Human Pose Estimation During 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 requirements for a degree except as fully acknowledged within the text.

I also certify that the 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

Robotic systems designed for physical Human-Robot Collaboration (pHRC) are being increasingly used to augment the strength of a human co-worker by providing assistance during the collaboration. The pose of the human body greatly affects the physical strength of the human co-worker and is often difficult to measure in real pHRC applications due to factors such as poor illumination, air quality and the close proximity of the human co-worker to the robot. This thesis aims to address three research challenges in human pose estimation during pHRC in practical industry applications: (1) the effect of interaction between the human and the robot on the pose of the human; (2) whether the pose of the human can be estimated by exploiting the Human-Robot Interaction (HRI); and (3) if the estimated pose can be used to facilitate real-time appraisal of the human co-worker's physical strength.

The challenge in determining the pose of a human co-worker during pHRC was approached in two ways. Firstly, experiments were performed to observe the effect that the interaction between the human and the robot had on the adopted pose of the human upper limb. This study determined whether existing pose estimation methods can be used in real pHRC applications. The second approach was to exploit the HRI for estimating the pose of the human in applications where the hand poses of the human co-worker were able to be inferred from the interaction. Thus the nullPose method was developed to estimate the pose of the human upper body in real-time. The nullPose method integrates sensor measurements and approximations to the pose of the upper body whilst ensuring the estimated poses are humanly possible. The nullPose method was then used to perform a real-time appraisal of the human co-worker's capability which was compared to a conventional batch-processed method of estimating the human strength.

Experiments were conducted in two different environments to verify the methods. The first environment was a motion capture lab which allowed the pose of the human to be recorded such that the effect of HRI on the upper limb pose was able to be studied. This environment also allowed the estimated pose from the nullPose method to be compared to the real pose of the human co-worker. The second environment was an abrasive blasting chamber where a real pHRC operation was performed. This environment was used to determine the suitability of the nullPose method for use in real challenging industrial environments where traditional methods of pose estimation were not able to be relied upon.

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Contents

List of Figures

List of Tables

Acronyms & Abbreviations

1D	One-Dimensional
2D	Two-Dimensional
3D	Three-Dimensional
AAN	Assistance-as-Needed
ANBOT	Assistance-as-Needed roBOT
AR	Augmented Reality
CAS	Centre for Autonomous Systems
DOF	Degrees of Freedom
EMG	Electromyography
GH	Glenohumeral
HRI	Human-Robot Interaction
IAD	Intelligent Assist Device
IK	Inverse Kinematic
IMU	Inertial Measurement Unit
UTS	University of Technology Sydney
MoCap	Motion Capture
MRI	Magnetic Resonance Imaging

MTU Musculo-Tendon Units

pHRC physical Human-Robot Collaboration

pHRI physical Human-Robot Interaction

RMSD root mean square deviation

RMSE root mean square error

ROM range of motion

sEMG surface electromyography

SE(3) special Eucledian group representing a rigid transformation in a 3-dimensional Euclidean Space

SO(3) special orthogonal group in 3 dimensions representing a rotation

SG shoulder girdle

SNS Saturation into the Null Space

WMSD Workplace Musculoskeletal Disorder

Glossary of Terms

Assistance	The act of helping someone by sharing the work or load.
Bimanual	Requiring two hands.
Capability	The power or ability to perform a certain operation.
Collaboration	The action of working with another human or robot to complete an operation.
Fatigue	The decline in the capability of a human.
Human co-worker	The human collaborating with the robot to complete an operation.
Inverse kinematics	Calculation performed to determine the joint values given a pose in Cartesian co-ordinates.
Kinematic chain	An assembly of rigid bodies connected by joints.
Musculoskeletal	Relating to the musculature and skeletal structure of a body.
Operation	Work to be completed by the human and robot.
Real-time	Able to respond to input immediately.
Physical strength	The amount of force able to be generated or opposed at the hand of the human co-worker.
Pose	The position and orientation of an object such as the end effector of a robot or the hand of the human co-worker.
Redundancy	The ability to adopt a different configuration without affecting the end-effector pose.
Swivel angle	The angle between the vertical plane passing through the shoulder and the wrist and the plane containing the whole upper limb.

Task	Motion to be accommodated by the joints of the upper limb kinematic models.
Target	A kinematic constraint obtained through sensors or approximations, used by the nullPose method to generate a better upper body pose estimate.
Torso half	The upper body of the human divided vertically in half.
Unimanual	Using a single hand.
Upper body	The human human from the waist up including the upper limbs, torso and head.
Upper body half	The human upper body from the waist up divided vertically in half. Each upper body half consists of a torso half and an upper limb.
Upper limb	The human upper limb starting from the shoulder down to the hand.