Short and Long Distance Marker Detection Technique in Outdoor and Indoor Environments for Embedded Systems

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***Abstract*— During the last years, the market of embedded vision-based systems has been growing at an accelerated rate. Virtual and augmented reality has the potential to become one of the most innovative technologies for the next decade. One of the most important aspects of these technologies is related to the spatial location of objects or people in defined environments, for which there are several techniques. One of the most widely used is based on visual marker recognition. The main problems of these approaches are related to the accuracy, the changing environments, the processing time, the operating range/distance and the price. The popularization of these technologies produces a pull effect toward the companies developing the best technology at the lowest price. This paper proposes a marker design and an algorithm to detect the markers under different ambient conditions, with a long range to be executed on embedded systems with low computational requirements. The proposed method reduces the existing problems in the state-of-the-art related to the use of different environments and conditions such as different distances or different illumination. Moreover, the requisites of the method are minimal to reduce the cost of deployment.**

Keywords—Marker detector; Embedded Systems; Positioning System;

I. Introduction

Positioning systems are used in a large number of domains such as healthcare, sports, marketing, industrial, military, entertainment and safety systems among many others [1] [2]. These domains use emerging technologies such as augmented and virtual reality. Augmented reality is technology that enables the introduction of computer-generated elements in a view of the real world. Usually, this technology must use efficient methods to positioning the user in the environment. Most usual methods of positioning are based on visual recognition of markers. Visual recognition can be used in outdoor and indoor environments as opposed to other techniques such as GPS that only works in outdoor scenarios. However, optical methods have the inconvenience of the computational requisites. In most cases, they need to be processed in high-performance systems to accomplish common requisites of augmented reality such as real-time requirements. Also, considering that the market tends to embed these applications in low-level computational systems such as mobile devices or embedded systems, it is essential to provide an accurate, efficient, fast and low-power marker detection method.

One of the biggest problems of detection methods is accuracy. The real scenarios can be very different environments with multiple conditions. This is a critical obstacle in the marker recognition process. The variability of conditions among environments hinders the process of marker detection. The changes in illumination or distance complicate the achievement of the necessary accuracy. Another important issue to consider is the computational load of the process. The use of embedded systems limits the computational complexity of the detection algorithm. On an embedded system, pose tracking is often the most CPU-intensive task [11]. Embedded systems have, among other limitations, low memory and computational capabilities. The detection of a marker using a visual recognition technique is computationally quite intensive and it limits the operations that the method can perform. An important requisite is the execution time of the algorithm. These technologies need to obtain results with a high throughput to provide information to the positioning methods and enable calculation in real time.

The popularization of augmented reality produces a pull effect toward the companies developing the best technology at the lowest price. The use of low-performance cameras such as built-in mobile devices is one of the limitations that the market imposes on the detection method. The use of specialized cameras such as infrared ones or those with special filters facilitates the task of designing specific markers and detection methods [3] [13]. However, the objective is to use popular and low-cost components.

This paper presents a marker detection technique that meets all the given requirements:

- Low-computational requirements that enable the integration of the method in an embedded system such as a mobile device.

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- High throughput processing the image and obtaining results.
- Accuracy in detecting markers in different environments and conditions, at various distances with different illuminations.
- Low cost of the complete system. The use of "popular" cameras and markers with cheap build and distribution costs is necessary.

The technique presented in this paper is based on visual recognition. With the use of low-cost markers (composed of a LED and a contrasting surface), it is possible to detect them with accuracy and efficiency. The algorithm presented reduces the high-complexity operations in the processor such as multiplications or divisions and bases the technique on the calculation of the derivative of the luminosity by subtractions. This image processing is fast, straightforward and robust under changes in lighting conditions and distances. This allows a high-performance calculation in the processor and enables the increase in performance with the use of a DSP module.

The paper is organized as follows. Section 2 presents an analysis of the state-of-the-art. Section 3 describes the design marker structure. Section 4 deals with the proposed algorithm implemented to detect the markers using embedded systems. Section 5 reports experimental results with several examples, and Section 6 states the conclusions.

II. State-of-the-art

In the last years, there has been a growing interest in systems and products related to the location of objects in three dimensions (3D). Sectors such as gaming, medicine, and robotics among many others evolve using this technology. For example, Virtual and Augmented Reality has the potential to be one of the most influential technologies for a decade, according to industry analyst firm CCS Insight [17]. Virtual and Augmented Reality market forecasts predict revenues of $120 billion by 2020 [18].

