Synchronized Multi-Sensor Motion Capture System for Wildlife Data Collection

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Abstract— This proposal presents the design and implementation of a synchronized multi-sensor motion capture system using Raspberry Pi embedded platforms. The system will detect motion and automatically trigger synchronized data acquisition across multiple sensing modalities including RGB imaging, thermal imaging, and range sensing. The captured data will be timestamped and stored in a structured format on local storage devices for later analysis. The project aims to explore low-cost embedded hardware integration, synchronization methods, multimodal sensing, and practical device prototyping. The proposed prototype can support future applications in robotics, smart environments, surveillance systems, and edge AI research.

I. Introduction

Embedded sensing systems increasingly rely on combining multiple sensing modalities to improve environmental awareness and data reliability. RGB cameras provide visual information, thermal cameras capture temperature variations, and range sensors provide distance and motion information. However, synchronizing data acquisition across these heterogeneous sensors remains a practical challenge in low-cost embedded platforms.

This project proposes the development of a compact synchronized sensing platform built around Raspberry Pi 5 and Raspberry Pi Pico microcontrollers. The system will detect motion events and trigger synchronized acquisition across all connected devices for a short acquisition window of approximately five seconds.

II. Project Objective

a) Develop a synchronized multi-sensor embedded prototype.
b) Detect motion automatically using connected sensing devices.
c) Trigger synchronized acquisition across RGB, thermal, and range sensors.
d) Store timestamped multimodal datasets in structured formats.
e) Investigate practical synchronization techniques for low-cost embedded systems.
f) Create a scalable architecture for future sensing experiments.

III. Literature Review

Multimodal sensing systems have become increasingly important in embedded systems, robotics, smart environments, and edge artificial intelligence applications. Combining multiple sensing modalities such as RGB imaging, thermal imaging, and range sensing improves environmental awareness and system reliability compared to single-sensor solutions [1]. Recent advances in low-cost embedded computing platforms, particularly the Raspberry Pi ecosystem, have enabled the development of compact and scalable sensing devices for research and prototyping purposes [2].

RGB cameras are widely used in computer vision applications because they provide rich visual information suitable for object detection, motion analysis, and scene understanding [3]. However, RGB imaging alone is often sensitive to environmental conditions such as low illumination, shadows, or weather effects. Thermal cameras overcome some of these limitations by detecting infrared radiation rather than visible light, allowing reliable detection of temperature variations even in dark or visually complex environments [4]. Thermal sensing has been applied successfully in surveillance, human activity monitoring, and occupancy detection systems [5].

Range sensing technologies such as Time-of-Flight (ToF) sensors and radar sensors provide additional spatial information by measuring object distance and motion. Sensors such as the VL53L0X ToF module are compact, inexpensive, and suitable for embedded sensing applications [6]. Radar-based sensing has also become increasingly popular for motion detection and environmental monitoring because it operates reliably under different lighting conditions and can detect movement through certain materials [7]. Integrating these sensing modalities into a synchronized system can significantly improve sensing robustness and provide richer datasets for analysis.

Sensor synchronization is a major challenge in multimodal embedded systems. Different sensing devices often operate at different sampling rates and communication protocols, leading to timing inconsistencies and data misalignment [8]. Previous research has explored hardware-triggered synchronization and timestamp-based software synchronization techniques to address these issues [9]. Hardware synchronization methods generally provide higher timing accuracy but require additional circuitry and coordination mechanisms, while software synchronization approaches are easier to implement but may introduce latency [10].

Embedded platforms such as Raspberry Pi and microcontroller-based systems are commonly used for multimodal sensing research due to their flexibility and low cost [11]. Raspberry Pi Pico boards provide efficient low-level control for interfacing with sensors, while Raspberry Pi 5 offers sufficient processing power for coordinating data acquisition and storage tasks [12]. Several studies have demonstrated the use of Raspberry Pi systems for edge AI, environmental monitoring, and synchronized sensing applications [13].

Data storage and structured dataset generation are also critical aspects of multimodal sensing systems. Timestamped and synchronized datasets are essential for machine learning, robotics, and sensor fusion research [14]. Proper organization of multimodal data improves reproducibility and simplifies later analysis [15]. This proposed project builds upon these existing developments by creating a low-cost synchronized sensing platform capable of coordinated acquisition from RGB, thermal, and range sensing devices.

Overall, current literature demonstrates strong interest in multimodal sensing and embedded prototyping, but there remains a need for accessible and scalable low-cost systems that support synchronized sensing across heterogeneous devices. The proposed project aims to address this gap by developing a practical embedded prototype suitable for experimentation and future research applications.

