illy [10] with the above mentioned considerations. Main marker elements consisted of squares, triangles and circles. Generated images were produced on a color calibrated display and printer.

Marker images were set up on room walls and images were captured by a 5 megapixel Logitech C170 webcam (cheap cmos camera) in average home illumination: bright room near window with added average LED lighting condition. We discovered that marker image has to be bigger than a certain size otherwise elements are not detected well. Horizontal marker size was determined at 30cm. We made measurements from 3 distances, 90 degrees (normal) in front of marker image, also 45 and 60 degrees to normal. There were extra images taken 45 degrees bellow the image as well (this is a possible situation when a mobile robot is looking upwards). Distances from marker were 1.5m and 3m respectively to an average European room of 15-20 square meters. Generated images were color filtered, and segmented. First of all by transforming the RGB values to HSV, which is more invariant to illumination, by using histogram equalization we can take the advantages of the Hue value selection.

Thus we could focus on particular colors and apply feature tracking on the marker images with specific algorithms for contour detection, hough transformation for circles and lines, edge point detection in intersections. OpenCV [15] open source software was used and algorithms were run in a Windows Visual Studio C++ environment. Then the output of each algorithm was inspected, whether certain contours or color values are appropriate in respect of the original marker image. Features were collected, to be able to define equations that represent geometric space - by specifying the shape of the marker elements inside marker cells, cell arrangement together with orientation cell and border as parities - to retrieve spatial information [10].

Triangulation methods, introduced under section 2 and 3, are further clarified by determining inertial measurement unit (IMU) accuracy and pixel error (result of visual detection problem due to improper lighting, low camera resolution and too high viewing angle or probable threshold inaccuracy occurring during feature detection).

VI. RESULTS

Our experiments resulted in the following image captures and detected features; we have discovered errors that we tried to optimize on the go. In the first set of pictures the results are as follows: original image, printed image on wall, HSV color separation. After this beginning process we started feature detection as shown in Fig. 5.

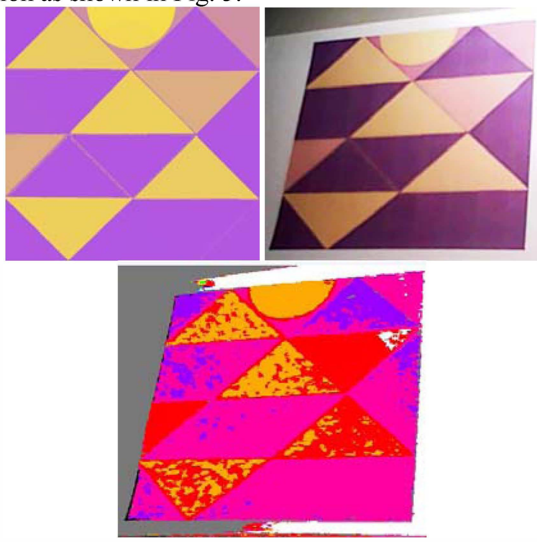

Fig. 5. Marker image - beginning process

Corner and edge detection for various marker element shapes were one of the most important results of feature detection as shown in Fig. 6.

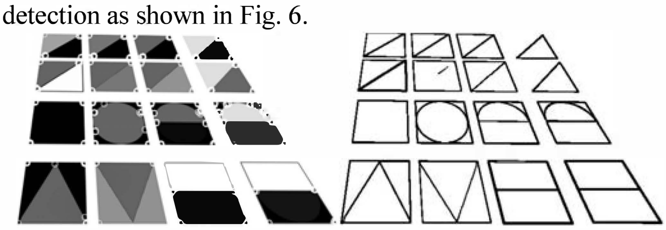

Fig. 6. Accurate corner and edge detection of the proposed marker elements

Bichrome or trichrome harmonies can be efficiently detected even at tilted degrees, these results, shown on Fig. 7, are selections of Coloroid harmony values.

