

XCLK Frequency Optimization on ESP32-CAM and Telegram-Based Smart Doorbell Systems

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ABSTRACT

This research is motivated by the limitations of the conventional doorbell system that only uses sound indicators without providing visual information and remote notifications. The research aims to design and implement an Internet of Things (IoT)-based smart doorbell system using ESP32-CAM and Telegram and analyze the influence of XCLK frequency optimization on system stability and response. The method used is a prototype through the stages of design, implementation, testing, and evaluation of the system. The system was developed using the ESP32-CAM as the main controller and camera module, push button as a trigger, buzzer as a voice indicator, and Telegram Bot as a medium for sending real-time visual notifications. Tests were conducted on XCLK frequency variations of 1 MHz, 5 MHz, 20 MHz, 50 MHz, and 100 MHz to evaluate system performance. The results showed that the 20 MHz XCLK frequency produced the most optimal performance with stable image capture, faster system response, and consistent notification delivery. Low frequencies cause response delays, while high frequencies trigger instability and system restarts. Thus, XCLK frequency optimization is based on [pay attention again to foreign terms in italics. In the same journal, if foreign terms still have to be italicized.significantly affect the reliability and performance of the ESP32-CAM-based smart doorbell system.

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1. Introduction

The development of the Internet of Things (IoT) has encouraged the implementation of home security systems that are integrated with internet networks and mobile devices [1], [3]. One of the applications is a smart doorbell that is able to provide visual information related to the arrival of guests. Conventional doorbell systems still have limitations because they rely only on sound indicators, making it difficult for users to monitor visitors when they are outside the home or away from the door area [1], [2]. This condition shows the need for a more responsive and informative monitoring system.

This study utilizes ESP32-CAM as the main controller. The ESP32-CAM is used because it has been integrated with the camera module and WiFi connectivity in one low-power device [5], [11]. In addition, Telegram is used as a notification medium [To integrate ESP32-CAM and users, the telegram platform is used. This platform is utilized to send visitor images captured by the ESP32-CAM directly to the

user's smartphone without the need for additional systems. Telegram was chosen among other similar applications because of its lightweight API and easy to integrate with embedded systems.]as it provides a lightweight API that is easy to integrate with embedded systems [2], [21]. The integration of the two allows the delivery of visitor images directly to the smartphone without the need for additional servers [1], [4].

Several previous studies have developed home security systems using ESP32-CAM and Telegram for door monitoring, facial identification, and the sending of visual notifications [1[This reference explains what they do.]], [4], [14], [15]. Other research shows that Telegram has relatively low communication latency on remote monitoring systems [21]. However, most of the research still focuses on the implementation of f[this is the implementation of the basic function, what does it mean? just explain, for example, it still focuses on the implementation of the tool.]basic information without evaluating the camera's internal parameters that affect device performance.

Based on the study, the analysis of the influence of XCLK frequency on the performance of ESP32-CAM cameras is still limited, especially in terms of operational stability, system response, and image quality [11], [18]. Previous research has also not discussed the influence of camera clock configuration on the risk of crashes, system restarts, and the success of image transmission [11]. In fact, XCLK frequencies have a direct effect on sensor initialization, image processing, and data communication stability [11], [18].

The novelty of this study lies in the evaluation of the effect of XCLK frequency variation on smart doorbell performance using an event-triggered system approach, where the process of taking pictures and sending notifications is only carried out when the bell button is pressed [1], [4]. This study focuses on analyzing camera stability, system response, and Telegram notification delivery performance on various XCLK frequency configurations.

Based on these problems, this study aims to design and implement a smart doorbell system using ESP32-CAM and Telegram and analyze the influence of XCLK frequency on system performance. The results of the research are expected to contribute to the development of a more stable, responsive, and efficient home security system.

