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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 ）

Long-reach robotic arms are useful for many applications due to their large workspaces, long operation time, and redundant degrees of freedom, such as infrastructure inspection, nuclear plant decommissioning, and firefighting. However, a fundamental problem of building or operating a long robotic arm is that even an extremely small end effector reaction force or the arm gravity itself can result in significant torques on proximal joints that are difficult for actuators to handle. Previous researchers proposed many specially designed long robotic arms that can counteract external reaction forces and arm gravity. However, those specialized long arms have two drawbacks. (1) Their force compensation mechanisms are hard to be applied to other existing long robotic arms and (2) They are hard to be customized to different missions.

To solve the fundamental problem of long robotic arms and overcome the drawbacks of specialized long robotic arms, the goal of this dissertation is to develop a watch-like thrust-generating attachable device, called flying watch, which can be attached to the links of a long robotic arm with a mission-dependent attachment allocation and generate thrusts in cooperation with the original arm actuators to enhance arm strength. Flying watch is useful for boosting the strength and versatility of long robotic arms as well as designing reconfigurable long robotic arms.

The contributions of this dissertation are as follows. (1) Proposing the concept, design, and dynamic model of flying watch. (2) Proposing a method called Allocation Optimization based on Weighted Situations (AOWS) for customizing flying watch attachment allocation to a specific mission and verifying its performance using simulations. (3) Proposing a model-based flying watch thrust planner, called Watch-Actuator Cooperation for Arm Enhancement (WACAE), and verifying its performance using simulations. (4) Proposing a model-free flying watch thrust planner, called Physical-gradient-based Optimization of Thrust (POT), and demonstrating POT using a physical robotic arm.

This dissertation describes the design, attachment allocation customization, and thrust planning theories of flying watch and corresponding prototype and experiments. The organization of this dissertation is as follows.

Chapter 1: This Chapter introduces the motivation and goal of this flying watch research. It also provides a systematic review of related works, such as thrust driven robotic arms, thrust-assisted robots, and aerial manipulation and transformation.

Chapter 2: This Chapter introduces the concept, design, selection, and mathematical model of flying watch. It first introduces the flying watch concept and varieties of flying watch designs and prototypes. Then it introduces how to choose an appropriate flying watch for a specific long robotic arm and how to determine the application scope for a specific flying watch. Finally, it derives the equation of motion of flying watch, which will be the theoretic foundation of flying watch attachment allocation customization and thrust planning.

Chapter 3: After understanding flying watch design and building several flying watch prototypes in Chapter 2, the next question would be how to attach flying watches for a specific mission and what is the property of a certain flying watch attachment allocation. This Chapter answers those questions. More specifically, this Chapter first introduces several analysis tools for understanding the properties of a flying watch attachment allocation. Then an automated design tool, called Allocation Optimization based on Weighted Situations (AOWS), is introduced for generating an optimal flying watch attachment allocation according to a specific mission. With such customized attachment allocation, flying watches will be able to enhance a robotic arm in a mission-dependent way. Finally, AOWS is verified in simulations.

Chapter 4: After building and properly attaching flying watches, the next problem is to control watch thrusts. This Chapter solves this problem by introducing an offline model-based thrust planner, called Watch-Actuator Cooperation for Arm Enhancement (WACAE). WACAE is an offline model-based method because it requires an arm model and prior knowledge of a mission and the thrust planning is done before a mission. WACAE is suitable when we have a precise arm model and

know exactly what will happen during a mission. We will also show simulation verifications of WACAE in this Chapter.

Chapter 5: This Chapter introduces an online model-free thrust planner, called Physical-gradient-based Optimization of Thrust (POT). POT requires no prior knowledge about the robotic arm, attachment allocation, and mission and the flying watch thrusts are determined during a mission. POT can adapt to unexpected situations during a mission and is suitable when we do not know clearly what will happen during a mission. We will demonstrate using POT to enhance a planar arm that originally can only operate on a horizontal plane. After enhancement, the arm can operate on a tilted plane.

Chapter 6: This Chapter summarizes theories and experiments included in this dissertation. In addition, this Chapter discusses possible future research directions of flying watch.