Human Teleoperation of a Laterally Mounted Robot Arm

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Contents

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Abstract

Abstract goes here.

Declaration of originality

I hereby confirm that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Copyright statement

Acknowledgments

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1 Introduction

The goal of this project is to create a system for controlling and teleoperating a robot arm with a human arm. In order to maintain simplicity in the project scope, the robot arm is assumed to be shoulder-mounted and has the seven degrees of freedom (DoF) [1], matching that of a healthy human arm.

1.1 Background and motivation

The motivation for this project comes from articles within the books: “Human–robot teleoperation based on Imus” [2] and “Whole-body human-motion based robot teleoperation” [3], which both describe research into remote teleoperation of shoulder-mounted robot arms. Both articles describe the use of an inertial measurement unit (IMU) based solution to obtain data from the human operator. The limitation in both of these articles is that they only map the end effector position of the robot arm to the wrist position. Because the human arm has redundancy in the number of joints available [4], a robot arm only mapping the end effector position could end up with its forearm or upper arm in a position that causes collisions, even though the end effector is in the target position. This ambiguity could lead to collisions with obstacles in the environment, and lack of safety for people within the envelope of the robot arm.

Whilst not necessarily critical in the use cases that Zhou et al. and Lyu et al. describe - remote welding inspection and simple delivery and manipulation tasks for an elderly patient - a scenario that is obstacle rich would require precise control of the robot arm. One such scenario is an underwater environment where a telescopic robot arm is attempting to collect a sample. Whilst Jin et al. describes a potential autonomous solution [5], this method is comparatively slow to the prospect of remote teleoperation: ranging from five to nine seconds in the simple case where the target object and origin of the robot arm is stationary. Consequently, the complexity increase for the case where nothing is stationary, a more realistic use case, would mean that this method would be inefficient compared to the intuition of a trained operator. Additionally, Jankowski and Grabowski shows that for tasks involving teleoperation of a robot for pick and place tasks, virtual reality style mapping of head movements with arm to end effector mapping is more efficient and less error prone than a typical joystick [6].

Other potential areas of application of full arm tracking could be in the medical industry and with surgical robots, where collisions with patients is unwanted. Likewise, nuclear decommissioning robots where absolute accuracy of matching an operator's intentions is critical.

1.2 Aims and objectives

The overall aim is to create a system for mapping the joint angles of a human arm to a shoulder-mounted robot arm.

To achieve this goal, there will be an evaluation of available arm tracking methods. Many methods currently exist for tracking the joint angles of robot arms, including: IMU based solutions discussed earlier, attitude and heading reference systems [7], computer vision based systems [8], and flex sensor based systems [9], among others. A rigorous examination of these methods will be conducted as a prerequisite to the final implementation, to understand the applicability and feasibility of each tracking system. Relevant tracking metrics will be discussed in the literature review, but include factors such as cost, accuracy, engineering complexity, etc. These metrics have been selected in order to allow for the feasible completion of this project given the time, scope and availability of resources for the final year project.

Finally, it is acknowledged that the procurement of a seven DoF robot arm is unlikely for a Bachelor's thesis. Hence, the final implementation of the tracking method will be created in the form of a simulation in CoppeliaSim. This has the advantage of being able to set up precise scenes for the evaluation of the final tracking method chosen, as well as comparison with baseline methods such as joysticks or pure end effector mapping. Likewise, the robot could be customised to match the proportions of the operator's arm perfectly, which would increase ease of use for the operator.

2 Literature review

2.1 Introduction

The measurement of human arm joint angles has been an interest of academia for several decades: with one of the first examples being demonstrated by Liu et al. In industrial settings, full body tracking has primarily been used in the film industry to map an actor's performance onto computer generated characters [11]. The main advantage of this is to save time in the creation of realistic looking movements [12], as an actor is able to portray realistic and nuanced motion that gets digitised.

Therefore, it seems logical that one should be able to combine the two applications - have a skilled operator trained in specific movement patterns to remotely control industrial robots where traditional control methods (e.g. joysticks) are unsuitable. For example, in an application that compared participants performance between a purely joystick based control method, and VR control with hand tracking, tasks were completed up to 1.8 times faster and with a quarter of the errors (1.54% compared to 8.65%) in the best cases) [6].

