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Low-Cost Object Size Estimation Using ESP32-CAM and Computer Vision

***Abstract*—This paper presents a complete and validated low-cost system for object dimension estimation using the ESP32-CAM microcontroller and computer vision techniques. The proposed solution leverages the integrated OV2640 camera and the wireless capabilities of the ESP32-CAM, combined with image processing algorithms implemented in Python using the OpenCV and NumPy libraries. Using ArUco markers as physical scale references, the system establishes accurate pixel-to-centimeter conversion ratios, enabling precise, real-time estimation of object dimensions. A series of experiments were conducted under controlled conditions using objects of known size and various geometries. The results demonstrate a high degree of precision, with an average error below 1.5%. The low cost, portability, and ease of implementation of the system make it a practical alternative to traditional measurement methods, particularly in contexts where cost or accessibility constraints exist. The proposed system has shown broader applicability, its modular design enables adaptation for industrial automation, environmental sensing and smart agriculture scenarios. This research confirms the potential of combining embedded hardware with efficient computer vision techniques to deliver reliable, scalable, and affordable measurement solutions in diverse real-world applications.**

***Index Terms*—ESP32-CAM, OpenCV, ArUco markers, embedded systems, low-cost measurement**

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I. Introduction

4

Accurate object size estimation is critical in numerous fields, including industrial automation, environmental monitoring, agriculture, logistics, and scientific research. Traditional methods for dimensional measurement often rely on manual tools or expensive and complex technologies such as LiDAR, stereoscopic vision, or ultrasonic sensors. Although effective, these systems are frequently constrained by high cost, bulky configurations and limited accessibility, particularly in remote or hazardous environments. In geophysical and volcanic studies, for example, the ability to estimate the size and evolution of surface phenomena such as fumaroles, gas and steam emissions from active volcanic vents is essential to assess eruption risk and understand underlying geothermal activity [1] [2]. However, traditional techniques for measuring these emissions, such as direct observation and remote sensing, are expensive and have limitations with respect to the frequency and accessibility of the collected data [3].

Recent advances in embedded computing and open-source computer vision frameworks have enabled the development of affordable, compact, and flexible systems capable of addressing these limitations. Among the most promising hardware platforms is the ESP32-CAM, a low-cost microcontroller with integrated wireless connectivity and an on-board OV2640 camera module. When combined with robust image processing libraries like OpenCV and NumPy, this device enables the construction of lightweight vision-based systems suitable for real-time measurement applications.

This paper presents designing and validating a low-cost, vision-based system for object dimension estimation using ESP32-CAM and ArUco marker-based reference scaling. The proposed solution captures images of objects, detects calibrated visual markers within the scene, and calculates physical dimensions by converting pixel distances into real-world units. Experiments under controlled conditions demonstrate the ability of the system to estimate dimensions with an average error below 1.5%, highlighting its reliability and efficiency.

The main scientific contribution of this work lies in demonstrating that low-power embedded hardware, when paired with efficient computer vision techniques, can deliver accurate and scalable solutions for object measurement tasks. Unlike previous works that focus solely on object detection or classification, this study emphasizes dimensional accuracy using monocular vision and minimal hardware, contributing to the growing field of accessible and reproducible measurement technologies. The versatility of the proposed approach allows it to be easily adapted for use in a wide range of real-world applications where cost, simplicity, and accuracy are key constraints.

The rest of this paper is organized as follows: Section II reviews related work; Section III details the system methodology; Section IV presents experimental results; and Section V concludes the paper with key findings and future directions.

II. Related Work

Accurate object size estimation is a key task in various fields, including industrial automation, environmental monitoring, and geospatial analysis. Several technologies have been developed to address this challenge.

