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Development of a Cost-Effective Surveillance System using ESP32 Cam for Remote Monitoring

P Marichamy[1], P Lingeswari[2], B Dhanam[3], R Ashok[4], M Surya Prakash[5], and I Muhammed Yousaf[6]
[1-6]P. S. R Engineering College, Sivakasi, Tamil Nadu, India
Email: pmarichamy@psr.edu.in, lingeswari@psr.edu.in, dhanam@psr.edu.in, ashokkrish151@gmail.com, surya25125@gmail.com, yusufyusuf41541@gmail.com

***Abstract*— SmartGuard is a cost-effective and simple home security solution that is designed to match the requirements of modern living. With an increasing number of people moving to urban areas, home security is becoming a critical need. The solution is based on Internet of Things (IoT) technology. Specifically, ESP32-CAM is used. This is a module that has a camera and Wi-Fi connectivity. This means that it can take photos and videos and send real-time notifications using Telegram. The solution is quite simple. No extra hardware is needed. It is cost-effective and environment-friendly because it consumes low power. Moreover, it is simple to install. This ensures that it is accessible to every individual. In addition, Telegram is used by a majority of people. Therefore, this solution is quite simple. SmartGuard is the ideal solution for the people who is planning to enhance their home security.**

***Index Terms*— ESP32-CAM, IoT, Smart Surveillance, PIR Sensor, Motion Detection, Telegram Alert and Wireless Monitoring.**

I. INTRODUCTION

In the few years' people have been looking for security systems that are affordable and work well. This is because people are getting more worried about safety at home in the office and in places that are away from cities. The old way of watching over these places with CCTV cameras requires someone to always be watching. It is expensive to set up and needs a good internet connection, which is not good for small areas or places in the country. Now that Internet of Things technology is getting better, a cheap system that can send messages in real time is made. The ESP32-CAM module is a choice for these systems because it has a tiny computer, a camera and Wi-Fi all in one. This makes the system simpler and cheaper. This project is about making a security system using the ESP32-CAM and a special sensor that can detect when someone is moving. The sensor sees when someone is moving and tells the ESP32-CAM to take a picture [1]. Then the picture is sent to the user through the Telegram messaging app so the user can watch from away without needing to see video all the time. The system is designed to use power and send less data by only taking pictures when it sees movement. It is meant to be easy to use, not expensive and simple to set up. The best thing about this project is that it is an Internet of Things security solution that can be made with just a few parts and still works well. The ESP32-CAM and the security system are important, for this project. The security system and the ESP32-CAM are used to make a surveillance system that is practical and easy to use [2]. In homes and small places, it is hard to keep everything safe all the time. This is because the usual systems that watch over things are very expensive and complicated.

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Most of these systems need to record video all the time store a lot of videos and have someone watching them all the time. Also, these systems use a lot of energy. May not work well in areas that are far away from cities and do not have many resources. A system is needed that works automatically and can send warnings right away without someone always watching [3]. The usual systems that watch over things like CCTV cameras work all the time. Need special equipment to watch them. These systems are expensive to set up and maintain. Some new systems use things, like Raspberry Pi to watch things but they use more energy and make the system more complicated.

Many of the systems that already exist also need to send video all the time, which uses data and needs the internet to work. Also, most simple systems do not have a way to send warnings away to the person using them. It uses the ESP32-CAM module and a PIR motion sensor. The PIR sensor finds movement. Tells the ESP32-CAM to take a picture only when it needs to [4]. The picture is then sent to the person using it over the internet through the Telegram messaging platform. This way of sending data when something happens reduces the amount of data sent and the energy used. The system is small, cheap and easy to set up without needing someone to always watch it or complicated equipment. The system is a surveillance solution that provides real-time alerts without continuous monitoring it is based on the ESP32-CAM module and a PIR motion sensor the ESP32-CAM module and the PIR motion sensor work together to provide a low-cost and automated surveillance system [5]. These systems are expensive to set up and maintain. Some new systems use things, like Raspberry Pi to watch things but they use more energy and make the system more complicated. Many of the systems that already exist also need to send video all the time, which uses data and needs the internet to work. Also, most simple systems do not have a way to send warnings away to the person using them. It uses the ESP32-CAM module and a PIR motion sensor. The PIR sensor finds movement. Tells the ESP32-CAM to take a picture only when it needs to.