2. Research Methods

This study uses a prototype method to support the process of designing, implementing, and evaluating the system in stages [1], [8]. This method was chosen because of the development of embedded systems and the Internet of [AT the beginning there was already an abbreviation for IoT, next under it no longer need to write the internet of things directly, just write IoT.] Things (IoT) requires hands-on testing of hardware, software, and network communication integrations [3], [8]. The research was directed at evaluating the influence of XCLK parameters on camera performance on Telegram-based smart doorbell systems.

The research stages began with the identification of problems and literature studies related to smart doorbells, IoT communication, and camera clock configurations [1], [3], [11]. The next stage includes hardware design, software implementation, clock parameter configuration, system testing, and analysis of test results. The development process is carried out iteratively so that each function can be evaluated and refined during implementation [1], [8].

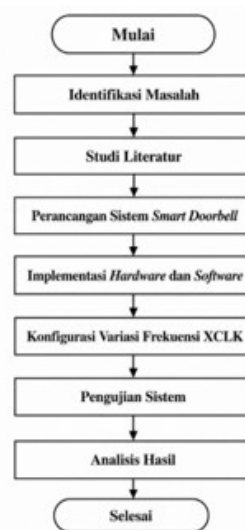


Figure 1. Research Stages.

The research flow in Figure 1 shows the stages of research carried out systematically starting from problem identification, literature study, system design, hardware and software implementation, configuration

of XCLK frequency variations, system testing, to analysis of test results to determine the most optimal frequency configuration [1], [8].

The prototype method and the explanation don't need to be entered until the bottom of the prototype explanation just delete it. Just explain the stages of the research from problem identification to analysis of the results.]The prototype method is used because it supports the system development process iteratively so that each function can be tested and evaluated during implementation [1], [8]. This approach makes it easier to adjust device configurations and test parameters without having to repeat the entire system design process [8], [13].

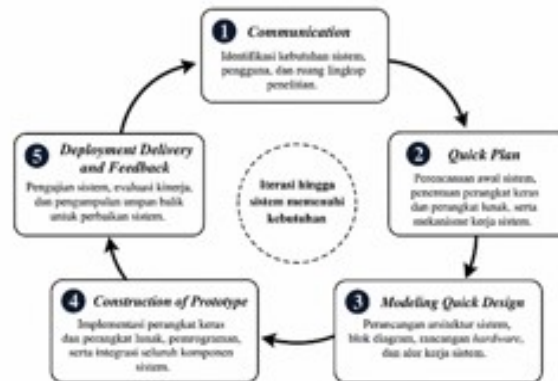


Figure 2. Prototype Method

Figure 2 illustrates the stages of the prototype method, which consist of communication, quick plan, modeling quick design, construction of prototype, and deployment, delivery, and feedback [1], [8]. These stages are carried out sequentially to ensure that the system development process is systematic and user-oriented. The communication stage focuses on identifying user requirements, while the quick planning stage defines the project scope and development strategy. The modeling quick design stage produces the initial system design, followed by prototype construction to implement the proposed features. Finally, deployment, delivery, and feedback are conducted to evaluate the prototype and refine the system until it meets the research objectives and user requirements.

1. Communication

The communication stage is carried out to identify the system requirements and define the scope of the research before the development process begins [1], [8]. During this stage, information is gathered to ensure that the proposed system addresses the intended objectives and user needs. The main requirements identified include the capability to visually monitor visitors using the ESP32-CAM module, transmit real-time notifications through Telegram Bots, establish internet connectivity via WiFi, and evaluate the effect of different XCLK frequencies on camera performance. In addition, this stage includes identifying the testing parameters and performance indicators that will be used to assess the functionality, reliability, and effectiveness of the proposed system during the evaluation process.

2. Quick plan

The quick plan stage focuses on planning the hardware and software components required for system development. The hardware consists of an ESP32-CAM, push button, buzzer, and power supply, while the software includes the Arduino IDE and the Telegram Bot API for programming and notification services [1], [4], [21]. During this stage, the interaction between hardware and software is also defined to ensure proper system integration. The system adopts an event-triggered approach, where image capture and notification transmission are activated only when the bell button is pressed, thereby improving operational efficiency [1], [4]. In addition, a testing plan is established by determining several XCLK frequency variations to evaluate their impact on camera performance and overall system effectiveness.

