論 文 の 要 旨

題 目 A Study on High-Speed-Vision-Based Vibration Spectrum Imaging

（高速ビジョンに基づく振動スペクトルイメージングに関する研究）

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Several studies that utilized vibration information for inspections in various fields have been conducted in recent years. Two main methods have been used to detect vibration displacement: contact measurement and non-contact measurement. In contact measurement, contact sensors such as accelerometers are directly installed on the target objects to inspect conditions. It is necessary to attach the sensor to the reference point on the structure when attaching a contact sensor. However, it is often difficult or impossible to access the structural points at which it is installed. In non-contact measurement, the vibration displacement of the object is directly measured with sensors such as an eddy current sensor, an optical fiber sensor, a laser Doppler vibrometer, and an offline-based high-speed vision system. Beneficial vibration analysis of the time-varying data measured by optical sensors in the frequency domain can then be conducted after remotely measuring the vibrated conditions of the target objects. Especially in the case of engineering, it is essential to measure the vibration displacement. Besides, it is always necessary to monitor and analyze the running condition of a machine during its operation. It is necessary to perform vibration analysis and vibration design of mechanical structures to improve their vibration resistance. Therefore, vibration detection with non-contact sensors is essential.

Real-time high-speed vision systems to capture high-speed phenomena that the human eye cannot see have been developed. With the acceleration of parallel processing on field programmable gate arrays (FPGAs) and graphics processing units (GPUs), various real-time application examples with high frame rates have been reported, such as bridge vibration analysis, vibration source localization, and multiple objects tracking systems. Such high-speed vision systems can function as dynamic sensing tools for simultaneously analyzing rapid phenomena vibrating at frequencies of dozens or hundreds of Hertz, which cannot be seen by the human eye and standard video signal formats (e.g, NTSC 30 fps or PAL 25 fps).

In this study, we develop a vibration spectrum imaging system that implements the pixel-level vibration frequency analysis to capture the time-varying brightness changes in images as a vibration distribution. It realizes dynamic sensing functions for simultaneously analyzing fast phenomena vibrating at frequencies of dozens or hundreds of Hz, which cannot be seen by the human eye. Our high-speed vision-based vibration analysis target is a human-invisible but audible phenomenon vibrating at an audio frequency level. The vibration spectrum imaging system consists of a high-speed vision used as a sensor for capturing the time-varying changes in an image as a vibration distribution with the acceleration of parallel processing on GPU. We propose novel concepts to realize that a vibration spectrum imaging for the high frequency targets fluctuate at dozens or hundreds of Hz and high-speed moving and vibrating objects such as multi-copter and honeybee. The pixel-level vibration spectrum imaging method expands two types of applications for flying objects.

The first application proposes a fast algorithm for vision-based vibration source localization for flying multi-copter that can detect vibration sources at hundreds of Hertz by inspecting time-varying brightness signals at each pixel in HFR images. Our algorithm can significantly reduce the computational complexity of pixel-level digital filters for vibration source localization by virtually adjusting the sampling rate to twice the vibration frequency of a target object to be tracked using downsampled HFR images with frame interpolation while locking in vibration frequency for tracking objects.

The second application is pixel-level flight activity sensing method by utilizing pixel-level vibration source localization and vibration spectrum imaging for flying honeybee. This concept shows the flight activity sensing that can track and quantify the vibration properties in brightness at the pixel around wing-flapping honeybees by executing two-step pixel-level STFTs for an HFR video. In several experimental results, flying honeybees in 1024×1024 images captured at 500 fps demonstrate that, even when the image region of the honeybee is low resolution, robust tracking can be achieved with activity sensing in the frequency range up to 250 Hz, which is the Nyquist frequency when we analyze a 500 fps video. The trajectory of a detected and labeled honeybee is monitored with the peak frequency of these tracked STFTs as its flight activity.

This thesis is organized as 6 Chapters.

Chapter 2 summarized related works on vibration measurement, high-speed vision and vibration source tracking.

In Chapter 3, a real-time high-speed vision-based vibration spectrum imaging for visualization of time-varying frequency response was developed to verify the effectiveness of our real-time vibration spectrum imaging method. They were demonstrated using the vibration results for a fan, multi-copter, and guitar string, which had rotating or vibrating frequencies in the range of hundreds of Hz.

Chapter 4 explains the fast vibration source localization for a multi-copter using pixel-level digital filters was proposed to verify the effectiveness of pixel-level accuracy in vibration source tracking through several experimental results of offline high-framerate videos and real-time implementation, which displayed various flight scenarios of a multi-copter with its propellers rotating at 90-100 Hz.

In Chapter 5, an HFR-video-based honeybee activity sensing was proposed to realize the activity sensing of honeybees flying in a natural outdoor environment by inspecting pixel-level temporal frequency responses in the brightness in an HFR video, computed by executing STFTs of the brightness signals at all pixels. The effectiveness of the proposed algorithm was verified in several experiments which are how the spatial resolution of an HFR video affects the sensitivity in our honeybee activity sensing algorithm and the trajectories and flying activities of honeybees in the outdoor scene.

In Chapter 6, it summarized the contributions of this study and discussed future work.

The appendix included the summary and future implementation of Onsite-Team-Project in the TAOYAKA program which I belonged to become a global leader with a broad perspective and learned onsite reverse innovation and bottom-up approach in a disadvantaged area with plenty of natural resources during master and Ph.D. courses in Hiroshima University.