EXPLORING EMBEDDED PLATFORMS FOR SMART HEALTH MONITORING OF BRIDGE STRUCTURES

RESEARCH EXCHANGE VISIT REPORT
COLLABORATION WITH THE EMERGING TECHNOLOGY LAB (ETL)
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INTRODUCTION

During my research exchange at the Emerging Technology Lab (ETL) at the National University of Sciences & Technology (NUST) in Pakistan, I was able to combine my expertise in infrastructure monitoring from the Smart Infrastructure Technology Lab (SITL) at Chung-Ang University with ETL's focus on embedded platforms for sensing and analysis. The aim of this collaboration was to investigate the potential of stand-alone edge devices in measuring structural displacements using computer vision techniques. Initially, I attempted to use a Raspberry Pi and its camera to monitor bridges in real-time, utilizing QR Code detection to track displacements. However, due to high computational demands, I transitioned to the NVIDIA Jetson Nano platform to accommodate high-speed monitoring and improved image quality. This transition required modifications to the ArduCam hardware to achieve higher frame rates, as the original driver limitations constrained performance. Throughout this process, I utilized a UNIX-based environment to develop and integrate both the hardware and software components of the monitoring prototypes. Furthermore, I explored the use of ArUCo markers as fiducial markers, which enabled 6-degree-of-freedom (6DoF) pose estimation. I am grateful to NUST and Dr. Sajid Gul Khawaja of the ETL for providing me with this valuable research opportunity.

RESEARCH ACTIVITIES

FOCUS AREAS

1. #### EMBEDDED SYSTEM PLATFORMS

   My investigation commenced with evaluating various Raspberry Pi models in terms of their real-time bridge displacement monitoring capabilities. I assessed their computational prowess by examining CPU clock speeds, the number of cores, available RAM, and I/O interfaces. To facilitate image acquisition, I integrated the PiCam and researched its specifications, including resolution, frame rates, and compatibility, as well as camera control libraries. However, the Raspberry Pi's limitations in handling high-resolution images and achieving the necessary frame rates for displacement tracking became evident. Consequently, I shifted my focus to the NVIDIA Jetson Nano platform. Through comprehensive benchmark comparisons, I discovered the Jetson Nano's superior computational power and GPU acceleration, which offered substantial advantages for image processing within my monitoring system.

   To optimize my setup further, I needed to make direct modifications to the ArduCam hardware. By perusing documentation and online forums, I identified potential modifications to overcome the driver-imposed frame rate limits on the Jetson Nano. These modifications allowed me to overcome the limitations I encountered when working with the Raspberry Pi and to fully harness the capabilities of the NVIDIA Jetson Nano platform for my bridge displacement monitoring application.

2. ROBOT OPERATING SYSTEM INTEGRATION

   I employed the ROS software framework for my system due to its modular design, multi-camera synchronization support, and extensive development tools. To ensure effective communication between the various components of my monitoring system, I carefully examined existing ROS nodes and packages designed for camera interfaces, image processing, and displacement calculations. A thorough understanding of ROS concepts, such as topics, messages, and services, was essential in designing the communication architecture for my system.

OUTCOMES

The practical experimentation that I conducted provided me with important insights into the potential limitations of various Raspberry Pi models for real-time bridge monitoring workloads. I carefully documented the differences in image capture speed and algorithm execution time. The successful hardware modification of the ArduCam for higher frame rate video capture on the Jetson Nano was confirmed through measured improvements. Through this project, I gained valuable experience working in UNIX-based environments, managing relevant software dependencies and tools. My investigation of ArUCo markers focused on their accuracy and processing speed under different lighting conditions. Importantly, my research emphasized the necessity of a multi-camera system for comprehensive six-degree-of-freedom displacement monitoring, leading me to explore the concepts of image stitching, triangulation, and multi-camera calibration. I successfully developed a proof-of-concept offline system using webcams and a PC, which will inform the future use of high-speed industrial cameras.

COLLABORATION AND KNOWLEDGE EXCHANGE

During my tenure at the Emerging Technology Lab, I actively participated in meaningful discussions and brainstorming sessions with the ETL researchers. These interactions revolved around monitoring strategies, optimal practices for selecting embedded systems, and enhancement methods. I contributed my knowledge and skills in bridge health monitoring, and simultaneously acquired new proficiencies in ROS development and the innovative customization of embedded hardware platforms to suit specific research objectives.

OBSERVATIONS OF NUST RESEARCH ENVIRONMENT

The research environment at NUST was both inviting and stimulating, equipped with well-equipped labs, access to specialized tools, and a rich culture of mentorship. I was particularly intrigued by NUST's emphasis on applied research and observed both similarities and interesting differences when compared to my experiences at Chung-Ang University.

IMPACT AND FUTURE DIRECTIONS

This research collaboration has greatly influenced the development of my proposed real-time, edge-based bridge monitoring system. The knowledge acquired at NUST will direct the selection of hardware and the design of my ROS system architecture. The expertise I have gained in creating ROS nodes and workflows provides a solid basis for future work with more capable embedded platforms and the integration of industrial-grade sensors. Moreover, I envision adapting my offline system for on-site data collection, with the aim of progressing towards real-time processing as hardware capabilities are enhanced.

CONCLUSION

The progress made in the development of the innovative bridge infrastructure monitoring solution at NUST represents a significant advancement. With the assistance of the Raspberry Pi prototypes, I was able to transition to a more complex framework based on ROS and multi-camera technology. This collaboration has not only enhanced my technical proficiency but has also emphasized the importance of international research partnerships in expediting the development of transformative technologies.