3. Modeling quick design

The quick design modeling stage is carried out by developing system block diagrams and hardware circuit designs that represent the overall architecture of the proposed system [8], [13]. This stage aims to provide a clear visualization of the system structure, data flow, relationships among hardware and software components, and the operational mechanism before the implementation process begins. The design serves as a blueprint to minimize development errors and ensure that all system requirements identified in the previous stages are properly integrated. The communication flow between components is illustrated through block diagrams that describe the sequence of input acquisition, data processing by the ESP32-CAM, image capture, and notification delivery to users via the Telegram Bot platform [1], [3], [21]. These diagrams also facilitate system validation and simplify the implementation, testing, and troubleshooting processes during prototype development.

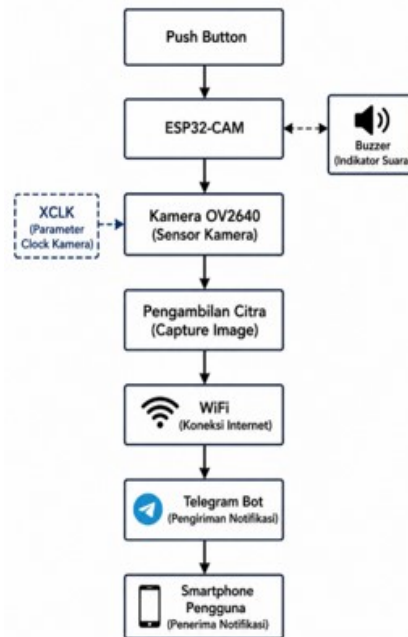


Figure 3. System Diagram Blocks

Based on the block diagram, the push button serves as the trigger for this block diagram to enter into the explanation of the research stages of system design. When the button is pressed, the ESP32-CAM activates the camera to take pictures, then transmits the image over the internet network to the Telegram Bot [1], [4], [21]. Buzzers are used as a local indicator that the system is active [1], [15].

The hardware design is then compiled based on the communication needs between components and the pin configuration used during the system implementation [4], [13].

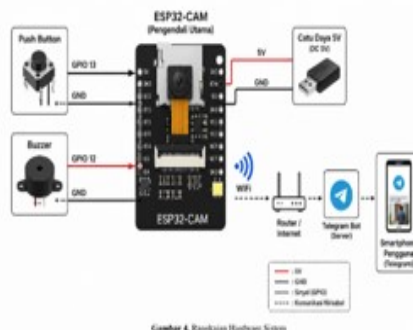


Figure 4. Hardware Networks

Figure 4 shows the relationships between the hardware components that comprise ESP32-CAM [this section goes into the section of the research stages that are hardware and software implementation.], push buttons, buzzers, and resources [4], [13]. Each component is connected according to the input and output functions to support the process of image capture and notification delivery [1], [4], [21].

Table 1. System Pin Configuration

Yes	Components	Pin	Function
1.	Push button	GPIO 13	Input
2.	Buzzer	GPIO 12	Output
3.	OV2640 Camera	Internal	Camera

4.	Wi-Fi	Internal	Communication
5.	Power Supply	5V, GND	Power Supply

Table 1 shows the pin configuration used on the smart doorbell system. The push button serves as the main input to activate the system's working process, while the buzzer is used as a local sound indicator when the bell button is pressed [1], [15]. The OV2640 camera integrated on the ESP32-CAM plays a role in the image acquisition process, while the built-in WiFi module is used for data communication and notification transmission via Telegram [4], [5], [21]. All components are supplied with power through 5V and GND pins so that the system can operate as designed.

4. Construction of Prototype

The construction of prototype stage is carried out *Stage construction of prototype*. This is done by implementing the system design into a device that can operate according to research needs [1], [8]. Hardware implementation includes the assembly of ESP32-CAM as the main controller, push button as input, *buzzer* as a sound indicator, as well as supporting resources according to the configuration that has been designed [4], [13].