Likewise, research from Doisy et al. also seems to indicate that the time to complete a novel teleoperation task was initially better when users had their head movements mapped to the control of the robot's vision systems [13]. However, it is important to acknowledge that this study also showed that overall performance improved with experience between trial groups, and participants with more experience controlling the robot did better when controlling the robot via joystick. The overall takeaway from this is that whether or not a novel approach to teleoperation is more effective than traditional joysticks is strongly dependent on the task. Research conducted by Zhou et al. shows that the control of a seven degree of freedom robot, could be improved via human arm teleoperation, which strengthens the justification for this project.

2.2 Project requirements

In order to compare the final system to existing systems and research, a baseline performance must be characterised. This has been categorised into three distinct goals for the final system: position based requirements, time based requirements and resource based requirements. These requirements will help to compare the existing technologies in the next subsection.

Existing research into the lower bounds of human arm accuracy shows that experienced surgeons have approximately $5°$ of vertical movement range on all joints when asked to hold their hand on a target, and close to $3°$ range for horizontal movement. The study performed by Nisky et al. was performed with novice and expert surgeons, which would imply that this range of joint movement is above average for most humans. Taking this into account, the requirements are that the final system must be able to measure joint rotation in each joint up to a resolution of $5°$. Any movement measured less than this resolution is presumed to be 'noise' from human inaccuracy, and will therefore need to be smoothed out in the final implementation. This way the system is able to accurately capture the intent of the operator's movement, whilst preserving some level of accuracy.

Similar research exists for time based requirements as well, especially in the area of latency. It seems intuitive that more delay in a teleoperation system will decrease performance - research suggests that this manifests itself within two key figures of 600 ms and 1500 ms [15]. Task performance generally decreased with latency, with task performance falling at a latency of 600 ms and any latency above 1500 ms showing the most significant drop in task performance. Therefore the final arm tracking system should aim to measure arm angles well below the 600 ms threshold. The Nyquist criterion equivalent of this threshold is used as a well informed estimate of how much latency can be present in the system, leaving a final requirement of 300 ms.

The budget for this project is £180. This means that the final solution must be cheaper to implement than this. Likewise, the time to complete this project is 30 unit credits worth of time, equating to 240 hours of time commitment, excluding time required for completing written deliverables. Both of these factors will mean that the final solution favours simpler, more complete solutions - anything novel is a potential failure point that could mean the project does not complete.

2.3 Survey of existing tracking technologies

In order to fully evaluate the myriad of arm tracking methods available, a Pugh Matrix has been created to evaluate and compare several factors between each method. Each method will score $1 - 5$ in each category, with a brief comment justifying the score in each column.

Below are the decision factors of the Pugh Matrix and a brief description of how they are scored:

- **Complexity** - This is calculated based on a well reasoned estimate of the total time to build the system. Each multiple of 48 hours reduces the score by 1, e.g. $0 - 48$ hours would score 5, $49 - 96$ hours would score 4.
- **Cheapness** - This is calculated based on a well reasoned estimate of the total cost of building the system. Each multiple of £36 reduces the score by 1, e.g. £$0-$£36 would score 5, £$37-$£72 would score 4.
- **Accuracy** - This is calculated from available research on the accuracy of this method. Each multiple of $5°$ above $5°$ reduces the score by 1, e.g. an absolute accuracy of $6 - 10°$ would score 4, $11 - 15°$ would score 3.
- **Latency** - This is calculated from available research on the time it takes to obtain a single measurement of all 7 joint angles from this method. Each multiple of 100 ms above 300 ms reduces the score by 1, e.g. a latency of 301 ms $- 400$ ms would score 4.

