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Design of an Infrared Detection System Integrated with a 2.4GHz Patch Antenna for Wireless Surveillance Applications

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Abstract: This project describes the design and development of an infrared (IR) sensor system combined with a 2x2 rectangle microstrip patch antenna operating at 2.4GHz for wireless communication in surveillance applications. The system uses infrared technology to detect obstacles or intrusions by capturing IR radiation from objects. The detected signals are processed and transmitted wirelessly through a compact 2.4 GHz patch antenna, allowing real - time monitoring over a reliable connection. By combining infrared sensors with RF communication, the system improves remote monitoring, reduces the need for wired infrastructure and allows flexible use in various environments. The 2.4 GHz frequency band was chosen because it is widely available, affordable and works well with existing wireless systems. The antenna is designed to provide high gain, bandwidth and efficiency for stable data transmission. This system is ideal for security and surveillance tasks such as border monitoring, industrial safety and smart environments. It offers benefits like low power use, cost - effectiveness, a compact design and reliable detection, making it a strong alternative to traditional surveillance systems.

Keywords: Tang Nano 9K FPGA, Patch Antenna, Surveillance, Infrared Sensor, Intrusion Detection, RF Communication

I. INRODUCTION

Security and surveillance have become more important as concerns about safety grow in public areas, industrial sites, and smart infrastructure. Most traditional systems utilize wired networks and off-the-shelf sensors, which can limit their flexibility, scalability, and effectiveness in dynamic environments. To overcome these issues, there is a need for compact, smart, and wireless surveillance solutions that are more reliable and can respond in real time. This project presents a compact, intelligent, wireless surveillance system designed to overcome the rigidity and scalability issues of traditional wired security networks. At its core, the system uses a custom-designed infrared (IR) sensor, built at the component level, to provide improved intrusion detection sensitivity and accuracy compared to generic commercial modules. To eliminate complex wiring, it incorporates a 2.4 GHz microstrip patch antenna that enables real time wireless signal transmission while perfectly balancing range, bandwidth and power consumption. Additionally, a Tang Nano 9K FPGA drives system control and signal processing in real time, leveraging parallel processing to achieve high-speed data handling and faster response times than standard microcontroller-based designs. Ultimately, by combining a custom sensor, efficient RF communication and FPGA processing, this project provides a high performance, cost – effective solution ideal for public safety surveillance, industrial site security and smart infrastructure environments.

II. LITERATURE REVIEW

A. Infrared Sensor and Photodiode Technologies

Recent research on infrared (IR) sensing technologies mainly focuses on improving sensitivity, responsivity, signal-to-noise ratio and response speed for imaging, healthcare and detection applications. Advanced IR LEDs, graphene – based photodiodes, InGaAs sensors, thermopile sensors and nano-antenna IR detectors demonstrated improved quantum efficiency and faster response for near – infrared applications [1], [4], [5], [6], [8], [9], [13]. However, challenges such as environmental noise, limited wavelength tuning, and detectivity limitations remain.

B. Healthcare and Biomedical Monitoring Systems

IR – based biomedical systems were developed for heart rate, blood pressure and photoplethysmography monitoring using IR photodiodes and thermal sensors [3], [5]. These systems achieved high accuracy, low cost and real-time monitoring capabilities. However, sensor, stability, calibration and signal interference continue to affect overall performance.

C. Human Detection and Security Systems

Several studies proposed PIR and thermal IR sensor-based systems for human detection, motion tracking, and security applications [7], [11], [14], [16], [17], [18]. These systems provided high detection accuracy, low power consumption, and privacy-preserving monitoring. However, false triggering, environmental disturbances, and limited sensing range reduced reliability in practical environments.

D. Transportation and Communication Applications

IR sensors were also used in obstacle detection, railway monitoring, and wireless communication systems [2], [10], [12], [19]. These systems improved safety and communication efficiency using IR sensors, Zigbee modules, GPS, and antennas. However, communication range limitations and environmental effects remain major challenges.