There are several techniques in the state-of-the-art related to position estimation: mechanical, ultrasonic and magnetic techniques, Global position systems (GPS), inertial sensors like accelerometers and gyroscopes or radio technologies [2][12]. However, all these techniques need specific components or even large and expensive deployments such as the case of radio methods [4]. When vision systems are used, usually, optical approaches are necessary. This is the reason for performing pre-processing of the region of interest where the individual is located using imaging algorithms that detect corners, edges or reference markers; then, with these data, it is possible to obtain the real 3D coordinates of the environment.

In this paper, the technique presented is focused on visual approaches. The use of visual approaches only needs the use of cameras. Usually, these methods are based on the recognition of markers (and building an environmental model) or detecting relative movement between frames.

In [14], the authors survey different methods related to vision-based systems for localization and identification purposes. Through a study of the techniques presented, it can be appreciated that all detection methods are based on operations. The video stream is captured from a camera to analyze each frame with specialized computer vision algorithms to localize desired objects. The techniques presented in [5-7] base the positioning on the detection of markers. However, the main problem is the search for the markers in the whole image when the camera moves quickly, which is too slow. Because of this problem, the real-time requirement is not met. In [8, 9] algorithms are presented for black and white pattern detection. The main problem of these marker detection techniques is the illumination that is required in the environment where the images will be taken. In dark scenarios, the points to be detected may be not located. Because of this, the techniques are limited to being used in controlled scenarios: daylight outdoors or indoors under controlled brightness. For example, the method presented in [9], in addition to the disadvantages, it requires use of complex algorithms to increase the contrast and databases to store specific markers. This increases the computing time and limits the platforms and domains where it can be utilized, because for example, in applications such as virtual reality is necessary a fast processing time to obtain the necessary framerate to show to the user a clear an undistorted video that generates a good user experience. Furthermore, the distance between markers and user is limited to a few meters. In order to increase the detection range, the use of markers with light is proposed. In [16] the use of light sources with varying luminance or pulsed light has been proposed, the latter of which can cause synchronization failures. Other techniques propose using blinking LEDs as markers [12]. This algorithm reports good results, but it needs high-performance camera sensors. The use of light markers has problems in scenarios with high luminance. In these cases, the algorithms cannot differentiate the light of the marker and other light sources. This again limits the environments of use to environments without bright light sources in them.

In [10], a marker is proposed which can be detected in the long range. It is based on the same idea as [8], the use of black and white patterns. The marker structure is a colored circle inside a black circle. The main problem of this technique appears when the background is not clear.

In most of the cited articles, the main problem of the detection algorithm is variable lighting. In most of the cases, the markers are detected through color or image segmentations. The second problem is the detection range. Several algorithms are robust enough under environmental changes, but they cannot detect markers beyond a few meters. As is reported in [14], where more than 25 optical, indoor positioning systems are evaluated, techniques that report good accuracy and coverage or distances have a low frame rate or use a very expensive camera. Moreover, it is important to remark that these methods are not specifically designed for embedded systems.

III. Marker Design

The proposed marker follows the patented method described in [19] [20]. It is composed of a light-emitting diode (LED) and a black contrast surface. The use of a LED is due to the advantages that they have over other light sources such as incandescent light: lower energy consumption, longer lifetime, improved physical robustness and smaller size. These characteristics are important, but the most important of them is that, for this apparatus, a punctual light is required and LEDs are the ideal source to be used. With this kind of lights, (using more than 1 W of power) it is possible to visualize them at distances greater than 50 meters. Moreover, the light emitted by the diode is safe due to its optical power. The use of other kinds of light sources can be considered, but they do not offer advantages compared to LEDs. For example, the use of infrared sources can be implemented. The sensor of the camera can capture the light emitted in the visible spectrum and the infrared one. Another example can be incandescent or filament lamps, but they are diffuse light sources. This limits the distance for the detection method.

Fig. 1. Example of a marker

The second part of the marker is the contrasting surface. It is a black surface seeking to absorb as much light as possible (100% in the best case) without reflections. The dimensions must have sufficient size to be captured by the camera at any distance. The size depends on the camera and the maximum working distance. If the contrast surface is a few centimeters in diameter (for example 10cm*10cm in a square surface) and using a standard camera, it is clear that the optics of the camera cannot capture it more than a few meters away (8 or 9 meters). The shape of the surface is not limited to a square; it can be a circle or another shape. The only condition is that it must surround the light source. If the background behind the light source is dark enough, it is possible to remove the contrast surface. An example of a marker can be seen in Figure 1.