In this paper, a surveillance system is proposed. It uses the ESP32-CAM module with a Passive Infrared (PIR) sensor. The PIR sensor helps detect motion. The system sends images wirelessly. The system captures images when it detects motion. This reduces data transmission and power consumption. The ESP32-CAM allows real-time image acquisition. It sends images over Wi-Fi. The PIR sensor detects presence efficiently. The system sends captured images to the user through Telegram alerts. This allows access and timely notifications. The proposed solution improves security in environments. It minimizes monitoring and enhances system efficiency. The system provides a reliable approach for real-time surveillance. It uses hardware. This makes it efficient. The ESP32-CAM and PIR sensor work together. They provide a low-cost solution, for surveillance.

II. Related Works

Several research works have been carried out in the field of smart surveillance systems using IoT technologies. Many surveillance systems are based on computers like Raspberry Pi. These systems can process images and stream video all the time. They can also detect objects. They are expensive and use a lot of power [6]. They are also hard to set up. Some people have made surveillance systems using Arduino. These systems are simple. Do not cost a lot. However, they often do not have built-in Wi-Fi which makes it hard to monitor things in time. It is needed to add parts to these systems so they can communicate with us. There are also surveillance systems that use cloud storage. These systems can. Analyze the video footage online. They are scalable. Can be accessed from anywhere. However, they need an internet connection to work properly. Sometimes these systems can be slow which is not good for real-time applications. Some systems use motion sensors to detect movement [7]. This helps reduce video recording. However, many of these systems still need to be monitored all the time. They do not have a good way to alert users. This is a need for a surveillance system that's small, affordable and energy-efficient. It should also be able to alert users in time. It uses the ESP32-CAM module. This module has a camera and Wi-Fi all in one unit. It also has a motion sensor, which helps take pictures when something moves [8].

The system can send alerts to users using Telegram, which's a messaging app. Many of these systems use computers like Raspberry Pi, which can do image processing and stream video [9]. They are expensive use a lot of power and are hard to set up. Some people have also made surveillance systems using Arduino, which's a simpler way to do things. These systems use camera modules. They do not have built-in wireless communication. On the hand systems that use IP cameras can stream video all the time but they use a lot of bandwidth and need someone to watch them all the time [10]. People are also looking at cloud-based surveillance systems because they can store and analyze data from anywhere. However, these systems need an internet connection and can be slow. Also, there are concerns about privacy because the data is stored on servers that are not controlled by the user. Many systems use motion detection with Passive Infrared sensors to avoid recording when nothing is happening. However, many systems still record all the time. Do not have a good way

to send alerts in real time. Some advanced systems use image processing or artificial intelligence to detect objects. These systems need a lot of computing power and are not suitable for simple and affordable devices [11].

The proposed system uses the ESP32-CAM module, which has a camera and Wi-Fi and a PIR sensor to take pictures when it detects motion and Telegram to send notifications to the user. This system addresses the problems mentioned earlier. The ESP32-CAM module is a part of this system and it helps to make the system more efficient and effective. The use of Telegram, for notifications is also a part of the system as it allows the user to receive alerts in real time. The ESP32-CAM module and Telegram work together to make the system more useful and user-friendly [12]. Surveillance systems have been getting a lot of attention lately because of all the technologies coming out. At first people used CCTV cameras that had to record all the time and someone had to watch them all the time. These systems are still used a lot. They are not very good at saving space and they need someone to always be paying attention. To make these systems better researchers started using computers like Raspberry Pi. These tiny computers can look at pictures and videos. They are expensive and use a lot of power so they are not great for people who do not want to spend a lot of money. Also setting them up and taking care of them can be hard for people who're not very good with technology [13].

Some people have also made surveillance systems using Arduino and other similar things. These systems are easier to set up and do not cost much. They often need extra parts to work with cameras and send information over the internet which means they need more hardware. Now that wireless technology is getting better people are starting to use modules like ESP8266 to make surveillance systems that can connect to the internet [14]. These surveillance systems let people watch what is going on from away but they do not have cameras built in so they are not very good for surveillance systems that need to look at pictures. Some researchers have also been working on ways to detect movement so that the surveillance systems can be more efficient. They often use sensors that do not use a lot of power and are good, at detecting people moving around. However, a lot of these surveillance systems do not send alerts away. They send a lot of information all the time, which can make the network slow. There are also some advanced systems that use the internet and artificial intelligence to detect and classify objects. These systems make the surveillance smarter. They need a lot of power to work and a good internet connection and they also make people worry about their privacy [15]. It seems to need a surveillance system that is simple does not cost a lot and does not use a lot of power. It should also be able to send alerts away without needing a lot of complicated equipment. The system uses a module called ESP32-CAM that has a camera and Wi-Fi and it also uses a special sensor to detect movement. This makes it a good way to monitor things without using a lot of power and without needing a lot of hardware. Surveillance systems, like this one is very useful. The ESP32-CAM module is a part of this system. Surveillance systems that use this module can be very efficient.