E. Artificial Intelligence and Infrared Image Processing

AI-based infrared systems and image-processing techniques improved object detection, clutter suppression, and surveillance accuracy in infrared imagery [15], [20]. Although these methods enhanced detection performance, computational complexity and real-time processing remain key limitations.

F. Overall Analysis

The reviewed literature shows that infrared-based technologies provide efficient, low-cost, non-contact, and privacy-preserving solutions for sensing and monitoring applications. Most systems improved accuracy, response speed, and energy efficiency, while future research mainly focuses on improving robustness, intelligent processing, and real-time performance.

Overall Analysis

Ref	Frequency / Wavelength	Range	Sensitivity	Response Time
[1]	850 nm, 940 nm	Not specified	5 mV, 2 mV	Improved frequency response
[2]	IR LED based	0.156 m	68% accuracy	Not specified
[3]	2.34 Hz	Fingertip and wrist sensing	Gain 101 per stage, Accuracy > 95%	Not specified
[4]	50 kHz – 2 MHz	Not specified	Noise reduction >20 dB	Not specified
[5]	NIR	Not specified	0.7 A/W	61 µs
[6]	NIR InGaAs	Not specified	80% quantum efficiency	Not specified
[7]	Thermal IR	Indoor human detection	95–100% accuracy	Not specified
[8]	0.8–1.7 µm, 850 nm, 940 nm, 1.55 µm	10^{13} Jones detectivity	65 A/W	~1 ps
[9]	Infrared sensor	Human detection	140 V/W	17 ms
[10]	2.5 GHz	Wireless communication range	>7 dB gain, 25 dB return loss	Not specified
[11]	PIR,50Hz	1–13 m	0.4–0.8 m tracking error	Not specified
[12]	780 nm – 50 µm	2 cm – 4.5 m	2 cm sensing distance	Not specified
[13]	3–5 µm, 8–14 µm	MWIR or LWIR imaging	Lower than cooled IR detectors	High-speed sensing
[14]	PIR sensor	1–2 m	120°–180° detection angle	Not specified
[15]	LWIR imagery	Infrared surveillance	69.13% robustness	Not specified
[16]	Thermal IR	3–5 m	+5°C to +50°C	Not specified
[17]	PIR sensor	Limited PIR range	High sensitivity	<200 ms
[18]	PIR sensor	5 m	3.5–5 V output	~10 s alarm
[19]	Infrared communication	10 – 100 m	20–40 bit/s, 100+ bit/s	Not specified
[20]	Infrared image sequences	Complex scene detection	F1 ≈ 0.98	~1.85

III. APPLICATIONS

1) Industrial Automation and Logistics:
   - Real – time object counting on conveyor belts.
   - Wireless inventory tracking using the 2.4 GHz ISM band.
2) Smart Security Systems:
   - Wireless perimeter fencing using IR tripwires.
   - Low – latency alert transmission via directional patch antenna to avoid interference.
3) IoT and Smart Infrastructure:
   - Smart parking occupancy detection.
   - Automated lighting control in large warehouses based on motion or presence detection.
4) Advanced Robotics:
   - Wireless proximity sensing for autonomous mobile robots (AMRs)
   - Hardware – accelerated sensor fusion (adding more sensors to the FPGA fabric)

IV. CONCLUSION AND FUTURE SCOPE

The proposed project demonstrates the design and implementation of an infrared (IR)-based surveillance system integrated with a 2. 4 GHz microstrip patch antenna for efficient wireless communication. A custom IR sensor is developed to improve detection accuracy and reliability, while the wireless module enables real-time monitoring without requiring complex wiring. Using The Tang Nano 9K FPGA board ensures fast signal processing, flexibility and reliable system performance. Overall, the system provides a compact, cost-effective and efficient solution suitable for modern surveillance applications such as security monitoring, industrial security and smart environments.

In the future, the system can be improved by integrating artificial intelligence and machine learning techniques to improve detection accuracy and reduce false alarms. The inclusion of multi-sensor fusion, such as combining infrared sensors with cameras or radar, can further increase reliability. Additionally, extending communication using long-range technologies such as LoRa or Sub-GHz networks can enable large-scale deployment. Improvements in antenna design, power optimization and IoT/cloud integration can also provide better coverage, remote accessibility and smarter data analysis, making the system more advanced and adaptable to next-generation intelligent surveillance systems.