The software implementation is carried out using the Arduino IDE which includes the configuration of the WiFi connection, the *Input* and *Output*, Telegram Bot API integration, as well as OV2640 camera initialization on ESP32-CAM [4], [5], [21]. The system is designed to be capable of image capture and send visual notifications via Telegram when the bell button is pressed [1], [4], [21].

At this stage, parameter configuration is also carried out *config.xclk_freq_hz* as the XCLK frequency setting to be used during testing [11], [18]. Such parameters allow for changes in the value *Clock* camera according to the variations that have been determined in the research scenario.

Before entering the testing stage, verification of the main functions of the system which includes network connection, camera initialization, image capture, buzzer activation, and notification delivery [1], [4], [21]. Verification is carried out to ensure that all system components and functions run according to design so that *the prototype* is ready for use at the *deployment delivery and feedback* stage [8], [13].

Table 2. XCLK Frequency Variations

Yes	Frequency	Unit of Description
1.	1 MHz	Low frequency
2.	5 MHz	Low frequency
3.	20 MHz	Standard frequency
4.	50 MHz	High frequency
5.	100 MHz	Very high frequency

The XCLK configuration is varied to obtain an overview of the camera's operational characteristics at several different clock levels [11], [18]. This approach allows an evaluation of the influence of the camera's internal parameters on image acquisition processes, data communication, and device response [11], [18]. Through comparison between configurations, it can be identified which clock value is most suitable to support the performance of smart doorbells based on ESP32-CAM and Telegram [1], [11].

Table 3. System Testing Parameters

Yes	Parameters	Indicator
1.	Camera Initialization	Succeed / Fail
2.	Image Quality	Good / Not Good
3.	System Response	Fast / Slow
4.	Notification Delay	Delivery Time

5.	Image Delivery	Succeed / Fail
6.	System Stability Stable	Stable / Unstable
7.	Crash/Restart	None / None

The parameters set are used as the basis for evaluating the performance of the device on each XCLK configuration tested [11], [18]. Observations were made on the operational aspects of the camera, data communication, and system reliability during the work process [11], [21]. The results of the evaluation of all these parameters were then used to determine the most suitable XCLK configuration to support the performance of smart doorbells based on ESP32-CAM and Telegram [1], [11], [18].

Data Analysis Techniques

The data analysis technique was carried out descriptively based on the results of observations obtained on each variation of XCLK frequency applied to the system. All test data were collected and compiled based on predetermined parameters, then compared to identify changes in the operational characteristics of the device in each configuration [11], [18]. The analysis focused on the system's ability to perform image acquisition, maintain camera stability, respond to user input, and support the process of sending notifications via Telegram [11], [18], [21].

The results of the observation were further evaluated to determine the relationship between the change in camera clock frequency and the performance of the ESP32-CAM on the smart doorbell developed [11], [18]. Comparisons between variations were carried out to obtain an idea of the most suitable operational conditions based on the reliability, responsiveness, and stability aspects of the device. Through this approach, it can be determined that XCLK configuration provides optimal performance in supporting monitoring and notification functions on ESP32-CAM and Telegram-based smart doorbell systems [1], [11], [21].

3. Results and Discussion

In this study, an *Internet of Things* (IoT)-based *smart doorbell* was successfully implemented which integrates ESP32-CAM, push buttons, buzzers, WiFi connections, and Telegram Bot [1], [4], [21]. (Not to mention, the G5 is a prototype of the smart doorbell. The results of the implementation of the System are designed to provide visual information on the arrival of guests through smartphones so that the monitoring process can be carried out remotely [1], [3].

The working mechanism starts when the *push button* is pressed, then the ESP32-CAM activates the buzzer and the OV2640 camera to take images [4], [5]. The acquisition results are then sent over the WiFi network to the Telegram Bot and forwarded to the user's account in the form of visual notifications [1], [4], [21]. This process allows guest arrival information to be received in *real-time* [21].