A. *Object Size Estimation Methods*

Accurate object size estimation is crucial in multiple fields, from manufacturing to environmental monitoring. Various technologies have been developed for this purpose:

- LiDAR (light detection and positioning): This technology uses laser pulses to measure distances with high precision, generating detailed three-dimensional models of the environment. Its ability to penetrate vegetation and provide accurate terrain data makes it ideal for cartography and forest management applications [4].
- Ultrasound: uses high-frequency sound waves to determine distances based on the time it takes for the echo to

return to the sensor. It is commonly used in robotics and automotive applications for obstacle detection. However, its precision can be affected by environmental factors such as temperature and humidity [5].
- Stereoscopic vision: involves using two separate cameras to simulate human depth perception, allowing distance and object size estimation. Although it provides precise results, its implementation can be complex due to the need for calibration and synchronization between cameras [6].

B. ESP32-CAM Applications in Object Measurement

The ESP32-CAM is a low-cost module that combines processing capabilities and Wi-Fi/Bluetooth connectivity with an integrated camera, making it ideal for computer vision applications in resource-limited environments. Its versatility has enabled its use in various projects:

- Object Detection: Implementations that use ESP32-CAM in conjunction with libraries such as OpenCVpre-trained models such as YOLOv3 to identify and classify in real time [7].
- Object Recognition with Neural Networks: Projects that employ ESP32-CAM to capture images and process them using convolutional neural networks, enabling the recognition of specific objects [8].
- Object Detection with Python and OpenCV: Guides explaining how to perform object detection using ESP32-CAM and tools such as Python and OpenCV, facilitating its implementation in applications such as surveillance and robotics [9].

C. Use of ArUco Markers in Computer Vision

ArUco markers are visual patterns that are used for detection and tracking in computer vision applications. They are characterized by their simplicity and robustness, enabling:

- Camera calibration: Facilitates obtaining intrinsic and extrinsic camera parameters, improving accuracy in augmented reality and measurement applications [10].
- Pose estimation: Allows determining the camera's position and orientation relative to the marker, essential in robotics and autonomous navigation [11].
- Scaling in images: Knowing the physical dimensions of the marker makes it possible to establish a reference scale in the image, simplifying the measurement of objects in the environment [12].

D. Summary and Contribution

Previous research has shown that LiDAR, ultrasonic sensors, and stereoscopic vision are effective for estimating object dimensions, but these methods often involve high costs, intricate calibration processes, or large hardware systems. In contrast, applications that use the ESP32-CAM have focused mostly on object detection or classification, offering a limited focus on detailed dimensional analysis. This study introduces a cost-effective and user-friendly solution that integrates ESP32-CAM with ArUco marker-based scaling and computer vision techniques to achieve precise object dimension estimation. Unlike earlier approaches, this system is designed for long-term use in environmental monitoring applications.

III. Methodology

This work focuses on developing an IoT-based system for estimating the object dimension using the ESP32-CAM microcontroller and advanced image processing techniques.

A. Hardware

- ESP32-CAM: This module integrates an ESP32 microcontroller with Wi-Fi and Bluetooth capabilities, accompanied by a 2-megapixel OV2640 camera. The ESP32 features a 32-bit processor, operating at 240 MHz, with 520 KB of internal SRAM and 4 MB of external PSRAM. The OV2640 camera offers a maximum resolution of $1600x1200$ pixels and supports output formats such as JPEG and BMP. The module also features a microSD card slot of up to 4 GB, facilitating local storage of captured images [13].
- Additional Sensors: Although ESP32-CAM does not include integrated environmental sensors, its support for interfaces such as UART, SPI, and I2C allows the incorporation of external sensors to measure parameters such as temperature, humidity, and gas composition, expanding the system's capabilities.

B. Software

- Python: Used for image processing and data analysis, taking advantage of its wide range of scientific and image manipulation libraries.
- OpenCV: This open source library provides tools for image processing operations such as filtering, edge detection, feature recognition, and object tracking [14].
- NumPy: Fundamental library for numerical computation in Python, facilitating mathematical operations and matrix manipulation, essential in image processing [15].
- Arduino IDE: Used for programming and configuring the ESP32-CAM, allowing custom firmware to be loaded and managing communication between the hardware and processing software.