IV. Detection of the Markers.

In order to detect the markers presented in the previous section, an algorithm is proposed, designed to be efficient in embedded systems. The first step of the process is the capture a frame from the camera. It only has one requisite: the information of the image cannot be captured in a compressed format to avoid the loss of information produced by the image processing.

The algorithm works with HSB or HSL image format. The two formats are very similar. The H component stands for Hue, and the S stands for Saturation in both cases. However, in HSB the B is for Brightness, and in HSL, the component L stands for Lightness. Brightness is perceived as the "amount of light" which can be any color while Lightness is best understood as the amount of white. Both values are given as a real number between 0 and 1 or as a percentage. The selection of a format depends on the LEDs characteristics. If the LEDs have color, the best option is the use of HSB. In the example presented, white LEDs are used. The algorithm works mainly with the third component: the brightness.

The main idea is to find the markers seeking a brightness pattern presented in Figure 2. This pattern allows the identification of the marker through the change of the brightness of the LED (about 100%) to the contrast zone (about 0%).

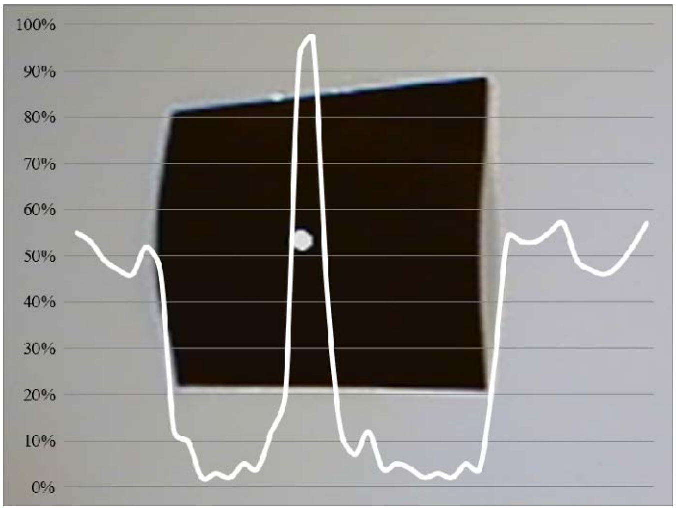

Fig. 2. Pattern to search in the brightness of the image.

Nevertheless, the search for the pattern cannot be done through fixed values due to the multiple scenarios and changing environmental conditions. If the scenario has a lot of light, the ranges of the LEDs and the contrasting surface change compared with a scenario with low brightness. That is why the use of ranges with fixed values is not efficient. To avoid this problem, the algorithm processes the image calculating the derived values of the brightness.

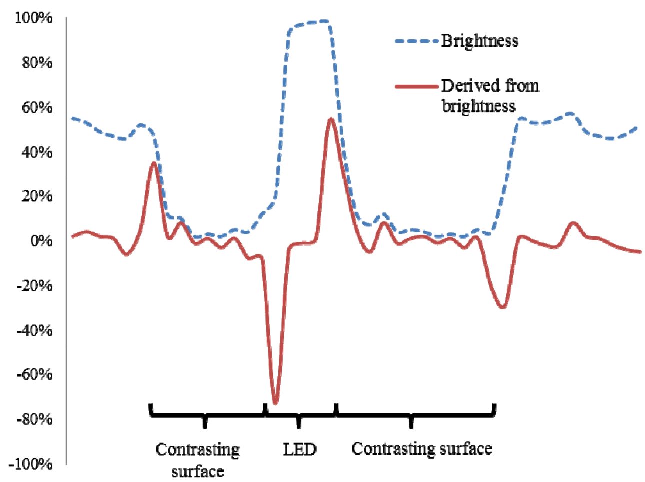

Fig. 3. Image derived.