The implementation results show that all components operate as planned. The functions of input, data processing, network communication, and notification delivery are carried out in an integrated manner so that *the prototype* is able to carry out the main functions of the *smart doorbell* well [1], [no need to use a reference because this is the result of its own research.][4]. This implementation is the basis for [delete.]evaluate the effect of XCLK configuration on device performance [11], [18]. The results of the implementation of the device used in this study are shown in Figure 5.

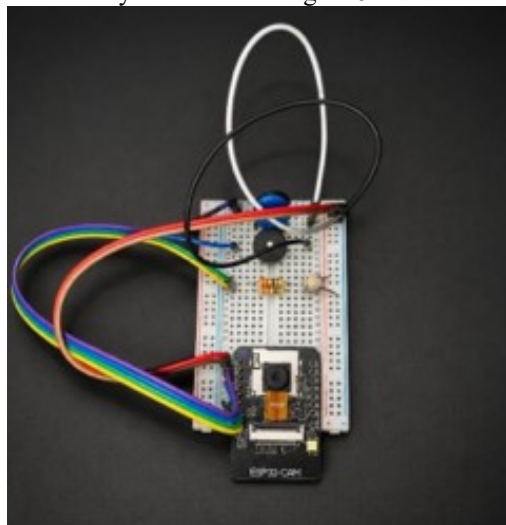


Figure 5. Prototype Smart doorbell.

The implementation of the device shows the successful integration of various key components in forming a smart doorbell that is able to carry out the visitor monitoring function automatically [1], [4]. ESP32-CAM acts as a control center that coordinates the process of receiving input, image acquisition, and data communication over the internet network [4], [5]. The realized design allows interaction between devices to take place in a structured manner, from system activation via push button to conveying information to users via Telegram Bot [1], [21].

The device architecture supports a working mechanism that connects input, processing, and output functions in a single operational unit [4], [13]. The push button is used as an initial trigger to execute the guest arrival detection process, while the *buzzer* provides local feedback when the device is active [1], [15]. Next, the camera module takes images which are then forwarded via WiFi connection to the Telegram service [4], [21]. The integration allows visual information to be sent automatically to the user so that the monitoring process can be carried out without location limitations [1], [3]. The configuration applied shows that each component has a complementary role in realizing a smart *doorbell* system that is able to provide more informative and connected guest arrival information.

Integration with Telegram Bot allows the device to function as a remote monitoring medium that can be accessed through the user's smartphone [1], [21]. Once the image-taking process is complete, the visual information is sent over the internet network and forwarded to the Telegram account that has been connected to the device [4], [21]. This mechanism allows users to quickly obtain guest arrival information without having to be in the same location as the smart doorbell [21]. In addition to being a means of notification, Telegram also acts as a communication interface that supports the automatic transmission of image acquisition data from devices to users [2], [21].

The implementation of visual notifications that users receive through the Telegram application is shown in Figure 6.



Figure 6. Telegram Notification Display.

The implementation of the Telegram service allows the delivery of guest arrival information directly to the user via a smartphone device connected to the Telegram Bot account [2], [21]. When the bell button is pressed, the device performs an image acquisition process and sends the camera capture over the internet network as part of the notifications that users receive [1], [4], [21]. The information received reflects the actual conditions in the entrance area so that users can know the whereabouts of visitors without having to check directly [1], [21].

The integration of communication media results in a more effective remote monitoring mechanism than conventional doorbells that rely only on sound indicators [1], [3]. The imagery delivery feature supports security needs by providing visual information that can be used to identify visitors before further interaction [4], [14]. The use of instant messaging platforms also provides ease of implementation because it does not require special applications or additional server infrastructure [2], [21]. Thus, the use of Telegram not only serves as a means of notification, but also enhances the system's ability to provide monitoring services that are more responsive, informative, and easily accessible to users [1], [21].

