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Wind Input and Acceleration & Displacement Outputs Monitoring System for High-Guyed Masts in ROSEHIPS Project

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ABSTRACT: This paper presents a battery-operated wireless long-term response measurement system for high-guyed masts in the UK, as a part of ROSEHIPS project. The monitoring system aims to capture wind speed and direction as input and 3D accelerations and 3D displacements as outputs for a target period of three months. GNSS (Global Navigation Satellite System) based time-synchronisation methods were used in all subsystems for accelerometer, anemometer, and Computer Vision based cameras. Epson E-M352 sensors were used to measure triaxial accelerations with extreme accuracy 0.2ug/ÖHz at multiple points along the height of the mast, together with an anemometer. Low-power consumption features of ESP32 microprocessor unit was utilized to achieve a longer battery life. To remotely monitor its 3D displacement, a wireless stereo vision system was developed using Raspberry Pi. The displacement is measured in the image plane of each camera, and the data is then uploaded to the cloud for 3D reconstruction. The measurement accuracy was validated through an outdoor test, where the two cameras were approximately 100 meters apart, and the target was located about 200 meters from both cameras. The results showed a measurement error of approximately 1 mm. The time synchronisation between the accelerometer and the stereo vision system was also evaluated. By using the system to track an accelerometer mounted on a cantilever, the time-sync error was found to be less than 1 ms.

KEY WORDS: Structural Health Monitoring, Wireless Sensor, Accelerometer, Stereo Vision, Anemometer.

1 INTRODUCTION

High-guyed masts are critical infrastructure for telecommunications and broadcasting, yet their slender designs make them vulnerable to environmental loads, particularly wind-induced vibrations [1].

Effective monitoring of these structures is essential to ensure safety and reliability [2]. Traditional wired systems face challenges including high installation costs, power supply limitations, and maintenance difficulties. Wireless, battery-operated systems offer an attractive solution, providing flexibility and ease of installation.

This paper presents a wireless long-term monitoring system developed as part of the ROSEHIPS project, specifically targeting high-guyed masts. It integrates Epson E-M352 accelerometers for accurate acceleration measurements, an anemometer for wind monitoring, and a Raspberry Pi-based stereo vision system for remote displacement tracking. GNSS-based synchronization [3] ensures precise timing across all sensors.

2 WIRELESS INPUT-OUTPUT MONITORING SYSTEM

2.1 Accelerometer

Figure 1. Accelerometer node

The accelerometer node consists of a M5Stack Core2 MPU based on esp32, a GNSS module, an accelerometer module for an Epson M-A352 sensor, and a battery module. M5Stack provides a convenient modular design, which an additional feature can be added a module layer stacked below the MPU. Light sleep was employed in esp32 to save power-consumption.

2.2 Stereo vision system

The wireless stereo vision system comprises two identical nodes (left and right), each equipped with a SONY IMX296 camera and lens, a Raspberry Pi 4B computer, a GNSS board and antenna, and a 4G communication module. The camera in each node is triggered by its Raspberry Pi via a jumper cable. To achieve synchronous image capture, both nodes use pulse-per-second (PPS) signals from the GNSS modules; upon receiving these PPS signals, the Raspberry Pi generates a synchronised 10 Hz trigger signal for the cameras.

First, the two nodes are positioned, and their geometric relationship is accurately determined using a GPS-RTK system for later 3D reconstruction. Users set an identical start time for both nodes, initiating synchronised 10 Hz image capture upon receiving the PPS signals. A measurement target is selected from the initial images of each node, ensuring the same target is tracked by both nodes. Each node independently measures the target's 2D displacement, and the data is uploaded to AWS. Finally, the 3D displacement is calculated in AWS using triangulation based on the uploaded 2D measurements and the known geometric relationship between the cameras

2.3 Anemometer

Anemometer used was a GILL 1350 ultrasonic anemometer, which measures wind speed and direction up to 10 Hz.

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3 SYNCHRONISATION VALIDATION

3.1 Setup

The time synchronisation between the accelerometers and the stereo vision system was validated. Three accelerometers (named ACC1, ACC2, and ACC3) were mounted on a cantilever beam. Two camera nodes (named CV1 and CV2) were placed 0.62 m from the structure, as shown in Figure 2. The validation consisted of three subtests: (1) synchronisation error between accelerometers, (2) synchronisation error between camera nodes, and (3) synchronisation error between accelerometers and cameras.

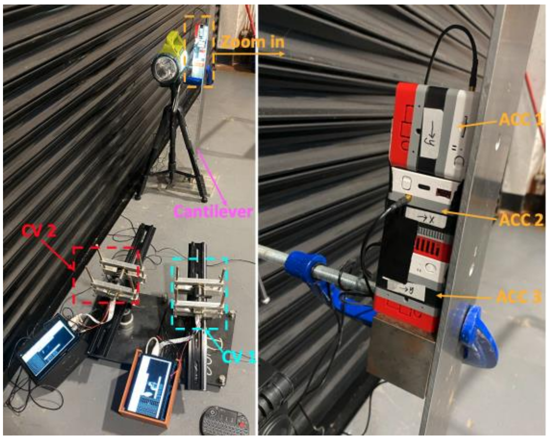

Figure 2. Experiment setup.

