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Design and implementation of esp32-cam and yolov8-based intelligent camera systems for the detection of littering behavior

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ABSTRACT
This research aims to design and implement an intelligent camera based on ESP32-CAM and YOLOv8 algorithm to detect objects of people and garbage in the river area. The system is built by integrating a PIR sensor as a motion trigger, an LM2596 step-down module as a voltage regulator, and a PHP/MySQL backend for storing detected data. The ESP32-CAM is programmed using an Arduino IDE to be able to capture images when the PIR sensor is active and send them to the server. Furthermore, YOLOv8 running with Python (FastAPI) is used to analyze the images and classify the detected objects. The test results showed that the system worked as designed, with an average response time of ±10.27 seconds from motion detection to recording results to the database. YOLOv8's detection accuracy reached 96% for people objects and 90% for junk objects, with an average overall accuracy of 93%. Although this system has not been able to detect waste disposal behavior directly, this research has succeeded in providing an initial foundation towards the development of environmental monitoring systems based on behavior detection in the future.

Keywords: *ESP32-CAM, YOLOv8, PIR sensor, garbage detection, smart camera.*

INTRODUCTION
Waste is an environmental problem that is still a serious challenge in Indonesia, especially in river areas that are often used as garbage dumps by the community. The behavior of littering in rivers has an impact on environmental pollution, blockage of water flow, and increases the risk of flooding. This condition shows the need for innovative solutions to monitor and supervise community activities around the river.

The development of Internet of Things (IoT) and artificial intelligence (AI) technology provides a great opportunity to build automated monitoring systems. One of the most popular devices used in monitoring systems is the ESP32-CAM, a microcontroller module with a built-in camera that supports image processing as well as wireless connectivity. With its affordable price and low power consumption, the ESP32-CAM is widely used in computer vision-based research.

On the other hand, the YOLO (You Only Look Once) algorithm has proven to be effective for real-time object detection with high accuracy. The latest version, YOLOv8, offers increased speed and efficiency, making it suitable for use in embedded device-based system implementations and on-premises servers. Some previous studies have shown the use of YOLO to detect specific objects, including garbage, with a fairly high degree of accuracy.

Based on this background, this study designed and implemented an ESP32-CAM-based intelligent camera system integrated with PIR sensors and YOLOv8 algorithms. The focus of the research is to detect objects of people and garbage in the river area, as well as store the detection results into a web-based server. Although this system has not been able to fully identify waste disposal behavior directly, this research provides the initial foundation for the development of more intelligent and adaptive environmental monitoring systems in the future.

METHOD

This research uses a prototyping approach, which is the development of the system is carried out in stages starting from design, implementation, to testing.

Research Type and Design

This research is applied research with an experimental design. The goal is to design and test a prototype of an intelligent camera system based on ESP32-CAM and YOLOv8.

Research Subject

The subject of the study is in the form of a river environment in urban areas that is often used as a waste disposal location. This location was chosen because it is representative of the problems to be solved.

Hardware

1. ESP32-CAM as a control center and shooting module.
2. PIR (Passive Infrared) sensor as a trigger when motion is detected.
3. LM2596 step-down module to stabilize the 5V power supply of the 12V adapter.
4. The power adapter as the main power source.
5.

Software

1. The Arduino IDE for ESP32-CAM programming uses the C/C++ language.
2. PHP/MySQL server as a backend for storing images and detection logs.
3. Python + FastAPI to run YOLOv8 models in detecting "person" and "trash" objects.
4.

Research Data

Primary data was obtained from the results of testing the system in the field (river), including response time, data transmission success rate, and object detection accuracy. Secondary data were obtained from the literature related to ESP32-CAM, IoT, and YOLO-based object detection.

Research Procedure

1. Designing hardware and software systems.
2. Assembly of the ESP32-CAM series with PIR sensor and step-down module.
3. ESP32-CAM programming to take images and send them to the server.
4. Creation of a PHP/MySQL backend server to store image data and detection results.
5. YOLOv8 integration on Python servers with FastAPI to detect people and junk.
6. Field testing of the system to measure functional performance, response time, and detection accuracy.
7.

