Robot Confidence Modeling and Role Change in Physical Human-Robot Collaboration

by

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A thesis submitted in partial fulfilment of the
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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text.

I also certify that this thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

In physical Human-Robot Collaboration, the human is generally in control of the interaction while the robot provides assistance to its human co-worker. However, with the increasing level of intelligence of robot co-workers, peer-to-peer interaction is expected and believed to be an ideal approach to collaboration between the human and the robot in a collaborative activity. In the peer-to-peer collaboration, the human and its robot co-worker would observe each other's actions and intervene if one detects changes of their counterpart during the interaction which could negatively impact the task. Current research on safe pHRC only considers role change to be initiated from the human's perspective, not from the robot's perspective. This thesis aims to address three research challenges in pHRC: the robot's perception of its human co-worker during pHRC, modeling the robot's confidence in its human co-worker and how a robot would decide whether and when it should intervene (by taking control) in its human co-worker's actions during pHRC.

This research first developed effective methods that enable the robot's perception of its human co-worker during pHRC. The human's grasping pattern and grasping strength on a handlebar, the commonly used interface in pHRC, are used by the robot to identify the orientation of the human co-worker's hand and monitor the human's reaction to unexpected events. A method for identifying the human's hand orientation and detecting the human's reaction to unexpected events was developed by analyzing the human's grasping pattern and grasping strength.

The thesis then explored how the robot's confidence in its human co-worker during pHRC can be modeled. A novel robot confidence framework was developed for modeling the robot's confidence using the robot's perception of the human's performance. The framework was evaluated in a number of pHRC case studies where a robot and its human co-worker worked collaboratively.

Finally, this thesis explored how the robot's confidence in its human co-worker can be used to decide whether and when the robot should initiate a role change. A confidence-based role change method was developed. Experimental verification of the role change method was conducted in a collaborative grit-blasting operation between a human and a robot. The results demonstrated that the method successfully identified the points during a pHRC where the robot should initiate a role change and take the control away from its human co-worker.

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Acronyms & Abbreviations

CAS	Centre for Autonomous Systems
UTS	University of Technology, Sydney
pHRI	physical Human-Robot Interaction
HRI	Human-Robot Interaction
HHI	Human-Human Interaction
HCI	Human-Computer Interaction
ANBOT	Assistance-as-Needed-roBOT
FSPN	Fluid Stochastic Petri Net
SVM	Support Vector Machine
pHRC	physical Human-Robot Collaboration
TMMAS	Thrumode Matrix Array Sensor
PCA	Principal Component Analysis
LoA	Level of Autonomy
ARMAV	Auto-Regressive Moving Average Vector Form

Nomenclature

	General Formatting Style
$\sum\{\cdot\}$	Summation.
$\prod\{\cdot\}$	Product.
$\dot{\square}$	First derivative.
$\ddot{\square}$	Second derivative.
$\lvert\square\rvert$	Absolute value.
$\bar{\square}$	Average.
σ	Standard Deviation.
	Human Grasping
P	Pressure applied to a single cell in the TMMAS where $0 \leq P \leq 127$.
LF-SX	Grasping dataset at fixed orientations around the handlebar collected in the lab for Subject X.
LR-SX	Grasping dataset at random orientations around the handlebar collected in the lab for Subject X.
F_H	The force applied by the human measured using a load cell.
F_R	The virtual guidance force applied by the robot.
F_G	The grasping force applied by the human measured using the TMMAS.
	Confidence Based Role Change
	Performance Model
A	Generic task component.

ϕ_A	The robot's perception of the human's performance in task component A.
$\frac{\phi_A}{dt}$	The instantaneous change in the robot's perception of the human's performance.
$\phi_{A,0}$	The robot's initial perception of the human's performance in task component A.
$P_{p_1}(p_1)$	Penalty dependent on the observation p_1.
$R_{r_1}(r_1)$	Reward dependent on the observation r_1.
τ	Maximum reward or penalty in a single time step.
G_{p_1}	Enabling function for Penalty P_{A,p_1}.
G_{r_1}	Enabling function for Reward R_{A,r_1}.
B	Enabling condition which define situations where fluid is allowed to flow through the fluid arc.

Confidence Model

$\phi_{A,c}$	The robot's perception of the human's performance in a generic critical component A.
$\phi_{A,n}$	The robot's perception of the human's performance in a generic non-critical component A.
γ_A	The weighting of a non-critical component A.
C_{min}	The minimum confidence if the robot in the human if the human's performance in the critical components is at its maximum value.
C	The robot's current confidence in its human co-worker.

Control Model

t_H	A previous time horizon.
t_{step}	The time between each update of the robot's confidence in the human.
Ω	The control value which determines whether a role change is initiated.
ω_1	The second derivative of confidence component of Ω.
ω_2	The first derivative of confidence component of Ω.
ω_3	The confidence component of Ω.
$\bar{C}$	Average value of confidence in the time interval t_H.

$\bar{\dot{C}}$	Average value of the first derivative of confidence in the time interval t_H.
$\bar{\ddot{C}}$	Average value of the second derivative of confidence in the time interval t_H.
$\bar{C}_{thresh}$	The confidence threshold under which the value of ω_3 will be negative.
$\omega_{1,max}$	The maximum value of ω_1.
$\omega_{2,max}$	The maximum value of ω_2.
$\omega_{3,max}$	The maximum value of ω_3.
$\lambda_{\dot{C}}$	The sensitivity of ω_2 to changes in $\bar{\dot{C}}$.
$\lambda_{\ddot{C}}$	The sensitivity of ω_1 to changes in $\bar{\ddot{C}}$