III. PROPOSED SYSTEM

A. System Architecture

The smart surveillance system is made up of a design that can find movement take pictures and send notifications right away. It uses few parts. The system has three parts: the part that senses things the part that processes information and the part that communicates. The part that senses things uses a sensor that checks the area all the time for any movement. When it finds something moving the sensor sends a signal that says something is there. The part that processes information is a computer called the ESP32-CAM module. It gets the signal from the sensor. Tells the camera to take a picture. The ESP32-CAM module also looks at the information. Controls the whole system. The part that communicates is part of the ESP32-CAM module. Can connect to the internet. When a picture is taken it sends the picture to the Telegram server on the internet. Fig. 1 show the block diagram of the proposed system.

B. Component Specifications

The selection of components for the proposed system was guided by the requirements for reliability, cost-effectiveness, and suitability for hazardous environment operation. Table I summarizes the key components and their specifications.

The smart surveillance system is made to find movement and take pictures and then send out notifications in time. It does all this with a few pieces of hardware. The system has three parts: the part that senses things the part that processes information and the part that communicates. The part that senses things uses a sensor called a Passive Infrared sensor. This sensor is always looking at the environment to see if anything is moving. When it

sees something moving it sends a signal to say that something is there. The part that processes information is a computer called the ESP32-CAM module.

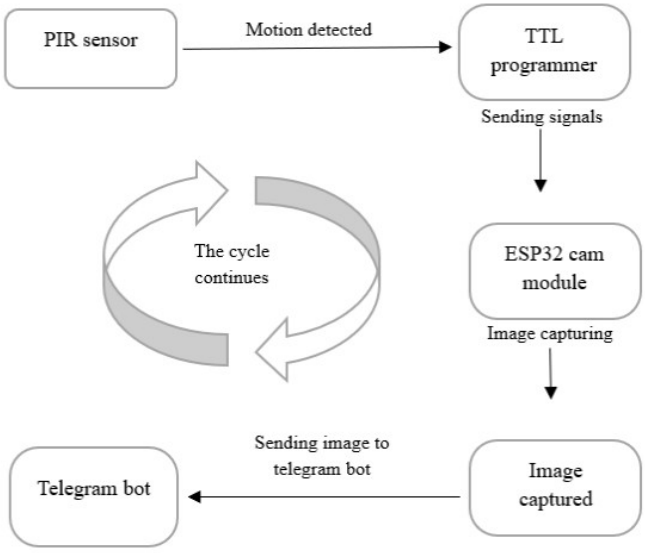

Figure 1. Block diagram of the proposed smart surveillance system

TABLE I. COMPONENT SPECIFICATIONS

Component	Model	Key specifications	Function
ESP32-CAM	AI-Thinker ESP32-CAM	240 MHz CPU, OV2640 Camera, Wi-Fi (802.11 b/g/n), 4MB PSRAM	Captures image, processes data, and sends it via Wi-Fi
PIR Sensor	HC-SR501	Operating Voltage: 5V, Detection Range: 3–7 m, Adjustable sensitivity	Detects motion and triggers the system
TTL Programmer	FTDI FT232RL	USB to UART, Supports 3.3V/5V logic	Used for uploading code to ESP32-CAM

C. Circuit Design

This is basically the idea of the circuit design of the proposed system. The ESP32-CAM module the PIR sensor and the TTL programmer are considered here. To make the system work correctly there is a need to connect everything and have a stable power supply, for the ESP32-CAM. Fig. 2 shows the circuit diagram of the proposed system.

The nRF24L01 wireless is connected to the ESP32 via the Serial Peripheral Interface (SPI) bus and it has been designed to handle very fast data transfer between the receiver and transmitter components. Table II shows the pin connection of the TTL programmer and ESP32 CAM microcontroller in details.