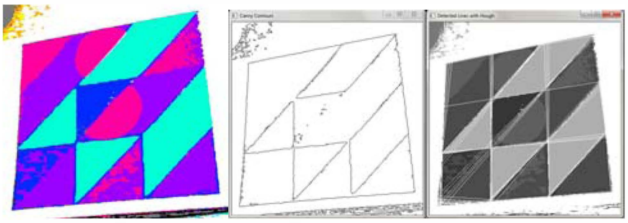

Fig. 7. HSV color separation, contour detection by canny algorithm and hough transformation for finding lines, as the basis for geometric equations to determine elements.

We have met some problems, first of all: circle detection problems. These did not occur until camera was set to normal in front of marker image, but feature detection problems begun when images were captured already at 45 degrees to normal. Possibly with a better ellipse detection algorithm, these problems will be solved in a further research phase, but higher CPU usage in not favorable. Monochrome harmony used in markers is not efficient for proper hue difference detection, if illumination is low and there is no apparent hue difference, thus marker cells can not bee defined (see Fig. 8).

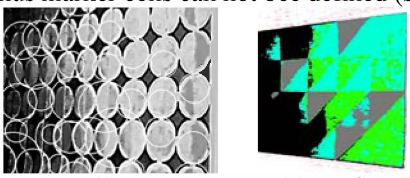

Fig. 8. Correct and incorrect recognition of circle elements, radius and monochrome image

Relative position to marker can be error corrected by determining viewing angle compared to the two sides and the middle of the bottom edge of the marker. Red line indicates the bottom edge length in regard to viewing angle of the actual robot position (see Fig. 9).

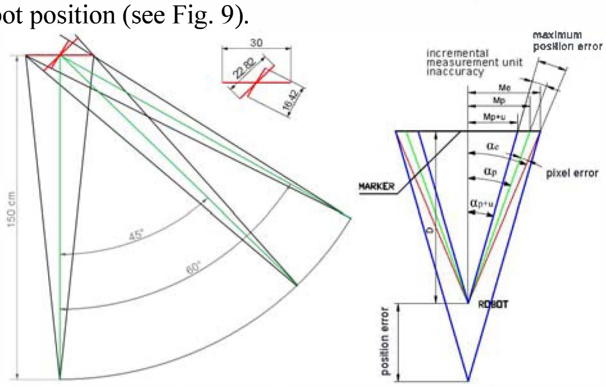

Fig. 9. Actual position's effect on marker length of bottom edge and summary of errors of the various inaccuracies

$$\alpha_e = \tan^{-1}\frac{M_e}{D} \qquad (1)$$

$$M_p = \frac{M_e \cdot (pix-2)}{pix} \qquad (2)$$

$$\alpha_p = \tan^{-1}\frac{M_p}{D} \qquad (3)$$

$$\alpha_{p+u} = \alpha_p - \alpha_u \qquad (4)$$

$$X = \frac{M_e}{\tan^{-1}\alpha_{p+u}} - D \qquad (5)$$

There are certain pixel and incremental measurement unit inaccuracies as mentioned in section 5, which are superponed onto the normal image size. Real viewing angle (α_e) is derived from M_e and D ratio (1), M_p is pixel error and α_p is viewing error with pixel error (*pix* and *pix-2* for right and left sides) (2), α_u is the IMU error (this can be opposite direction to pixel error) which is derived from M_p and D ratio (3), thus the total viewing angle with all errors is counted: α_{p+u} (4). Robot detects marker image width M_{p+u} and counts with viewing distance of actual position, from the middle of the marker, this to count the original location, thus with the α_{p+u} angle projected on M_e distance gives the maximum position error (X), which can be calibrated (5).

As a result of the experiments, we have settled for the 3x3 marker design, each cell having an "on" and "off" state, the "on" state resembling a certain triangle shape with specific color.

With duochrome shapes, detection is accurate from various degrees and distances.