C. Image Processing

1) Image Capture: The ESP32-CAM is configured to capture images of the fumaroles in real-time, storing them on a microSD card or transmitting them to a server for further processing.
2) Object Detection: The images were processed using OpenCV to identify and segment the fumaroles from the background, applying thresholding and contour detection techniques.
3) Scales with ArUco markers: ArUco markers, square binary patterns that are easily detectable in images, are placed in the fumarole environment to establish a scale reference. OpenCV provides functions to detect these markers and calculate their orientation and position in the image.

4) Knowing the physical dimensions of the markers allows one to determine the relationship between pixels and real-world units, allowing the fumarole dimensions to be accurately estimated.

This methodology combines affordable hardware and image processing techniques to develop an efficient system to estimate fumarole dimensions. It has the potential to be adaptable to various applications in industrial and environmental monitoring environments.

IV. Results

This section presents the results of tests performed using the developed system for object dimension estimation. To evaluate the precision and reliability of the proposed system, a series of tests were conducted using everyday objects with known dimensions; see Figs. 2 and 1. The aim was to compare the estimated dimensions produced by the system against ground truth measurements and quantify the error under controlled conditions.

- Description of the procedure: The tests were carried out using the ESP32-CAM at a resolution of 1024×768 pixels and an ArUco marker of known dimensions (5×5 cm) to establish the conversion scale between pixels and centimeters. The images were captured in a controlled environment with homogeneous lighting and processed using the OpenCV and NumPy libraries in Python. The test objects included flat surfaces and three-dimensional structures.
- Comparison between Actual and Estimated Measurements: Below is a table with a summary of some the measurements obtained:

Object	**Real (cm)**	**Estimated (cm)**	**% Error**
Cellphone	15.2	15.4	1.31
Cube	7.0	7.4	1.46
Door	192.0	192.5	0.26

- Error Analysis: The errors detected were less than 1.5% in most cases, demonstrating the high accuracy of the system in estimating dimensions. The discrepancies are mainly attributed to minor distortions in the image and variations in lighting, which could be minimized by adjusting the system parameters.

V. Conclusions

This work presents a complete and low-cost system for object dimension estimation using the ESP32-CAM microcontroller and computer vision techniques. The system achieves accurate, real-world-sized estimations of objects from a single camera view by integrating ArUco marker-based scale calibration with an image processing pipeline built on OpenCV and NumPy.

Experimental validation showed that the system has an average measurement error of less than 1.5%, confirming its effectiveness in controlled environments. The solution stands out for its affordability, portability and simplicity, making it a strong candidate for applications in industrial automation, smart agriculture, logistics, and environmental monitoring, especially in scenarios where high-end measurement systems are not feasible.