The connections, in the system are set up so the ESP32-CAM module, PIR sensor and TTL programmer can talk to each other. The PIR sensor gets its power from a 5V supply. The ground of the PIR sensor is connected to the ground as the ESP32-CAM module. The PIR sensor has an output pin that is connected to the GPIO13 pin of the ESP32-CAM module, which is used to detect motion. To program the system and send data back and forth TTL programmer is used. The TX pin of the FTDI module is connected to the U0R pin of the ESP32-CAM module and the RX pin of the FTDI is connected to the U0T pin of the ESP32-CAM module. This lets the FTDI and the ESP32-CAM module exchange data. The ground of the FTDI is also connected to the ground as the other parts and the VCC pin is connected to the 5V supply to power the ESP32-CAM module. When the code is uploaded to the system, the GPIO0 pin of the ESP32-CAM module is connected to the ground. This puts the ESP32-CAM module in flash mode.

After the code is uploaded, this connection is removed so the system can work normally. It is really important that all the connections are correct and the power supply is stable. If not, the system may not work right, it gets errors. The ESP32-CAM module and the PIR sensor and the TTL programmer all need to be connected to work properly.

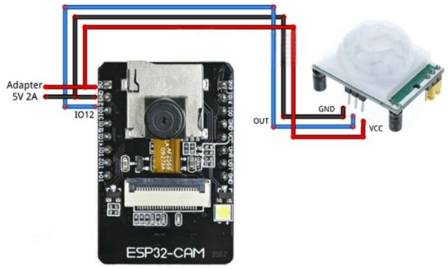

Figure 2. Circuit diagram of the proposed system

TABLE II. TTL PROGRAMMER TO ESP32 CAM PIN CONNECTIONS

Component	Pin	Connected To (ESP32-CAM)	Description
PIR Sensor	VCC	5V	Power supply for PIR sensor
PIR Sensor	GND	GND	Common ground
PIR Sensor	OUT	GPIO13	Motion detection signal input
TTL Programmer (FTDI)	TX	U0R (RX)	Serial communication (data to ESP32)
TTL Programmer (FTDI)	RX	U0T (TX)	Serial communication (data from ESP32)
TTL Programmer (FTDI)	GND	GND	Common ground
TTL Programmer (FTDI)	VCC	5V	Power supply to ESP32-CAM
ESP32-CAM	GPIO0	GND (during upload only)	Enables flash mode for programming

D. Working principle

The smart surveillance system works by detecting movement and sending pictures when something happens. It uses a sensor called a Passive Infrared sensor to watch the area around it. This sensor can tell when people or things are moving because they give off heat. When the sensor sees movement, it sends a signal to the ESP32-CAM module. The ESP32-CAM then turns on its camera. Takes a picture of what is happening. The picture is prepared to be sent to the user. The ESP32-CAM can connect to the internet using Wi-Fi. After taking the picture it sends the picture to the user's phone using the Telegram Bot API. The user gets a message away with the picture so they can see what is happening from far away. After sending the picture the system goes back to waiting and watching for movement. This way the system does not use much power and does not send unnecessary pictures. The smart surveillance system is like a camera that only takes pictures when something is happening. It is better, than a camera that takes pictures all the time because it saves power. It needs a power supply to work correctly. The sensor also needs to be set up right or it might take pictures when nothing is happening. If the power is not steady the ESP32-CAM might turn off and again which is not good.

E. Software Implementation

The software for the proposed system is made using the Arduino Integrated Development Environment. The ESP32-CAM module is programmed in Embedded C. This uses libraries for the camera, Wi-Fi and communication with the Telegram Bot API. First the ESP32-CAM connects to a Wi-Fi network. It uses credentials that are already set. After it connects the camera is set up with the resolution and frame size. This helps the image quality. How fast it sends. The PIR sensor is watched all the time. It is connected to a pin. When it detects motion the program takes a picture with the ESP32-CAM. The picture is changed into the format and sent over the internet. A Telegram Bot is added to the system. This bot sends the picture to the user. It uses a token and chat ID. This means the user gets the picture away. They do not need any apps. If something goes wrong like the Wi-Fi disconnects the system tries to fix it. It tries to reconnect and send the picture again. Delays are added to the system so it works smoothly and does not crash. The software is made to be easy to use and work well. It helps the surveillance system work in time and uses fewer resources. The ESP32-CAM software is designed to be simple and efficient. The ESP32-CAM system is made to be responsive and support real-time operation of the surveillance system. The software, for the ESP32-CAM is made to minimize resource usage.