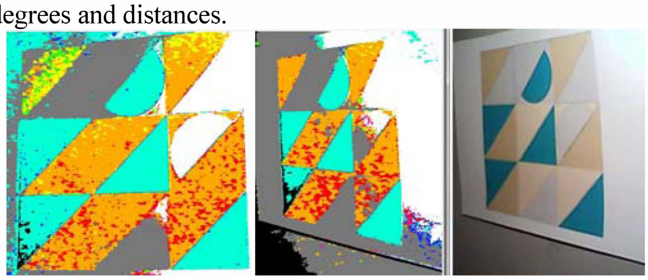

Fig. 10. Original image and HSV color separation is correct at 90 and 60 degrees as well

We found squares and triangles most accurately detectable (see Fig. 10 and 11). When dealing with circle elements a more detailed algorithm should be used, still half-circle and straight line combinations can enhance detection via line crossing point detection.

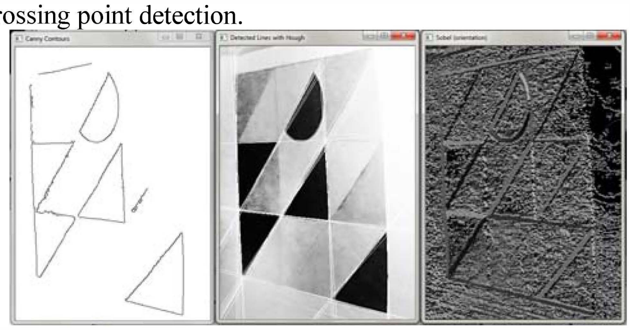

Fig. 11. Canny contour detection, hough and sobel transformations

In the next phase marker border was designed around the marker. The camera first has to detect marker border by using canny contour algorithm and hough transformation, thus from border line equations perspective distortion is defined. Inner border line, alias the data marker itself (shapes in marker cells and their arrangement) is defined via recognizing points at the lowest right and left points of the marker image, because these can be easily detected. Since marker has been placed high on the wall, while robot camera is lower, on the camera image (due to perspective distortion) these points are the most distant from each other horizontally. With the aesthetic marker we defined contrast values, thus border and non-data areas are in contrast compared to the colored data inside marker. Captured marker image with perspective distortion is retransformed into a 3x3 square. Using triangles as cell elements help in finding parallel diagonals with the diagonals of the main square for higher accuracy.

After detectable marker is verified, the 3x3 marker array is divided into nine cells according to inverse perspective projection and the shape of the lower right cell serves as an initiating orientation parity (O - identification cell). Its shape is generally a specially arranged triangle that secures orientation of the marker.

This leaves 8 cells, in case of counting on/off stages (filled or empty colored shape) for actual data coding to give appropriate location information, about the room, important routes and objects within. Code is to be read from the recognized orientation marker to the left until reaching border and then starting the next row (see Fig. 12).

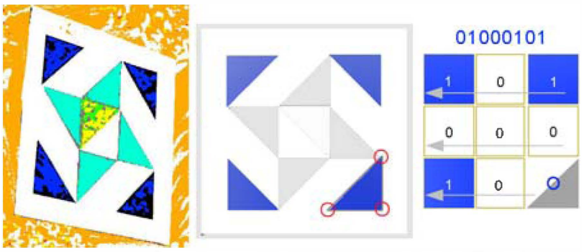

Fig. 12 Orientation cell and decoding order

Generated 8-bit (1byte) square array of 10x10cm cells (with orientation and border) gives altogether 2^8 =256 possible variations (only counting on/off of cells for one type of colored shape) from which position is to be determined. These parities (border and lower right shape) enable the robot to define marker orientation and location in relation to position via trigonometric calculation as described. If these are not well readable, a new photo has to be taken. Via using extra shapes or colors further validity checks are possible for data and error correction in case feature detection is improper due to visibility problem, IMU or pixel error.

In order to determine lines that create closed triangular shapes within the 3x3 square array we used the invariant method [3] moreover by repeating hough line transform algorithm on triangular closed areas, apical points are successfully determined and marker decoding starts.