IV. Proposed Hardware

The proposed prototype will primarily use hardware already available for the project. Additional sensing devices may be integrated during development if required.

a) Raspberry Pi 5
b) Raspberry Pi Pico 2 boards
c) RGB camera module
d) Thermal camera module
e) VL53L0X Time-of-Flight range sensors
f) MicroSD card / external storage devices

V. Methodology

The Raspberry Pi 5 will function as the primary coordination and processing unit, while Raspberry Pi Pico boards will handle low-level sensor interfacing and triggering. Once a motion event is detected, the system will simultaneously activate all connected sensors for a predefined acquisition period.

Captured data streams will be timestamped to maintain synchronization across sensing modalities. The collected data will be stored in structured folders with associated metadata including acquisition timestamps, sensor type, and capture settings. The system architecture is presented in Figure 1.

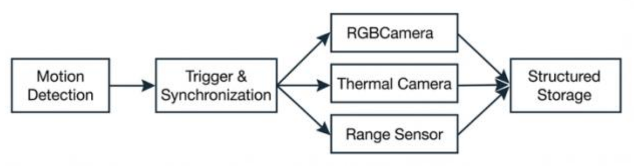

Figure 1: Proposed system architecture

VI. Responsible innovation

This project promotes responsible innovation by developing a low-cost and modular sensing platform using energy-efficient embedded hardware such as Raspberry Pi and Raspberry Pi Pico devices. The system is designed to collect data only when motion is detected, helping reduce unnecessary power consumption, storage usage, and processing overhead. The modular architecture also supports reuse and future upgrades, reducing electronic waste and improving the long-term sustainability of the prototype.

The project also considers responsible data collection and ethical use of sensing technologies. Any future deployment involving people or public environments would require appropriate data protection and ethical considerations, particularly when using RGB and thermal imaging. Overall, the proposed prototype aims to support accessible, sustainable, and practical embedded systems research while considering its broader social and environmental impact.

VII. Author bio(s) / experiences

I am a researcher and software engineer working in the field of Artificial Intelligence and Machine Learning, with a PhD in Computer Science. I am currently working as a Research Software Engineer at the University of Oxford. My professional background includes engineering-focused projects in industrial automation and AR/VR technologies for training and simulation within manufacturing industries. These projects have provided extensive experience in embedded systems, real-time data processing, software engineering, and applied AI solutions.

More recently, my research interests have shifted toward the application of AI technologies in wildlife conservation at the University of Oxford. My motivation for working in this area comes from the growing need to protect natural habitats and endangered species, which are increasingly threatened by environmental change and human activity. While much of modern technological innovation is driven by commercial and industrial objectives, I believe that AI and sensing technologies can also play an important role in supporting conservation efforts and sustainable environmental research. This motivates me to explore practical, low-cost sensing systems that can contribute to ecological monitoring and wildlife protection.

VIII. Acknowledgements

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IX. References

[1] R. Siegwart, I. Nourbakhsh, and D. Scaramuzza, *Introduction to Autonomous Mobile Robots*, MIT Press, 2011.

[2] E. Upton and G. Halfacree, *Raspberry Pi User Guide*, Wiley, 2016.

[3] R. Szeliski, *Computer Vision: Algorithms and Applications*, Springer, 2010.

[4] H. Budzier and G. Gerlach, *Thermal Infrared Sensors: Theory, Optimisation and Practice*, Wiley, 2011.

[5] M. Teutsch and W. Kruger, "Classification of moving objects from thermal infrared images," *Journal of Infrared Physics & Technology*, vol. 54, no. 4, pp. 281–287, 2011.

[6] STMicroelectronics, "VL53L0X Time-of-Flight Ranging Sensor Datasheet," 2023.

[7] F. Fioranelli, M. Ritchie, and H. Griffiths, "Performance analysis of centroid and SVD-based techniques for personnel recognition using multistatic micro-Doppler radar," *IET Radar, Sonar & Navigation*, vol. 10, no. 7, pp. 1211–1219, 2016.

[8] H. Kopetz, *Real-Time Systems: Design Principles for Distributed Embedded Applications*, Springer, 2011.

[9] A. Burns and A. Wellings, *Real-Time Systems and Programming Languages*, Addison-Wesley, 2009.

[10] J. Eidson, *Measurement, Control, and Communication Using IEEE 1588*, Springer, 2006.

[11] D. Molloy, *Exploring Raspberry Pi*, Wiley, 2016.

[12] Raspberry Pi Foundation, "Raspberry Pi Pico Documentation," 2024.

[13] A. Reghenzani, F. Cremonesi, and M. Cereda, "Edge computing with Raspberry Pi: A practical study," *Electronics*, vol. 10, no. 18, 2021.

[14] S. Thrun, W. Burgard, and D. Fox, *Probabilistic Robotics*, MIT Press, 2005.

[15] Y. LeCun, Y. Bengio, and G. Hinton, "Deep learning," *Nature*, vol. 521, pp. 436–444, 2015.