**Chapter 1**

**Background**

In the last few decades, the world has seen a radical shift in the way that autonomous systems are utilised in the manufacturing industry. As factories and warehouses begin to become more reliant on robots performing repetitive tasks, there has been an upsurge in the number of other industries looking to enhance their everyday operations through the implementation of autonomous systems. Thanks to recent robotic developments in the areas of portability, safety, and ease of use, this new generation of collaborative robots has been designed to work alongside humans in the workplace. Collaborative robots have continued to push the bounds of what was previously seen as work that could only be performed by a human worker.

The use of robots in a lab environment is not a foreign concept, although now they are being considered for use in liquid handling and data collection roles. It is believed that collaborative robots have reached a level of technological advancement that they are able to overcome the challenges faced by typical robots of rigid movements and being less adaptable to changing conditions.

A system that can measure the multitude of variables needed to accurately compute the physical properties of a liquid such as it mass, volume and viscosity would be a great benefit to a lab environment. The addition of such a system would allow a lab to effectively automate research and provide a cost-benefit to the organisations that utilise them.

In recent years there have been many attempts at developing a system that could perform these tasks to an acceptable degree. Methods such as the use of a camera to measure the changing height of a poured liquid, as presented in (Do & Burgard, 2018) and (Schenck & Fox, 2016), found that there were shortcomings with the use of transparent liquids such as oil. These methods were also susceptible to inaccurate data from their video data. Another intuitive method found was presented in (Liang, et al., 2020) and featured acquisition of liquid data based upon audio feedback of the pouring liquid. Like the previous methods this too was considered unsuitable due to erroneous data from the audio sensors and its incompatibility with highly viscous fluid.

The inspiration for this project was based upon the work presented in (Matl, et al., 2019). The method used in this paper was the use of a robotic arm with an accurate force/torque sensor. Based upon mechanical movements made by the arm and data readings for the mass and torque, it would be possible to accurately measure the properties of a liquid within a container such as mass, volume and viscosity. This method contained significant advantages over other papers such as having a wide range of liquids that could be accurately measured, regardless of viscosities or volume. Whereas other methods were centred around pouring of a liquid, this method was capable of measuring a liquid within an enclosed container. This project explores the use of this system design for the goal of autonomously measuring the physical properties of a liquid.

**Research Objectives**

The aim of this project is to develop a system that is capable of measuring the properties of a liquid through mechanical manipulation and data gathering via a robotic platform and mathematical models.

Specific objectives:

* Utilise the approach presented in (Matl, et al., 2019).
* Combine the above approach with a real autonomous system.
* Demonstrate the validity of this system as a solution to collecting physical properties of liquid samples.

**Report Organisation**

This report is organised as follows:

* Chapter 2 explores previous work that has been used to influence the project.
* Chapter 3 details the project approach and discusses the implementation of the chosen method.
* Chapter 4 presents the experimentation process and the project results gathered.
* Chapter 5 discusses the results and suggests project changes and potential future work that can be performed.
* Chapter 6 is the conclusions that were drawn from this research project.

**Chapter 2**

**Related Work**

**Liquid Mass Measurement**

Knowing the mass of a sample being manipulated by a collaborative robot has been a widely studied aspect of autonomous liquid handling systems. Due to the relative inaccuracy of visual data, liquid mass measurements are the prime method of calculating further physical properties of liquids such as volume from a known density, or density from a known volume. Solutions to the problem of collecting liquid mass data by autonomous systems has often been dependant on its final application. In the research papers (model based flow rate control) and (Outflow Liquid Falling Position) the solution to the problem of liquid mass measurement came from load-cell that were utilised during liquid pouring operations. Whereas this solution was adequate for the application of the systems described in the papers, it would be unsuitable for system applications involving careful handling of liquids.

This is in contrast to the method presented in (Matl, et al., 2019) where the liquid mass is based off of sensors readings from a force torque sensor. This is due to the project scope in (Matl, et al., 2019) being to design a system capable of measuring the physical properties of a liquid from within an enclosed container.

**Liquid Volume Measurement**