Method	Complexity $1-5$	Cheapness $1-5$	Accuracy $1-5$	Latency $(1-5)$	Total
IMU-based	3 Approximately 100 hours for drift correction	4 £$50-$£60	3 $2.8°$ [16]	5 <1 ms [17]	15
Pose estimation via computer vision	5 Existing solutions	5 £30 USB Camera	3 $10° - 15°$ [18]	5 ≤ 100 ms [19]	18
Flex Sensors	3 Moderate fab	4 £40-60	3 10-15° error	5 <100ms	15
AHRS	3 Moderate setup	3 £80-120	4 5-10° error	4 100-200ms	14
Marker tracking via computer vision	2 Very complex	2 £150+	5 <5° error	4 100-200ms	13

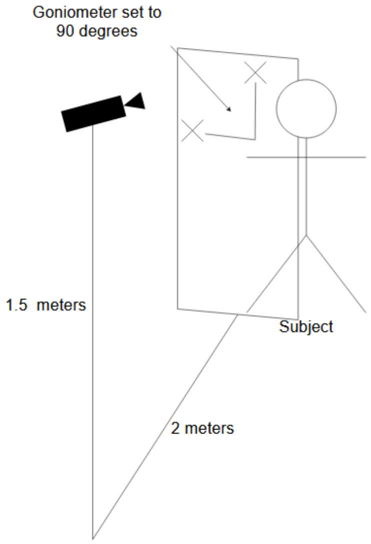
Table 1. Pugh Matrix with detailed scoring justifications

Analysis of existing methods shows that the two computer vision approaches score the same in terms of viability, therefore further analysis will be required to confirm the viability of each method. These will be performed in the form of accuracy and latency experiments, which will give the freedom of being able to analyse more factors than the literature - including accuracy of measuring multiple joints angles simultaneously.

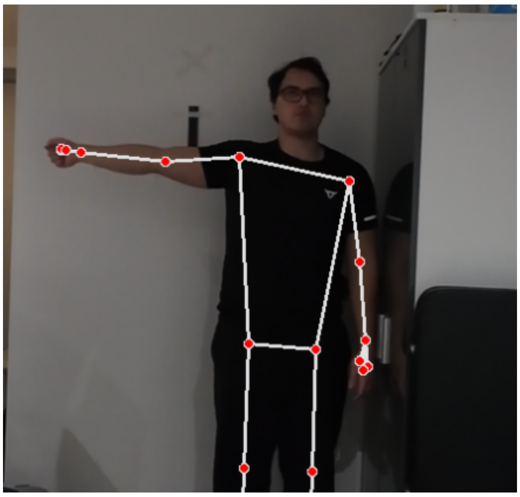
3 Methods

3.1 Comparison of both computer vision methods

In order to evaluate the accuracy of both computer vision methods, a simple experiment was set up to measure the absolute accuracy on the joint angles that can be measured. A goniometer is attached to the wall at $90°$, with two end positions marked at $90°$ and $180°$. The subject will move their arm repeatedly between these markers, and the recording is captured by a camera as described in fig 1.



(a) A diagram of the experimental setup.



(b) Example data capture

Fig. 1. The experimental setup, showing data capture.

The subject will then flex and extend their elbow between the two endpoints. In order to obtain a sufficient amount of data, 5 videos are recorded, each showing 10 flexion and extensions. This creates enough samples to perform ANOVA between each video, to maintain experimental integrity. In order to measure error, the graph of elbow flexion angles is extended towards the $90°$ and $180°$ endpoints. This secondary graph is then subtracted from the first graph to obtain the error value, from which we can calculate the root mean square error, and is shown in fig 2.