Before evaluating the XCLK frequency variation, functional testing is first carried out to ensure that all key features on the device have operated according to design. This test includes verification of input functions, image capture processes, voice indicator activation, network connectivity, and notification delivery mechanisms via Telegram [4], [21]. The stage aims to ensure that each component can work in an integrated manner so that the XCLK parameter evaluation process can be carried out on the condition of the device that has been functioning properly [8], [13]. The results of the functional testing of the system are shown in Table 4.

Table 4. System Functional Test Results.

Yes	Test Conditions	Buzzer Response	Telegram Notifications
1.	Button pressed Active	Active	Successful
2.	Button not pressed	Inactive	Not delivered
3.	Repeated emphasis	Active	Successful but slow
4.	Unstable WiFi connection	Active	Sent late

Functional evaluation shows that all components integrated in the smart doorbell are able to carry out their duties according to the design that has been set. The activation process through push buttons, image acquisition using cameras, voice indicators, network connectivity, and sending notifications via Telegram took place in an integrated manner without any interference with the main functions of the device [4], [21]. The integration between hardware and software results in a consistent working mechanism so that each stage of the operation can be executed well [1], [13]

The findings indicate that the prototype has met the functional needs of an IoT-based guest arrival monitoring system [1], [3]. The reliability of the basic functions that have been verified is an important foundation for further research at the XCLK parameter evaluation stage. With operational conditions that have been running according to specifications, the effect of configuration changes *Clock* cameras can be more objective because they are not affected by implementation problems or malfunctions in other supporting components [11], [18].

The operational characteristics of the camera on the ESP32-CAM are affected by the configuration *Clock* used during the image acquisition and processing process [11], [18]. Changes in the XCLK value have the potential to affect the way the device performs the image capture function, responds to input, maintains work stability, and communicates data to the notification platform [11], [18], [21]. Therefore, the implementation of multiple configurations *Clock* It is necessary to gain a more comprehensive understanding of the behavior of devices under various operational conditions. Evaluation of these aspects is important to identify the relationship between the camera's internal parameters and smart performance *Doorbell* developed [11], [18].

The results of observations on each XCLK configuration are presented in Table 5. namely the XCLK Frequency Variation Test Results.

Table 5. XCLK Frequency Variation Test Results.

Yes	XCLK (MHz)	Camera	System
1.	1	Very slow	Delayed
2.	5	Slow	Stable
3.	20	Stable	Responsive
4.	50	Inconsistency	Unstable
5.	100	Fail	Restart

The operational characteristics of the device show a close relationship between the XCLK configuration and the camera's ability to carry out the image acquisition process [11], [18]. *Clock* The camera serves as a synchronization source that regulates the working rate of the OV2640 sensor so that changes in its value directly affect the process of reading image data [11], [18]. When the clock value is in the low range, the acquisition process takes place slower and has an impact on delayed device response. This condition

indicates that the working speed of the sensor is not able to support the needs of data processing optimally, so the information produced takes longer to be forwarded to the next stage.

Configuration improvements *Clock* resulting in better characteristic changes than the previous range. This phenomenon is related to the increasing speed of synchronization between the camera sensor and the microcontroller so that the image taking process can take place more efficiently [11]. The impact is not only seen on the device's ability to respond to input from the bell button, but also on the smooth process of sending information to the notification service [21]. Maintained operational stability indicates that the device's resources are still able to accommodate the workload generated by the camera sensor.

The balance between speed and operational reliability is seen in the intermediate configuration, where the image acquisition process is stable and device response is maintained. These conditions indicate that the camera clock is operating at a range that corresponds to the characteristics of the OV2640 sensor and the processing capabilities of the ESP32-CAM [11], [18]. Good synchronization allows image data to be processed and forwarded consistently without interfering with the key functions of the smart doorbell. This situation becomes important because the effectiveness of the system depends heavily on the device's ability to capture visual information and convey it to the user in a relatively short time [1], [21].

