Human-Robot Collaboration with Robotic Assistance Confined to Local Motion to Assure Human Safety

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Abstract—Human-robot collaboration becomes more and more promising recently. By exploring the cognitive and dexterity capabilities of humans and the capacity of robots to produce repetitive work and provide assistance, human-robot collaboration combines both parties’ advantages. However, potential safety concerns exist in many human-robot collaboration systems. In this report, we present our recent studies on safe robotic-assist design and development for human-robot collaboration with the aim of extending humans’ motion accuracy while fully preserving the cognitive and dexterity capabilities of humans. We focus on collaborations where human operator with cognitive capability implements coarse global-motion and robot with high-speed sensory feedback realizes fine local motion. Safety for human is assured by confining the robot motion in a local manner and reducing the physical interaction from robot to human.

I. INTRODUCTION

Robots are a key element to achieve manufacturing competitiveness, especially if they are able to collaborate with humans in a shared workspace in the shop-floor, creating a co-working partnership. The paradigm for robot usage has changed from an idea in which robots work with complete autonomy to a scenario in which robots collaborate with humans. This means taking the best of each partner, by exploring the cognitive and dexterity capabilities of humans and the capacity of robots to produce repetitive work and provide assistance.

However, when robots are acting jointly with or close to humans, safety issue becomes a crucial aspect. In order to address the safety issue in human-robot collaboration, several research areas are established, such as safety assessment, safety through design, and safety through planning and control[1]. In this study, we focus on the safety design and implementation as it is the most important aspect and many efforts have been devoted in this area. For examples, in [2], safety design strategy is proposed for a production cell covering five main safety design aspects: human area and robot area, safety robot working zones, robot safety design, operator safety monitoring system, operational sequence safety control. Although potential collaboration risks can be effectively reduced with the proposed safety designs, it is said that risks are not totally being eliminated.

In this report, we present our recent studies on safe robotic-assist design and development for human-robot collaboration. The objectives are to keep human 100% safe even under system (e.g. sensors, controllers, mechatronics) failures and to extend humans’ motion accuracy while fully preserving the cognitive and dexterity capabilities of humans.

II. METHODOLOGY

A. Interaction analysis and safety issue

Safety issue is of great importance for human-robot collaboration systems. In order to address the safety issue, analysis of interaction methods in human-robot collaboration is introduced as shown in Fig.1. Physical interaction model (shown in Fig.1(a)) with robot physically interacting with human has been adopted by the majority of commercial collaborative robots for power-assist purpose. However, direct physical interaction between the robot and human poses potential stability and safety concerns. In contrast, there is only one-way effect from human to robot for the reduced interaction model as shown in Fig.1(b). Human-robot interface giving feedback to human operator is configurable and can be designed as non-contact. Therefore, assist behavior of robot is confined to local motion and is accordingly safe to human operator.

![Fig. 1. Interaction analysis of human-robot collaboration. (a): Physical interaction model (e.g. collaborative industrial robots under impedance control). In this model, the robot is supposed to estimate the intention of the human operator to form a joint intention. Both human and robot realize the global motion for a given task. However, physical interaction between robot and human operator is a potential risk for human safety. (b): Reduced interaction model. The robot only needs to realize local motion in an active manner and does not need the cognitive capability of understanding the intention of human operators. Human guides the robot globally while considering the limited motion range of the robot. Physical interaction from robot to human is reduced and thereby human safety is assured. Note that for both models, interactions between target and robot can be physically contact or non-contact according to different tasks.](image-url)
Coarse human motion (Low-bandwidth dynamics)  
- poor accuracy  
- tremor  
- Cognitive  

Fine compensation (High-bandwidth dynamics)  
- high-speed sensory feedback  
- Compensation module

POSITIONING ERROR \( \delta \)

A. Compact high-speed vision system

A new vision chip combining high-frame-rate imaging and highly parallel signal processing with high-resolution, high-sensitivity, low-power consumption, and small chip size is developed [5]. Comparing with conventional high-speed vision system, the new high-speed vision system (Fig.3) based on the newly developed vision chip will greatly save space and energy, and is very suitable for compact usage in robotic applications. Overall latency of high-speed visual feedback was measured to be within 3.0ms[6].

B. Robotic module for local assistance

A robotic module prototype capable of realizing fine compensation in two dimension \((x, y)\) direction is developed as shown in Fig.2. The module is lightweight with high-speed and accurate motion ability. The module is controlled with the feedback information from the new high-speed vision system, which is configured on the working table of the robotic module (see Fig.2). In order to show the advantages of the high-speed visual feedback, the compensation module is controlled by a simple proportional-derivative (PD) method instead of developing complex control algorithms. The module is configured at the end of a supporting mechanism formed by two frame links with three passive joints (see Fig.4, Fig.5). Therefore, a human operator moves the robotic module by one hand within \(x - y\) planar globally with less physical effort.

IV. HUMAN COARSE MOTION

Since the robotic module is designed for local motion and it has limited work range, it is necessary to inform a human operator by the human-robot interface during his/her implementation of coarse motion to assure a target always reachable for the robotic module. In order to avoid safety concerns as addressed above, human-robot interface giving feedback to human operator can be designed in a non-contact manner. Hereafter, we introduce two methods: vision perception and pneumatic haptic perception. Notice that contour tracing will be set as the application task hereafter.

A. Interface based on vision perception[7]

A small projector is configured to project a square area as the indication for human operator (Fig.4(c)). Human operator moves the robotic module along an arbitrarily placed target (here is a closed groove with 1mm width) only caring about that the target is always within the projected square. The projected square area is aligned with the ROI region of the high-speed camera’s images. Therefore, reference positions for regulation in images are continuously calculated by the
high-speed vision, and ideally they would lie on the center line of the groove. One sample image is shown in Fig.4(b).

![Fig. 4. Experimental setup for contour tracing by human-robot collaboration based on vision perception. (a): target workpiece; (b): image sample of high-speed vision; (c): indication of projected square for human operator.](image)

**B. Interface based on pneumatic haptic perception[8]**

As shown in Fig.5, for simplification, the haptic feedback is only realized along \( x \)-direction with two nozzles (with diameter of 1mm) that are configured around the handle to blow compressed air (0.2MPa) to the hand of human operator. Basically, the haptic feedback on human operator works as a supervisor telling the subject to guide the robotic module such that the target should be always kept within its limited work range. Therefore, encoder information of the robot module’s joint-\( x \) can be used as the control input for generating the pneumatic haptic feedback. Air flow on each nozzle is controlled with a PWM like method. The pulse of each air blow is determined by the valve’s physical parameters, and the air blow frequency is determined with the encoder information of the robot module’s joint-\( x \).

For average, tracing error under active assistance of the robotic module (with both methods) was around 3pixel in our experimental setup. Details can be referred in related works[7], [8].

![Fig. 5. Experimental setup of the human-robot collaboration system based on pneumatic haptic perception.](image)

**V. Summary**

This report presents our recent studies on safe human-robot collaboration based on reduced interaction between robot and human, with the aim of optimally combining the cognitive capabilities of human and accurate motion capabilities of robot. Under the proposed approach, human operator is for cognitive global-motion without caring much about accuracy. Fine local-motion in an active manner is realized by a robotic module based on high-speed visual feedback. In order to avoid safety concerns, robotic assistance is confined to local motion and human-robot interface giving feedback to human operator is designed in a non-contact manner.

However, the proposed method in this report is a complementary to existing systems based on physical interaction, and it is not good at implementing some traditional tasks such as power-assist applications.

**References**