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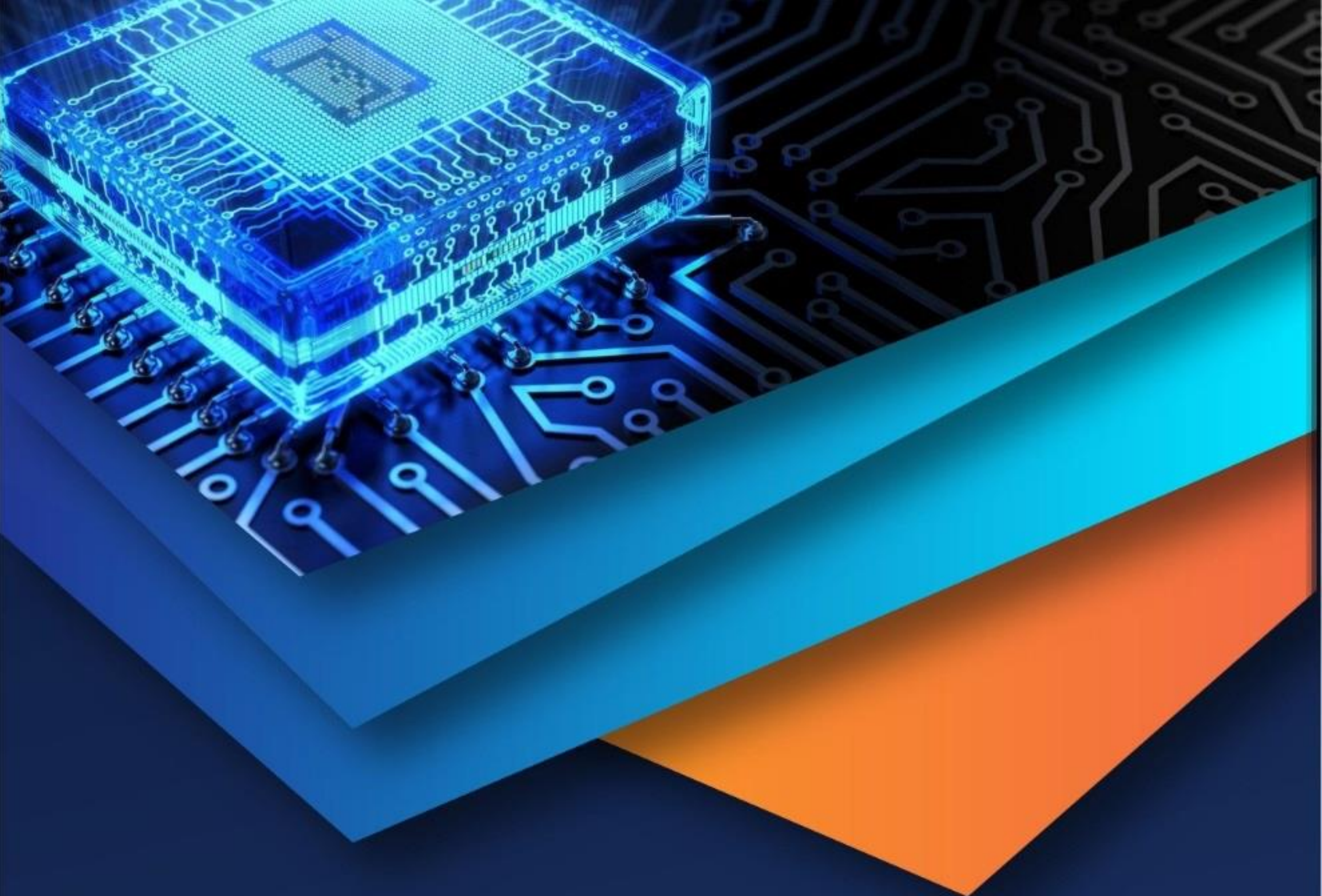

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