As can be observed in Figure 3, the red line shows the derivative from the brightness and the dotted line shows the pattern presented in Figure 2. The LED corresponds to the section where there is a negative slope, followed by a positive slope and another negative slope. To calculate the derivative function, very simple calculus is performed (Figure 4). The original image is traversed horizontally, vertically and diagonally by calculating the differences between the brightness pixel value and the next pixel value. The values obtained are truncated by the ranges of the max/min slope of the function point. These must be values in the ranges: [-100,-60] or [+60,+100]. The values that are not in these ranges are truncated to zero. As can be observed in Figure 4, this matrix has a circle with long slopes surrounding the LED. Finally, applying this method, it is obtained different matrices (one for each type of path of the matrix) with the interesting values of the derivate of brightness in this pixel and with zero in the places where the derivative of brightness is not a factor to consider.

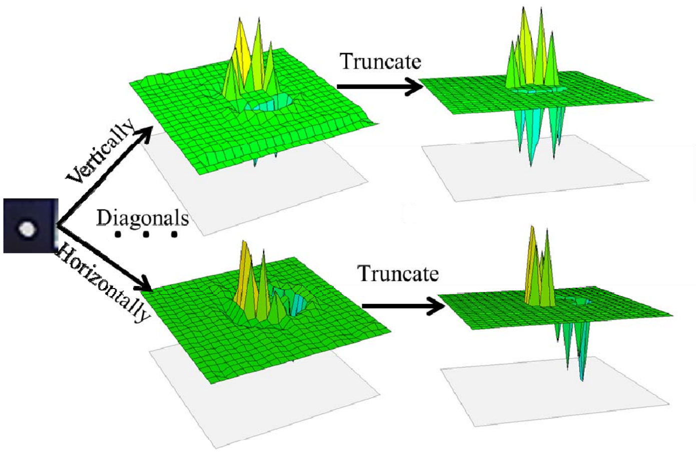

Fig. 4. Process of derivation using truncated calculus

Once the truncated slope matrices are calculated, they are used to find the patterns present in Figure 3. To detect them, an algorithm based on a state machine is used (Figure 5 shows a state transition diagram for this state machine). Each matrix is traversed in the same direction that it was generated. The first state is "Initial State". The state changes to "Downslope" when the pixel slope is less than a –MIN (-60). In other words, it changes to the next step when a long downslope is detected (The first negative peak in Figure 3). Once the Downslope is detected, the algorithm must be detecting a zone without slope. If it does not recognize this region, it is assumed that the sequence is not a pattern and the state machine returns to "Initial state". If a non-slope zone is detected, the machine passes to the "LED Potential Pixel" stage. These values can be part of the LED if an upslope is located in the next pixels. The upslope must be bigger than MIN (60). In this case, the pixels are stored as potential LED pixels in a matrix. If not, the machine returns to the "Initial state".

Once all the matrices (vertical, horizontal and diagonals) are processed with the pattern detector algorithm, the potential LED pixels are crossed, searching for coincidences in the possible LED pixels detected in all matrices. These coincidences must meet two main requirements: the first one is that the pixel must be detected in all the matrices (diagonal, vertical and horizontal). The second one is that the length of the LED or number of pixels (LED in Figure 3) for each LED must be similar in all the matrices. In other words, the LED should be rounded. With these two requirements, false positives are eliminated, filtering in this way other possible patterns that could be considered LEDs.

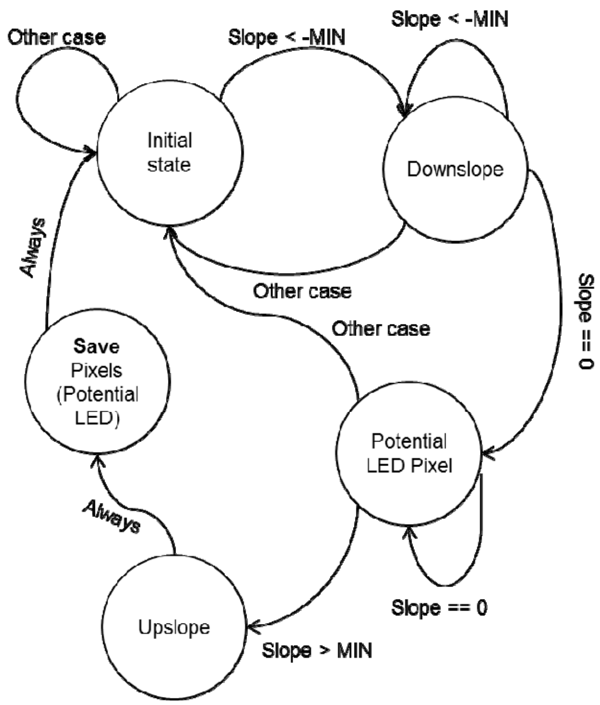

Fig. 5. State machine to detect the pattern.