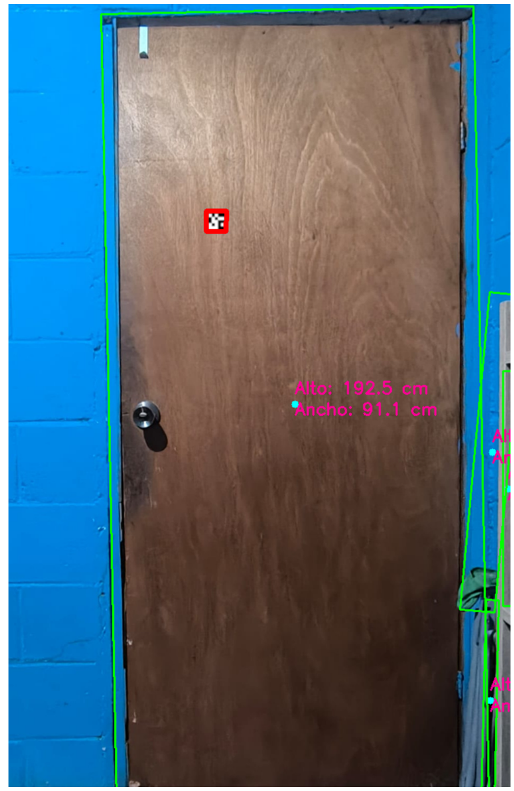

Fig. 1: Door measurements estimation

The proposed system also demonstrates the growing potential of embedded computer vision on resource-constrained hardware. However, limitations such as sensitivity to lighting conditions and fixed camera angles were observed. These factors may affect the accuracy of the measurement in uncontrolled settings.

Future work will address these limitations by implementing camera calibration routines, adding robustness to object segmentation, and exploring real-time data transmission through IoT integration. Field testing in outdoor and dynamic environments will also be carried out to evaluate the adaptability and performance of the system under real world conditions.

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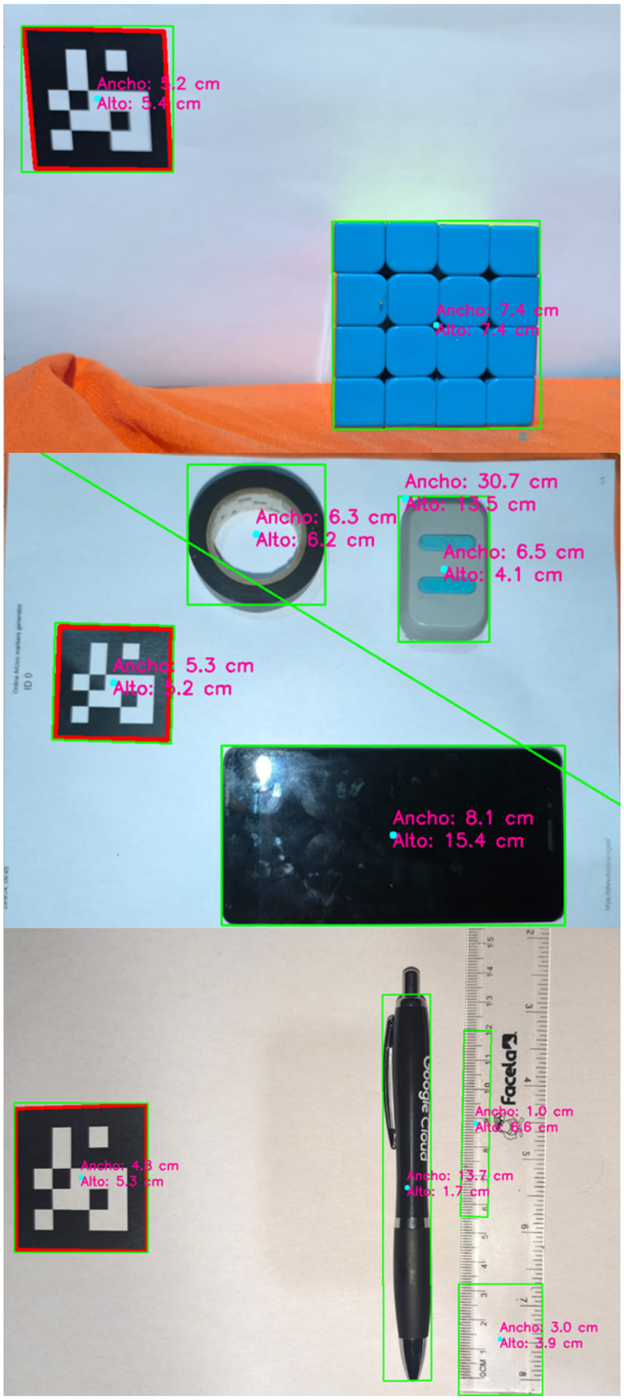

Fig. 2: Figures presented are size estimations of various objects made with the proposed system and methodology. .

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