F. System Advantages

The smart surveillance system that is being proposed has a lot of things going for it. It is not very expensive. It works well. The ESP32-CAM module is used in this system. This module has a camera and Wi-Fi in one unit. This means that there is no need to buy parts. The cost of the system is lower because of this. The system only takes pictures when it needs to. It does this when the PIR sensor finds movement. This way the system does not use a lot of power. It also does not send a lot of data. This is better than systems that take videos all the time. The

system can send messages to the user in time. It uses the Telegram platform to do this. The user gets a message away when something happens. The message has a picture in it. This means the user can watch what is going on from another place. They do not have to be there all the time. This makes the system very useful. The system is small and easy to set up. It can be used in places like homes and small offices. It can even be used in places that're far away. The system is also easy to take care of. You do not need to know a lot, about technology to use it. The smart surveillance system can be made better in the future. Object detection, video streaming and cloud storage is added. This means the system can be changed to fit the needs of the user. The system is flexible. Can be upgraded as needed. The smart surveillance system is a choice because of this.

IV. Results and Discussion

A. Experimental Setup

The smart surveillance system we are talking about was set up to see how it works in life. This system has an ESP32-CAM module, a PIR motion sensor. It is powered by a special 5V supply that does not change. This is where the lights are controlled. The PIR sensor is placed to monitor the area. This area is about 3 to 5 meters wide. The ESP32-CAM module was connected to a Wi-Fi network. This way it could send pictures. We also set up a Telegram Bot. We used a code and a chat ID to do this. We wanted to get alerts and pictures, from the ESP32-CAM module. When we were testing the system, we made it think someone was there. We did this by walking around the area that the PIR sensor was watching When it saw us the ESP32-CAM module took pictures. Sent them to us through Telegram. We did this time to see if the system always worked the same way how long it took to respond and if it was reliable. The ESP32-CAM module was stable because it needs a voltage to work right. At first the system would sometimes restart because the voltage was not stable. The smart surveillance system was tested times to see how it worked in different conditions. The ESP32-CAM module and the PIR sensor were a part of the smart surveillance system Fig. 3 shows the Hardware prototype of the proposed surveillance system.

B. Sensor performance

The PIR sensor was tested to see how well it works. We looked at things like how it can detect motion and how long it takes to respond. We also checked to see if it works well in situations. The PIR sensor was used inside a building to see if it can detect when people are moving around. The PIR sensor can detect people moving around within a meter like 3 to 5 meters. Table III shows the sensor performance metric.

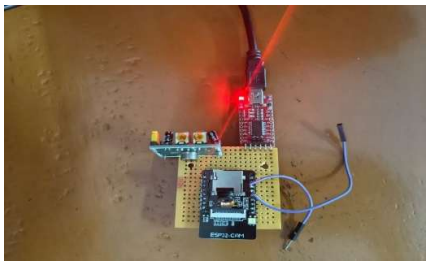

Figure 3. Hardware prototype of the proposed smart surveillance system using ESP32-cam

Table III. Sensor Performance Metrics

Parameter	Observed Value	Remarks
Detection Range	3 – 5 meters	Suitable for indoor monitoring
Response Time	< 1 second	Fast triggering of ESP32-CAM
Detection Accuracy	~90%	Reliable for human motion detection
False Trigger Rate	Low (occasional)	Due to temperature changes or pets
Power Consumption	Low	Energy-efficient operation

A. Wireless Communication Performance

The wireless communication of the proposed system was checked to see how well the wireless communication of the proposed system works. We looked at things, like how it takes to send something if the wireless communication of the proposed system works every time and if the network is stable. The ESP32-CAM uses its built-in Wi-Fi to send pictures to the user through the Telegram platform. When we tested the system, we connected the system to a Wi-Fi network in a room. It took around 3 to 5 seconds to send a picture after the

system detected motion. This includes the time it takes to take the picture process the picture and send the picture over the network. The system worked consistently when the Wi-Fi signal was strong. The wireless communication of the proposed system worked well. Table IV shows the communication performance of the proposed system.