V. Accuracy of the Method

In order to validate the technique, a bank of tests is implemented using GoogleTests [15]. The tests are composed of more than 450 different captured images in various scenarios. There are basic scenarios with few objects in the image (Basic in Table I), complex scenarios with multiple objects in the scene and different environments and luminescence (Medium in Table I) and very complex scenarios with trick objects that simulate LEDs or are similar to a LED (High complexity in Table I). All the scenarios have the markers positioned at different distances and locations. The number of markers in each image varies from none to more than six markers. The LEDs used in the markers are white SMD LEDs with low power (0.09 W) powered by a 3.3 v battery. The brightness of this kind of LEDs is not too high. Because of this, the maximum detection distance is about 20 meters. However, this range can be extended with the use of a camera with more quality, a brighter LED and/or a larger contrasting surface. In Figure 6, an example is presented of successful detection at 19 meters (First image). As can be observed the brightness of the LED is very low, and the contrasting surface is very small. This example is at the limits of the technique.

An example of a basic scenario is presented in the first image in Figure 6. This scenario is a clean scenario without bright objects. However, as was commented previously, this case has the problem of the distance of the marker. The second image in Figure 6 presents a medium scenario. Its complexity is greater due to the different environment present, with multiple conditions and changes. The last two images in Figure 6 show a complex scenario with multiple objects that reflect the sun and lamp lights. When a brilliant object reflects an external light, it can act like a LED and can produce a fault of the method.

In the left of Figure 6, the original images can be seen, with circles that show the position of the marker to the reader. The right is the image after being processed with a red mark over the marker.

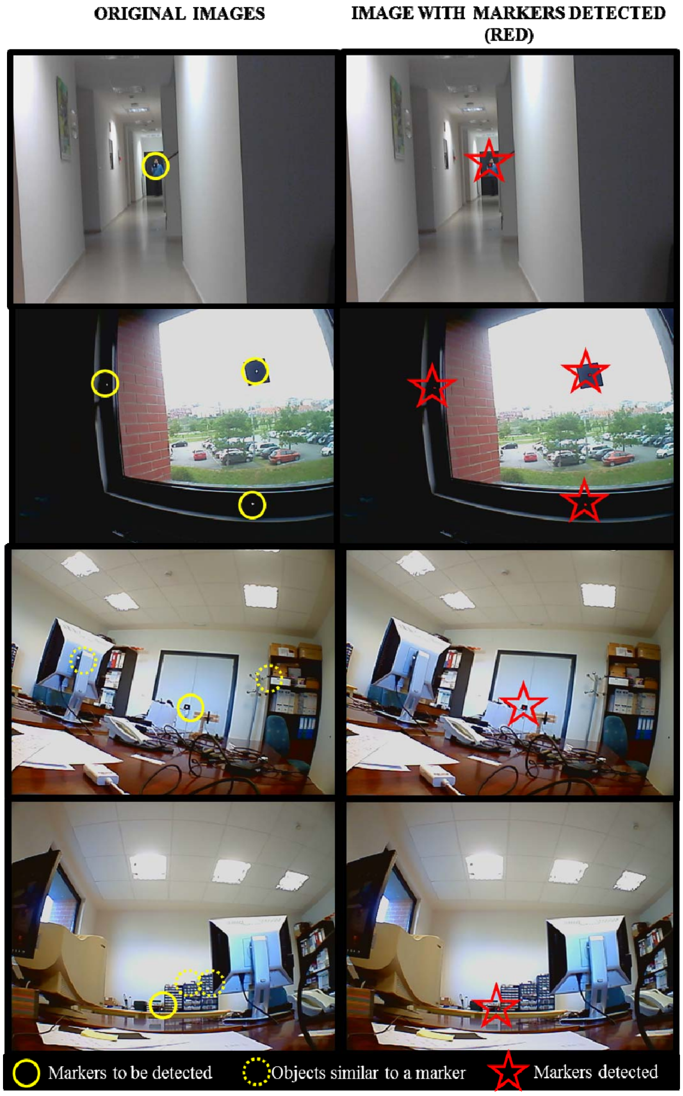

Fig. 6. Examples of the experiments

Table I shows the results obtained during the tests. As can be appreciated, the method has high accuracy under normal conditions; nearly 100%. The main problem of the technique appears in scenarios with multiple bright objects, with high luminescence. These objects under certain circumstances may act like a marker and produce a false detection. As can be appreciated, in the worst case, with very changing environments and multiple objects similar to a marker in the scene, the proposed method fails less than 14%, failing to detect only 5% of real markers.