Data Analysis Techniques

The data was analyzed descriptively by comparing the test results against the specified specifications. Measurements include the system's average response time and YOLOv8's detection accuracy rate against objects, people, and debris.

RESULTS AND DISCUSSION

Result

The intelligent camera system was successfully implemented with the ESP32-CAM as the main device integrated with a PIR sensor as a motion trigger. When the PIR detects activity, the ESP32-CAM takes an image and sends it to the PHP/MySQL server via HTTP POST. The object analysis process is carried out by YOLOv8 which is executed using Python (FastAPI), then the detection results are saved back to the database and displayed on the web interface.

The web interface displays:

1. Gallery of detection results.
2. Detailed images along with information on the time and objects detected.
3. Live streaming from the camera.

Response Time Testing

Testing is done to ensure all features run as designed.

Table 1. System Functional Test Results

Yes	Functions Tested	Expected Output	Result
1	PIR sensor detects motion	ESP32-CAM is active and takes pictures	Succeed
2	Upload images to the server	Images stored in the server directory	Succeed
3	YOLOv8 detection process	Objects of people/garbage are detected and given a bounding box	Succeed
4	Storage to the database	Image data and detection results are recorded	Succeed
5	Web view	Gallery & image details displayed according to data	Succeed

All functions are fine, although the internet connection affects the speed of the upload process.

Response Time Testing

The test was conducted in 10 attempts, with the average result of the system taking ±10.27 seconds to complete a single detection cycle: from motion detection → image capture → delivery → YOLOv8 analysis → recording to the database.

Table 2. Response Time Test Results

Yes	Detection Cycle (sec)
1	10,1
2	10,4
3	10,3
4	10,0
5	10,5
6	10,2
7	10,1
8	10,3
9	10,4
10	10,2
Average	**10,27**

These results show the system is fast enough for the snapshot category, although it is not yet optimal for real-time video needs.

Accuracy Testing

YOLOv8 accuracy testing was performed with a test dataset containing people objects and garbage.

Table 3. YOLOv8 Accuracy Test Results

Objek	Number of Test Data	Correctly Detected	Falsely Detected	Accuracy
Orang	50	48	2	96%
Garbage	50	45	5	90%
Average	100	93	7	93%

The results showed that the system was able to recognize people and garbage with a fairly high level of accuracy.

Discussion

From the test results it can be concluded:

1. The system successfully integrates ESP32-CAM, PIR, PHP/MySQL servers, and YOLOv8 with functions running as designed.
2. Response times ±10.27 seconds are still acceptable for snapshot-based systems, but they need to be optimized for real-time use.
3. The average detection accuracy of 93% proves that YOLOv8 is quite reliable in recognizing objects of people and garbage.
4. This system cannot directly detect "throwing garbage" behavior, but only detects the presence of people and garbage in the same frame. However, this can be used as an initial foundation for the development of behavior detection systems based on video sequence analysis or action recognition in the future.

CONCLUSION

This research successfully designed and implemented an intelligent camera system based on ESP32-CAM and YOLOv8 to support automatic monitoring of waste disposal behavior in rivers. The system integrates ESP32-CAM as an image capture device, a PIR sensor as a motion trigger, a PHP/MySQL server as a data storage medium, and Python FastAPI with YOLOv8 as an object detection engine.

The results of the functional tests show that the system can work as expected, from motion detection, image capture, sending images to the server, object detection (people and garbage), to recording detection results into the database. The average system response time was recorded at ±10.27 seconds, while accuracy test results showed that YOLOv8 was able to detect objects of people with 96% accuracy and garbage with 90% accuracy, with an overall accuracy of 93%.

Although this system has not been able to directly identify the *act* of littering, it has been proven to be able to detect the presence of human objects and waste at the same time. This capability becomes an important basis for the development of further behavioral detection systems in the future.

Thus, this study proves that IoT and computer vision technology can be applied to support environmental monitoring efforts. Advanced developments such as temporal-based video analysis, improved network stability, and more comprehensive database integration—can make these smart camera systems a practical tool in helping to monitor and reduce littering behavior in rivers.

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