TABLE IV. WIRELESS COMMUNICATION PERFORMANCE

Parameter	Observed Value	Remarks
Transmission Delay	3 – 5 seconds	Includes capture, processing, and sending time
Network Type	Wi-Fi (2.4 GHz)	Standard ESP32-CAM connectivity
Signal Range	~10 – 20 meters (indoor)	Depends on router and obstacles
Data Reliability	~92% success rate	Most images delivered successfully
Packet Loss	Low	Occurs during weak signal conditions
Reconnection Ability	Good	Automatically reconnects to Wi-Fi

B. System Performance Evaluation

The smart surveillance system was tested to see how well it works. We checked if it can detect motion accurately. It also needs to respond and send images fast. The systems reliability was also tested. The system was tested in homes to see how good it is at detecting motion. It also needs to send alerts to users. The test results show that the system works well in areas. It can detect motion. Send images most of the time. Sometimes it did not work perfectly. This was because of things like lighting and internet issues. The smart surveillance system still gives results. It has features like motion detection and image transmission. The systems reliability is good. The detection accuracy is also good. The response time is fast. Table V shows the system performance indicators, for the surveillance system.

TABLE V. SYSTEM PERFORMANCE INDICATORS

Performance Parameter	Measured Value
Motion Detection Range	3 – 5 meters
Detection Accuracy	~90%
Response Time	< 1 second
Image Transmission Delay	3 – 5 seconds
System Reliability	~92% success rate
Power Consumption	Low
Network Dependency	Moderate

C. Safety Monitoring Results

The system we tested was designed to keep an eye on safety. It did this by trying to detect movement and send alerts to the user on time. We tested it indoors to see how well it could spot people who might be intruders and send notifications quickly. The system actually worked well in most cases. It detected movement. Sent pictures to the user through Telegram. The alerts were reliable so the user could respond fast. The system only sent alerts when it actually detected movement. This meant the user did not get alerts. However, the system had some issues. Sometimes it sent alerts for no reason. This happened because of things like temperature changes or small objects moving around. The pictures were not super clear, in low light. This made it harder to figure out what was happening. These problems are shown in Figure 4, which shows the monitoring results of the system.

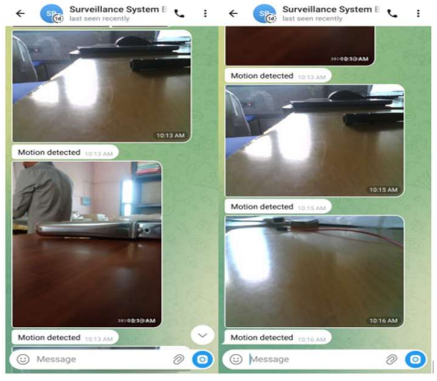

Figure. 4. Monitoring Result

D. Discussion

The smart surveillance system we tested works well for finding people moving around in real time and sending out alerts. It has a PIR sensor and an ESP32-CAM module that help it find people moving and take pictures away. We saw that it can do this in under one second which is great for keeping an eye on the surveillance system. The smart surveillance system talks to the internet which's important for how it works overall. It takes around 3 to 5 seconds to send pictures, which's okay for the smart surveillance system that needs to send out alerts right away. The smart surveillance system uses Wi-Fi and the Telegram platform, which makes it easy for people to get these alerts without needing any software. The smart surveillance system is very useful. The PIR sensor in the surveillance system is really good at detecting motion within a range of 3 to 5 meters. It can detect movement in a room 90 percent of the time which is very useful for the smart surveillance system in spaces. The smart surveillance system is great, at finding people moving around. However, the PIR sensor sometimes gets triggered by things that're not people, like sudden changes in temperature or animals. If we adjust the sensor correctly, we can reduce these triggers. The system is very reliable. Can capture and send images about 90 percent of the time. It only sends images when it needs to which helps save power and reduce data transmission.

V. CONCLUSIONS

In this paper, a smart surveillance system is implemented that is low-cost and efficient. It uses the ESP32-CAM module. The system uses a PIR sensor to detect motion. The system uses Wi-Fi to send pictures to the user through Telegram. It only works when it sees something moving. This helps save power and does not send data. The tests show that the system can see movement well. This is great for systems that do not have a lot of power or internet speed. The sensor that detects movement have some problems. The ESP32-CAM module can have power issues. If the power is not stable it may turn off and again. Also, the picture quality is not good when it is light because the ESP32-CAM module does not work well in the dark. The system also cannot tell if it is a person or an animal that is moving. This needs to be made better. It also sends alerts. They are not always on time. The camera and internet connection are all in one module. This makes the design simpler. It could see things moving and send data well. However, we found some problems. The system needs internet to work. The picture quality is also not good when it is dark. With these problems our system is a good and affordable way to watch things. In the end our system is good because it works well is simple and makes it good for homes, small offices and places that're far away. Other surveillance systems are not good, for these places because they are much work.

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