3.2 Results

(1) Synchronisation error between accelerometers

The structure was manually excited, and the accelerometers recorded the structural acceleration. Figure 2(a) shows the measurement results, and Figure 2(b) shows a zoomed view. If the sensors were perfectly synchronised, the measured data from all three sensors should have no phase lag. The observed phase lags were considered as synchronisation errors. The synchronisation error was 40 µs between ACC1 and ACC2, and 11 µs between ACC1 and ACC3.

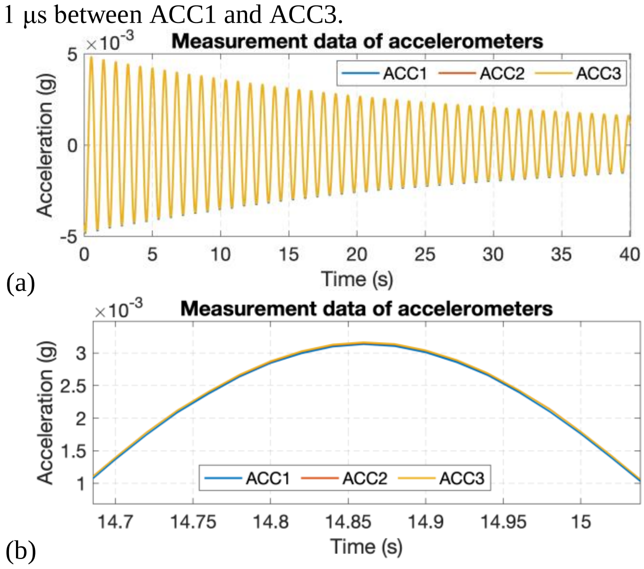

Figure 2 Measurement data of accelerometers.

(2) Synchronisation error between camera nodes

Figure 3(a) shows the measurement data from CV1 and CV2, and Figure 3(b) provides a zoomed view. The synchronisation error between the two camera nodes was 32 µs.

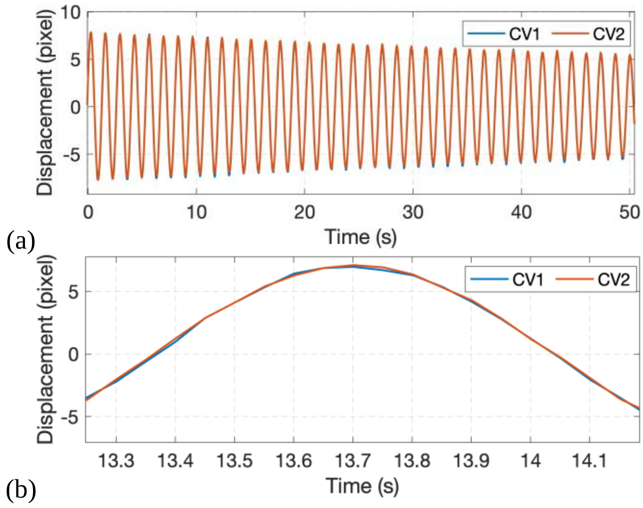

Figure 3 Measurement data of camera nodes.

(3) Synchronisation error between the accelerometer and camera

Acceleration and displacement are two different measurement units, but their waveforms are opposite when the signals are simple harmonic. The ACC1 data was multiplied by -1500 and then compared with the CV1 data. The synchronisation error between the two types of sensors was 309 µs.

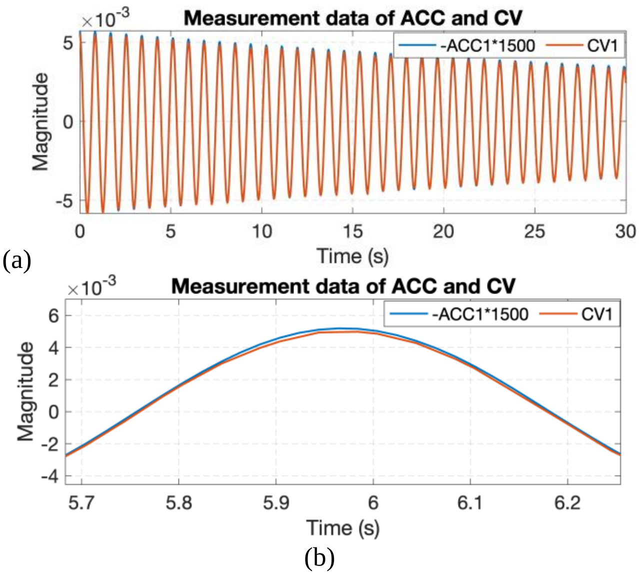

Figure 4 Measurement data of the accelerometer and camera.

4 CONCLUSION

The developed wireless sensors—including anemometers, accelerometers, and vision-based systems—help fill the gap in long-term input-output monitoring of high guyed masts at low cost. These heterogeneous sensors form a wireless sensor network, which also has potential for other structural health monitoring applications, such as using vision-based systems to capture vehicle input and accelerometers to measure structural response on bridges.

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