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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Chapter 1, “Introduction”, provides a detailed explanation regarding the background of radio frequency (RF) based motion sensing research and the main motivation of this study. In comparison with the commercial motion sensing that relies on optical sensor, Utilizing RF could enable the contactless human-computer interaction in private locations without raising privacy issues as well as in the non-line-of-sight environment. Hence, the main objective is to investigate the possibility of 3D hand trajectory tracking by utilizing only Wi-Fi channel state information (CSI) obtained from off-the-shelf Wi-Fi chip as well as developing the deterministic CSI model as a tool for studying the mechanism of Micro-Doppler effect during hand gesture.

Chapter 2, “Overview of Wi-FI CSI based Motion Sensing Technology”, explains the structure and model of Wi-Fi CSI and the available approaches to extract CSI from the commercial Wi-Fi chip. The fundamentals of OFDM radar in terms of the range and velocity estimation of the target moving object is generally described in details as well as explain the effect of micro-Doppler to the motion analysis. Then the extensive literature review on CSI-based motion sensing applications are categorically summarized in terms of merits and challenges.

Chapter 3, ″Mitigation of Undesired Phase Rotation in Measurement CSI″, explains the challenges when dealing with in the actual CSI. In Section 3.2, the effect of spatial mapping in multi-input-multi-output (MIMO) system is priory addressed followed by the undesired phase rotation due to the non-synchronization issues between Wi-Fi stations in Section 3.3. As a result, Doppler frequency is obscured by these factors and hardly obtainable from CSI. Then the novel phase rotation calibration is introduced in Section 3.4 to mitigate the undesired phase rotation without destroying the desired rotation of Doppler frequency. The validation showed that the result produced by our calibrated CSI has the agreement with the CSI reference measured from the vector network analyzer.

Chapter 4, ″Simulated Time-Variant CSI Model of Hand Gesture″, provides the detailed explanation of the development of deterministic CSI model which comprised of three main components and covered in Sections 4.2-4.4. First part constructs the physical movement of hand gesture by applying the non-rigid body motion of robot arm model as well as representing the surface of human limb with the simple geometrical shapes. Second part simulates the deterministic of micro-Doppler effect from the scattering theory of electromagnetic wave. Specifically, the development of circular-mesh physical optics (PO) approximation for the practical usage of the moving scattered is addressed and validated. The scattered wave produced by PO is then incorporated into the time-variant component of CSI model at the last part. In Section 4.5, the ability of the model to simulate micro-Doppler effect from the hand gesture motion is confirmed with the measurement results.

Chapter 5, ″Temporal Profile Extraction of Hand Doppler Signature″ explains the characteristic of micro-Doppler during hand gesture via human limb model. In Section 5.2, The analysis of micro-Doppler is conducted based on the Doppler and the scattered power distribution induced from the surface of the human limb. The study is concluded that the Doppler signature of the hand segment is likely located at the farthest peak on the Doppler power spectrum due to the faster speed relative to those produced by the arm movement. Therefore, In Section 5.2, a novel technique for extracting the temporal profile of a hand-only Doppler signature from the spectrum has been developed based on the peak detection method. In Section 5.3, the validation of the algorithm is conducted. The result revealed that the error from the extracted Doppler profile was fairly small in comparison with other techniques in CSI-based motion

sensing.

Chapter 6, ″Utilizing Doppler Frequency for Hand Motion Trajectory Tracking″ firstly formulates the trajectory estimation framework based on multi-static Doppler radar in Section 6.2. This framework recursively calculates both velocity and temporal position of hand gesture given a set of Doppler profiles captured from multiple Wi-Fi stations. Kalman filter (KF) is applied to mitigate the trajectory error from the recursive model. The optimization problem is applied to alternatively estimate the arbitrary initial position that could maintains the overall trajectory. In Section 6.3, the validation of trajectory tracking framework is validated. The hand trajectories could successfully be reconstructed. The validation concludes that the correctness of trajectory is highly sensitive to the extracted Doppler profile but robust to the initial position. Nevertheless, the impact of the initial position offset manifests in terms of additional orientation offset but does not contribute much to the shape distortion. The measurement campaign using commodity Wi-Fi devices also provided the promising results in the trajectory tracking of hand gestures. This experiment therefore confirmed the applicability of our tracking framework in practical.

Chapter 7, “Conclusion”, summarizes this thesis and the important contributions followed by the possible research topics and applications for the future motion sensing system.