An Intelligent Robotic Co-worker for Practical Industrial Applications

D.K. Liu, *Member, IEEE*, M. Carmichael, *Member, IEEE*, K. Waldron, *Member, IEEE*, and G. Dissanayake, *IEEE*

***Abstract*— This research is aimed to advance understanding on how robots can be enabled to provide physical assistance to diverse workers performing labor intensive tasks in industrial environments, and to develop methodologies that enable the development of assistive robotic systems. This presentation will discuss (1) the enabling methodologies developed in a 5-year research project, including a model-based adaptive scheme for estimating assistance need, human-pose recognition in dusty environments, physical human-robot interaction and safety framework; (2) system design and integration of an intelligent robotic co-worker; and (3) experimental results from field trials.**

I. Introduction

Physically intensive tasks and hazardous working environments are very common in many industry sectors. A typical example is abrasive blasting. This is an operation widely used in manufacturing industry (e.g. steel work surface preparation), transport industry (e.g. steel bridge maintenance), cleaning industry (e.g. ship and vessel surface maintenance), automotive industry (e.g. car parts cleaning and coating), construction industry (e.g. cleaning steel and concrete surfaces). Frequently, abrasive blasting operations require workers to spend long periods of time resisting large forces (up to 400N in ship maintenance [1]) and to adopt awkward body postures.

Physically intensive tasks are the primary cause of work-related injuries and difficulty in retaining skilled workers and increasing productivity. For example, in Australia, of the 531,800 people who experienced a work-related injury or illness during the year 2013-14, 34% (181,200) sustained their injury through lifting, pushing, pulling or bending tasks [2]. Aging working population is a future concern, since incidence of serious workers' compensation claims increase with employee age [3]. Therefore, the ultimate objectives of this research are to reduce injury, improve working conditions and increase productivity of workers performing industrial tasks that require significant physical effort and strength. Supplementing manual labor with robotic aids will have significant health, safety and economic benefits.

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D.K. Liu, M. Carmichael, K. Waldron and G. Dissanayake are with the Centre for Autonomous Systems at the University of Technology Sydney, POBox 123, Broadway, NSW 2007, Australian. (Dikai.liu@uts.edu.au, +61-2-95142587; marc.carmichael@uts.edu.au, Kenneth.wadron@uts.edu.au, and gamini.dissanayake@uts.edu.au).

There has been increasing interest throughout the world in the use of assistive robotic technology for augmenting human strength. However, a number of key research challenges need to be addressed before robotic systems can be deployed to physically assist human operators with varying physical sizes and strengths, and working in typical unstructured industrial environments. The challenges are: how much assistance is needed for an individual worker, how to provide the required assistance to a worker, what are the strategies for intuitive human-robot interaction, and how to ensure safety of human workers when they are in physical contact with robots?

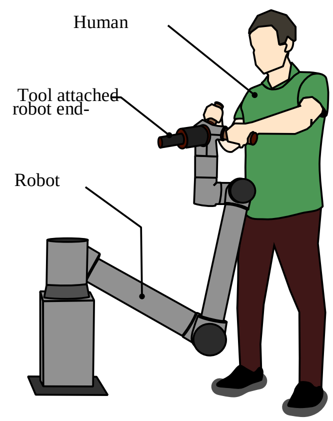


Figure 1 The robotic co-worker

II. Enabling Methodologies and Robotic Co-worker Development

This research addresses these aforementioned challenges in the development of a robotic co-worker to assist humans performing industrial abrasive blasting. The system, shown diagrammatically in Figure 1, utilizes a collaborative manipulator to support the blasting nozzle loads. Handles fitted with sensors allow human workers to intuitively control the motion of the nozzle whilst task loads are being supported.

The enabling methodologies developed and implemented in this robotic co-worker include (A) Human user pose recognition algorithms, (B) Model-based assistance-as-needed paradigm, (C) Physical human-robot interaction strategies, (D) Admittance control scheme, (E) Environmental and operational awareness algorithms.