TABLE I. RESULTS OF THE TESTS

Scenario	Basic scenario	Medium scenario	High-complexity scenario	TOTAL
Number of tests	170	143	165	478 Tests
Total Markers in tests	543	401	507	1451 markers
Fails type I (Not detected marker	3	20	29	52
Fails type II (Fake Marker detected)	0	0	37	37
Accuracy (%)	99%	95%	87%	94%

The technique is evaluated in an embedded platform. The selected target of this SW is an ODROID-XU+E. This platform is ARM based architecture. It has a Samsung Exynos5 processor with four Cortex-A15 and four Cortex-A7. This processor is widely used in embedded systems and mobile devices as the Samsung Galaxy S series. The wide use of this processor in mobile systems justifies the use of this platform because this technique is intended to be used, among other applications, in virtual and augmented reality systems executed on embedded platforms such as mobile devices.

The processing time results are presents in Table II. The first four rows show the execution times of the Derivative functions used to calculate the truncated slope matrices. The following four rows show the execution times of the Pattern functions of the state machine used to detect the pattern in the matrices. The last function (Cross Matrices) is the responsible for crossing all the matrices searching for coincidences. As a curious fact, the execution time of the horizontal, vertical, and diagonal functions are different due to the cache misses. As can be appreciated, the technique allows obtaining a frame rate of 15 frames per second using the code without optimizations in a big core (Cortex-A15 core). In the case of the execution of the technique in a little core, (Cortex-A7 core) the frame rate is reduced to about eight frames per second. .However, one of the significant characteristics of the technique is the low dependence between data. This allows parallelizing the code completely without time losses by waiting. In the case that the code is parallelized in the four little cores, the execution time of the technique is reduced to only 38 ms, which produces a frame rate of about 28 frames per second. In the case of the parallelization is executed over the 4 Big cores, the frame rate reaches almost 53 frames per second. More parallelizations or alternatives (such as the execution in a GPU) can be explored to achieve the necessary frame rate reducing the use of cores to each application.

TABLE II. EXECUTION TIME OF THE TECHNIQUE IN AN EXYNOS5 SYSTEM

Functions	1 Little core (A7)	1 Big core (A15)	4 Little cores (A7)	4 Big cores (A15)
Horizontally derivative	15,05 ms	6,9 ms	4,2 ms	1,87 ms
Vertically derivative	27,22 ms	14,64 ms	8,36 ms	4,9 ms
Diagonal Left derivative	20,45 ms	11,19 ms	5,81 ms	2,98 ms
Diagonal Right derivative	19,5 ms	10,79 ms	5,33 ms	2,63 ms
Pattern Horizontally	5,2 ms	0,93 ms	2,1 ms	0,29 ms
Pattern Vertically	10,06 ms	7,43 ms	2,63 ms	1,91 ms
Pattern Diagonally Left	12,02 ms	7,42 ms	3,53 ms	1,81 ms
Pattern Diagonally Right	10,72 ms	6,9 ms	3,7 ms	1,81 ms
Cross Matrices	7,93 ms	1,3 ms	2,84 ms	0,5 ms
TOTAL TIME	**128,15 ms**	**67,5 ms**	**38,5 ms**	**18,7 ms**
FRAME RATE	**7,8 frames/s**	**14,8 frames/s**	**25,97 frames/s**	**53,47 frames/s**

VI. CONCLUSIONS

This paper presents a technique for detecting markers in different environments and conditions with low computational requirements. The method presented is designed to be used in embedded systems and works with sufficient frame-rate to be usable in applications such as augmented reality. The technique is based on a visual recognition approach.

The paper proposes a low-cost marker (composed of a LED and a contrasting surface) that enables the detection of the marker at long distances. The technique is perfectly suited to embedded systems because it involves a reduced number of high-complexity operations in the processor such as multiplications or divisions and it is based on the calculation of the derivative of the luminosity by subtractions. This enables the increase in the performance using a DSP module. This image processing is fast, straightforward and robust under changing lighting conditions and distances.

This technique was validated with several tests under different conditions and scenarios, demonstrating the usability and the accuracy of the proposed method.

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