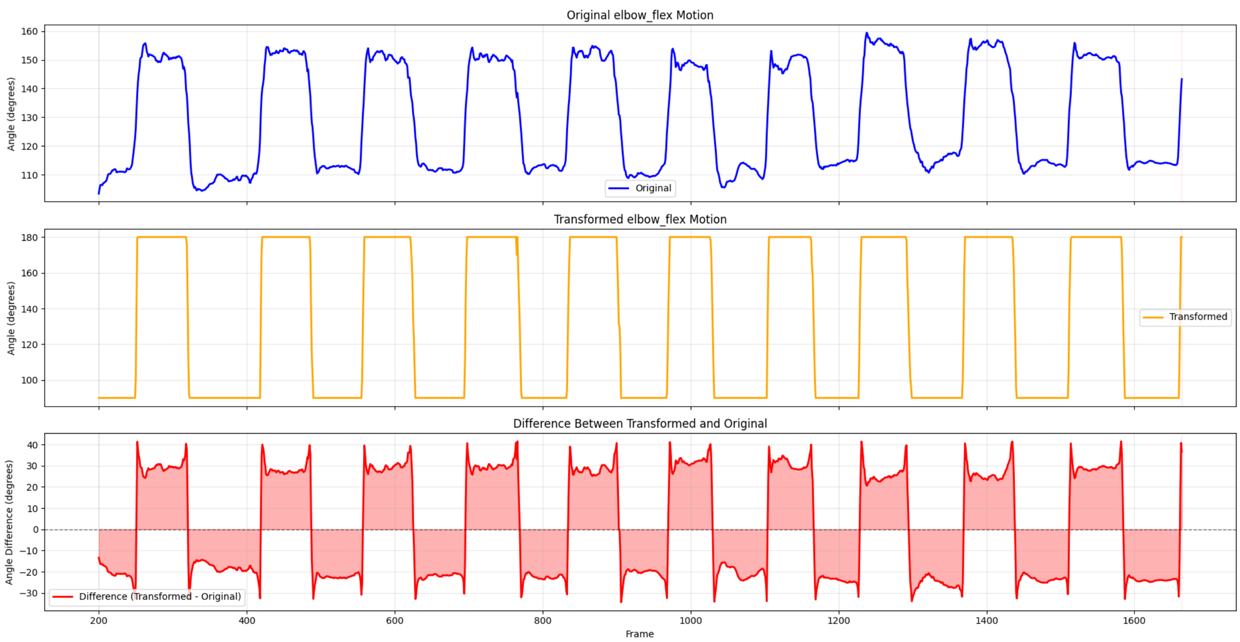


Fig. 2. Showing how RMSE is calculated from elbow flexion data.

Upon analysis of the RMSE, it was found that this value was $25.4°$. which was greater than the literature value of $10.37°$ [18]. Frame by frame analysis of the video showed that this descrepancy was not attributable to human error - the arm was clearly flexing and extending to the correct end-points. Plotting the inferred joint positions frame by frame revealed the culprit - perspective! The machine learning model used for joint position extraction is finding extra movement in the depth axis of the video, and attributing it to roll in the elbow axis, instead of flexion. This is clearly shown in fig 3.

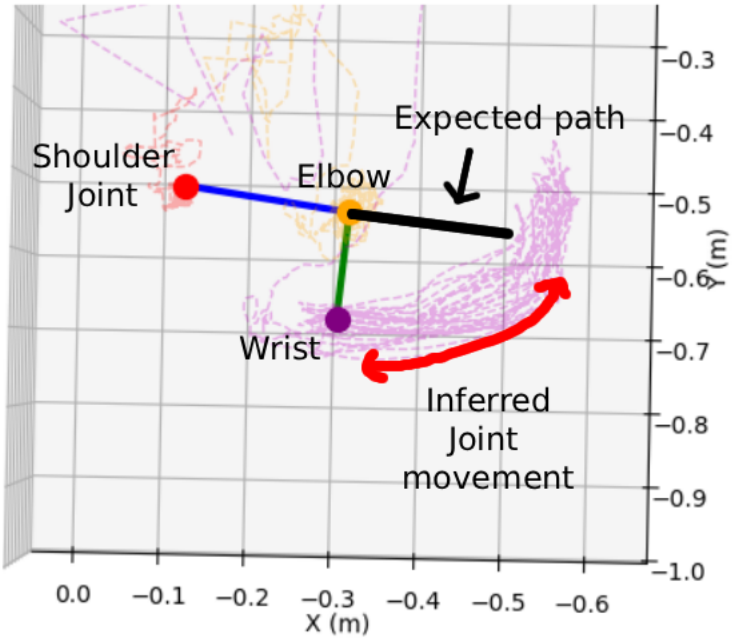


Fig. 3. Top view of inferred 3D joint positions.

3.2 Summary

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4 Results and discussion

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5 Conclusions and future work

5.1 Conclusions

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Appendices

A Project outline

Project outline as submitted at the start of the project is a required appendix. Put here.

B Risk assessment

Risk assessment is a required appendix. Put here.