A. Human pose recognition

A robotic coworker having knowledge of its human operator's pose can be used to facilitate beneficial functions, for example avoiding collision with the user or adapting its behavior based on user proximity. More complex uses include identifying the worker's intentions during tasks, or estimating physiological factors such as physical fatigue. Sensors such as the Microsoft Kinect capable of skeletal tracking have become popular in the robotics field. Human pose recognition in the industrial setting presents several challenges. Working closely with a robotic co-workers means that occlusions are likely. Additionally, many industrial setting are less than ideal. Abrasive blasting is a particularly challenging setting due to airborne particles reducing visibility. Research on pose recognition in this project includes effect of external force and two-hand operation on upper limb pose during human-robot interaction, and parallel mechanism based method for pose estimation. Ongoing research is focusing on methods of robustly estimating user pose in the presence of occlusions and poor visibility.

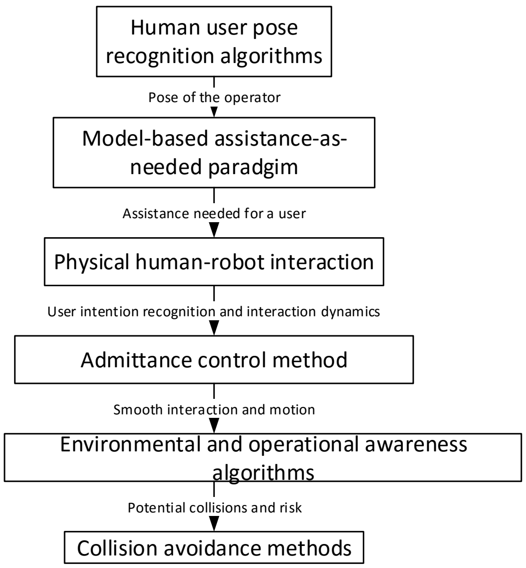


Figure 2 The enabling methodologies developed and implemented in the robotic system

B. Model-based Assistance Paradigm

For assistance to be beneficial it needs to be provided in the appropriate manner. Research into robotic rehabilitation has shown that significant benefits can be obtained by adapting assistance based on the task being performed and the capabilities of the subject. However little research has been conducted into adaptive paradigms for industrial applications. We developed and implemented a model-based Assistance-As-Needed (AAN) paradigm. The AAN paradigm uses a musculoskeletal model to estimate the strength capabilities of workers and then adapt the assistance provided based on this estimation [4].

C. Physical Human-Robot Interaction

For improving physical human-robot interaction, the grip strength of the human operator is used to improve the interaction [5]. Also important is how the interaction feels to the user. It was quickly discovered that robot operation near kinematic singularities was troublesome as it would result in user concern and discomfort. A method of handing singularities was developed that has characteristics favorable to physical human-robot interaction [6].

D. Admittance Control Scheme

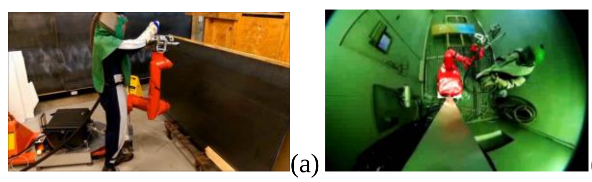
User control is facilitated by an admittance control scheme based on [7]. The interaction forces between worker and robot are measured and used to control tool motion. The proportion of task load supported by the robot is adapted according to the AAN paradigm. The result is an intuitive, adaptable interaction.

E. Environmental and Operational Awareness

The system has integrated sensing for measuring the environment and workers surrounding the robot. A custom sensor array consisting of 4 Microsoft Kinect V1 cameras was developed. Algorithms for facilitating environmental collision avoidance were implemented as part of the system's safety framework.

III. Testing and Trials in Lab Setup and Real Industry Environments

The prototype robotic co-worker has been extensively tested in both lab setup (Figure 3a) and a real industry abrasive blasting environment (Figure 3b). After these tests and trials, this robot is ready for deployment in September 2017.



(a) (b)

Figure 3 (a) testing in a lab setup; (b) trials in an industry grit-blasting environment

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