Configuration changes towards a higher range show symptoms of decreased operational stability. This phenomenon is related to the increasing work rate of sensors that are no longer balanced with the data processing and communication capabilities of the device [11], [18]. As a result, the image acquisition process becomes inconsistent and the notification function has the potential to be affected because the data generated cannot always be processed optimally. The stability of the device is affected by the system's ability to maintain synchronization between the camera, memory, and microcontroller during the process [11].

The most extreme characteristics appear at the highest configuration, where the camera cannot operate normally and the device undergoes repeated restarts. This condition indicates a discrepancy between the given clock and the working ability of the sensor and its supporting subsystems [11], [18]. This phenomenon shows that an increase in the value of XCLK does not necessarily result in an increase in performance, but rather must be adjusted to the operational limits of the device. Thus, the camera clock configuration has an important role in determining the reliability of smart doorbells because it affects the quality of image acquisition, device response, data communication continuity, and the success of delivering notifications to users [11], [18], [21].

The findings of the study show that the XCLK configuration has a direct influence on the operational characteristics of the ESP32-CAM, in particular on the image acquisition process and the stability of the device [11], [18]. Theoretically, XCLK serves as the main clock source for the OV2640 camera sensor that determines the readout speed and synchronization of image data before it is processed by a microcontroller [11]. A clock value that is too low can reduce the rate of image acquisition resulting in a slower device response, while a value that is too high can potentially cause synchronization mismatches between sensors, memory, and processors [11], [18]. These characteristics are in line with the working principle of embedded systems which demand a balance between processing speed and the ability of the hardware to handle data flows stably [18].

The results obtained are also in line with various previous studies that used ESP32-CAM as an image acquisition device in Internet of Things applications [4], [5], [18]. A number of studies report that the stability of the camera is strongly influenced by the clock configuration used, as these parameters are directly related to the process of sensor initialization and image data transfer [11], [18]. When the configuration is outside the appropriate working range, the device is prone to operational disruptions such as image capture failure, decreased performance consistency, and system restarts [11]. The findings reinforce the view that clock parameter optimization is an important aspect in the development of ESP32-CAM-based applications [11], [18].

The main difference between this study and some previous studies lies in the focus of the evaluation that specifically analyzes the effect of XCLK variations on the performance of smart doorbells integrated with Telegram services. Most previous studies have focused on the implementation of monitoring functions and notification delivery, while analysis of the camera's internal parameters is still relatively limited [1], [4], [21]. Through this approach, this study not only evaluates the success of the implementation of the device, but also provides an understanding of the relationship between the camera clock configuration and the system's ability to perform the visitor monitoring function reliably. Thus, the results obtained contribute additionally to the development of ESP32-CAM-based systems that require a balance between image acquisition speed, operational stability, and data communication [11], [18], [21].

4. Conclusion

The implementation of smart doorbells based on ESP32-CAM and Telegram resulted in a visitor monitoring system that is able to integrate image acquisition functions, network communication, and visual notification delivery in one connected platform [1], [4], [21]. The integration between components allows

guest arrival information to be received by users via Telegram effectively, thus supporting the need for remote monitoring in Internet of Things (IoT)-based home environments [1], [3], [21]. The developed architecture suggests that the use of instant messaging services can be a practical and easy-to-implement alternative to support camera-based security and monitoring systems [2], [21].

Evaluation of the XCLK variation proves that the camera clock parameters have a significant influence on the operational characteristics of the ESP32-CAM [11], [18]. Configuration changes affect the device's ability to perform image acquisition, maintain work stability, respond to input, and support the process of sending information [11], [18], [21]. A clock range that is too low leads to a decrease in responsiveness, while a value that is too high results in operational interruptions and camera malfunctions [11], [18]. Among the configurations tested, the 20 MHz value provides the best balance between stability and working speed, making it the most suitable to support the performance of ESP32-CAM and Telegram-based smart doorbells. These findings confirm the importance of XCLK optimization as one of the factors that determine reliability

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