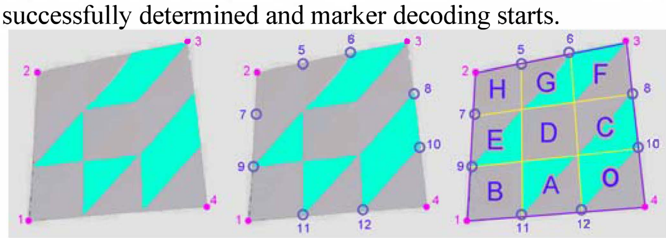

Fig. 13. Steps to define marker identification cells

Decoding is based on identification cells (A to H), their boundaries and apical points of the closed areas are at the trisect points of each marker side (see Fig. 13), where coordinates were calculated by equations, as introduced below, X_i and Y_i give rows and columns of the appropriate pixels for points to be determined (6-9).

As detection goes from one identification cell to another the algorithm counts defined colored data pixels (HSV value defined) and non-colored pixels (HSV value not defined), via calculating ratio and threshold value, filled or empty value of a given cell is calculated and then compared to data stored in memory (10).

$$X_5 = X_2 + \frac{X_3 - X_2}{3}\ ;\ Y_5 = Y_2 + \frac{Y_3 - Y_2}{3}\ ;$$

$$X_6 = X_2 + \frac{2(X_3 - X_2)}{3};\ Y_6 = Y_2 + \frac{2(Y_3 - Y_2)}{3} \tag{6}$$

$$X_7 = X_1 + \frac{2(X_2 - X_1)}{3};\ Y_7 = Y_1 + \frac{2(Y_2 - Y_1)}{3}\ ;$$

$$X_8 = X_3 + \frac{X_4 - X_3}{3}\ ;\ Y_8 = Y_3 + \frac{Y_4 - Y_3}{3} \tag{7}$$

$$X_9 = X_1 + \frac{X_2 - X_1}{3}\ ;\ Y_9 = Y_1 + \frac{Y_2 - Y_1}{3}\ ;$$

$$X_{10} = X_3 + \frac{2(X_4 - X_3)}{3};\ Y_{10} = Y_3 + \frac{2(Y_4 - Y_3)}{3} \tag{8}$$

$$X_{11} = X_1 + \frac{X_4 - X_1}{3}\ ;\ Y_{11} = Y_1 + \frac{Y_4 - Y_1}{3}\ ;$$

$$X_{12} = X_1 + \frac{2(X_4 - X_1)}{3};\ Y_{12} = Y_1 + \frac{2(Y_4 - Y_1)}{3} \tag{9}$$

$$f_i = \frac{n_{iempty}}{n_{ifilled}} \tag{10}$$

Mobile robot navigating within the living environment via properly placed markers can identify several positioning points, using the above described method, thus it can define its location more precisely, moreover maneuver more safely and reliably (see Fig. 14).

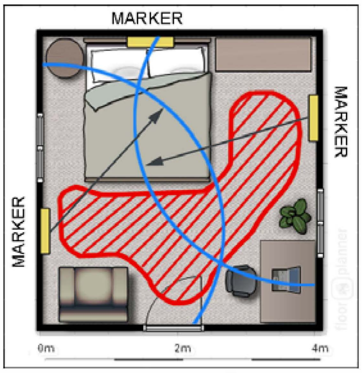

Fig. 14. Average room with possible robot movement and proper marker placement

VII. Conclusions and Future Work

We have presented a new aesthetic marker system that endows robot localization with a new human aspect. The associated Coloroid color harmony selection enhances the perceptual and psychological side of markers to be seamlessly implemented in everyday living environments. Given the importance of color processing in machine vision during the iterative design process we found OpenCV very useful and the selected algorithms improve robustness of marker detection.

Further measurements are needed for various lighting conditions as well, eg. fluorescent lamp lighting with specific spectrums, where we will need another type of setup environment and measurement instruments: more calibrated printers, spectrophotometer to define greater and more precise values. Color harmonies, shapes and arrangement of elements depend on the person and also the interior of the living environment, thus experiments are continued with detailed tests on aesthetic preferences.

With this research we set up fundamentals to enhance fast and robust localization in human living environments. With regards to continued acquisition of form and color harmonies and optimizing the detectable elements, we plan to further improve localization by generating markers that introduce a contemporary robot-readable design aesthetics.

Acknowledgement

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