主　論　文　の　要　約

論文題目　A study on robust speed and separation monitoring for risk estimation of human hand intrusion
(人間の手の侵入のリスク見積もりのためのロバストな速度と分離のモニタリングに関する研究)

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論　文　内　容　の　要　約

In this research, robust speed and separation monitoring is discussed for enabling 3-dimensional human and robot collaboration which is considered to be one of the promising solutions to increase productivity during non-contact oriented collaborative operation. The thesis consists of five chapters. The first chapter introduces the background of this research with related safety standards. Chapter 2 demonstrates methodology estimating the probability of intrusion with respect to the protective separation distance using interference theory. Chapter 3 exhibits the difference of potential runaway motion in task space regarding the geometric relationship between the human and the robot using dynamic manipulability ellipsoid. Chapter 4 provides an asymmetric safety Kalman filter designed with a hybrid strategy of compensation and rejection approach. In Chapter 6, the major conclusion is made from the upper mentioned chapters in terms of safety and productivity of collaborative tasks using speed and separation monitoring.

In Chapter 1, background and related research are described. Currently, a flexible production system in which humans and robots collaborate is expected at production sites. One of the reasons for this is that this production system is thought to bring higher productivity than a conventional rigid workspace. In such a human-robot collaborative system, it is indispensable to ensure human safety, and in this chapter, speed and separation monitoring which is one of the collaborative functions is described. Also, in accordance with safety standard ISO/TS 15066, protective separation distance which is the minimum allowable distance when using speed and separation monitoring is explained. Finally, the objectives and contributions of this thesis are described.

In Chapter 2, 3-dimensional human hand intrusion against protective separation distance is discussed with interference theory. The conventional interference theory concerns how the failure of the system can be estimated from the perspective of a mechanical sense. By introducing the interference theory, in order to estimate the probability of intrusion, the PSD and the separation distance between the human and the robot is compared. As for the collaborative task, the battery assembling task was chosen to demonstrate the HRC task. As a result, it was experimentally proven that if the time variable is considered in the IT, it is possible to prevent the POI of the human hand into the PSD from being overestimated. In addition, to investigate the contribution of each component of the PSD to the POI of the human hand, a simulation-based on typical parameters was executed. Consequently, it was shown that reducing the POI of the human hand is possible by modifying parameters such as the stopping time, the margin factors of the robot, and the safety-related sensor system, which represents the intrusion distance and the measurement uncertainties.

In Chapter 3, considerations regarding the robot's runaway motion during the human and robot collaboration are discussed from the perspective of foreseeable single fault especially about the motor drive. Although the possibility of runaway motion of the robot should be considered in terms of mechanical, electrical, or external reasons, no explicit guidelines exist in the current stage of safety regulations. In this chapter, runaway distance which originates in potential runaway motion in task space is computed for different relative orientations between the human and the robot. Two relative postures of the operator and the robot were examined to estimate the potential runaway motion of the robot: frontal orientation (A), and perpendicular orientation (B). From the result, it was found that the volume of potential runaway motion space for the case of orientation A is larger than that of B because orientation A is more affected by the main axis of the acceleration ellipsoid than B. Therefore, in order to reduce the runaway distance, it is effective to avoid the frontal arrangement of robots and humans. Considering the basic concept of risk, it is reasonable to take the severity of contact into the SSM function. In this respect, expected transferred energy was used to calculate the maximum permissible velocity of the robot assuming potential contact based on the dynamic properties of the robot and the biomechanical limit of human injury.

In Chapter 4, a novel robust Kalman filter is proposed having the ability to resist temporary and additive outlier originating in miss-detection of the radar based wireless sensor. Even though there have been great discussions about effective robust Kalman filters for noisy environments such as false alarm, few have focused on temporary outlier especially due to the miss-detection. In this respect, the asymmetric approach using compensation and rejection strategy is introduced to react differently against the type of the outlier. As for the experiment, the outlier ratio is compared between fast and slow-motion using a human hand test piece. As a result, the proposed filter showed relatively higher performance than the conventional OD-KF method in terms of resisting additive and temporary outlier generated by the miss-detection during the measurement.

In Chapter 5, makes a brief summary of presented studies and investigations which are performed throughout the thesis, and conclusions regarding robust speed and separation monitoring.