Towards a Universal End Effector: The Design and Development of Production Technology's Intelligent Robot Hand

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Abstract

Research into robot hands for industrial use began in the early 1980s and there are now many examples of robot hands in existence. The reason for research into robot hands is that standard robot end effectors have to be designed for each application and are therefore costly. A universal end effector is needed that will be able to perform any parts handling operation or use other tools for other industrial operations. Existing robot hand research would therefore benefit from new concepts, designs and control systems.

The Department of Production Technology is developing an intelligent robot hand of a novel configuration, with the ultimate aim of producing a universal end effector. The concept of PTIRH (Production Technology's Intelligent Robot Hand) is that it is a multi-fingered manipulator with a configuration of two thumbs and two fingers.

Research by the author for this thesis concentrated on five major areas. First, the background research into the state of the art in robot hand research. Second, the initiation, development and analysis of the novel configuration concept of PTIRH. Third, specification, testing and analysis of air muscle actuation, including design, development and testing of a servo pneumatic control valve for the air muscles. Fourth, choice of sensors for the robot hand, including testing and analysis of two custom made air pressure sensors. Fifth, definition, design, construction, development, testing and analysis of the mechanical structure for an early prototype of PTIRH. Development of an intelligent controller for PTIRH was outside the scope of the author's research.

The results of the analysis on the air muscles showed that they could be a suitable direct drive actuator for an intelligent robotic hand. The force, pressure and position sensor results indicate that the sensors could form the basis of the feedback loop for an intelligent controller. The configuration of PTIRH enables it to grasp objects with little reliance on friction. This was demonstrated with an early prototype of the robot hand, which had one finger with actuation and three other static digits, by successfully manually arranging the digits into stable grasps of various objects.

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Author's Publication

The following publication was prepared during research for this thesis:

Harris, M.T. & Nahavandi, S., *Design and Development of an Intelligent Robotic Hand*, Proceedings of the 2nd New Zealand Postgraduate Conference for Engineering and Technology Students, Auckland University, New Zealand, pp. 119-124, August 1995.

Chapter 1

INTRODUCTION

1.1 Topic of Research

The robot hand project which is being undertaken in the Department of Production Technology at Massey University is known as PTIRH (Production Technology's Intelligent Robot Hand). PTIRH is intended to be a major step forward towards universal end effectors for robots and to be able to perform small assembly and material manipulation operations.

The research undertaken by the author is concerned with the design and development of the mechanical robot hand, which is to be a step towards a universal robot hand. A robot hand is a multi-fingered manipulator for a robot. The human hand is a successful design for a multi-fingered manipulator and so examination of the human hand is important in the design of robot hands. The dexterity of a robot hand comes from considering dexterity issues in the design of the mechanical structure and the intelligent control system.

The development of a universal robot hand is becoming essential for applications in which changes in robot arm end effectors are undesirable. Space exploration is one field where it is important that a single end effector be able to grasp and manipulate any object deemed necessary [1]. In the factory, time spent changing end effectors can delay an automated process and a single universal gripper could be of lower cost than many specialised end effector manipulators. Ideally a single end effector would be able to perform every operation required of the robot system. Instead of being just a complicated tool on the end of the robot arm, the end effector should be capable of using other tools. Salisbury [2] states that robot hands can be used to extend manipulation capability in terms of cost effectiveness and in terms of the overall complexity of tasks that may be performed.

PTIRH will use a novel form of actuator for robot hands which the author believes to have advantages over the DC electric motors and pulley systems approach of other robot hands.

The hand configuration is two thumbs and two fingers. No other hands of this configuration have been found in an exhaustive search of the literature. Two thumbs will be advantageous in grasping and manipulating due to the lesser reliance on friction to maintain the grasp. This will enable the grasp and manipulation control system to be simpler, possibly at the expense of a more complex control system for moving the extra thumb.

1.2 Scope of Research

The research reported here concerns the development of a robot hand that is to be a step towards a universal end effector. In particular, this thesis reports on the processes involved with the design of the mechanical robot hand, the implementation of the design and testing of the design. The development of an intelligent controller is outside the scope of this research.

Robot hands to date have suffered from limitations imposed by their mechanical design and availability of actuators. To achieve a robot hand which avoids the limitations of other robot hands, two novel concepts were proposed. These were: the use of a non-anthropomorphic configuration of PTIRH and the use of novel pneumatic 'air muscle' actuators. Through the use of these two concepts in the design of the robot hand and integrating sensors in to the design of the hand, a mechanical hand will be constructed to enable research and development in the area of an intelligent control system for the hand.

Research in both concept areas was to follow a planned development cycle of design, implementation and testing. The aim of the design phase consisted of firstly investigating the topic and secondly developing specifications. The implementation phase was concerned with taking the specifications and implementing them on a prototype.

It was realised early on in the research that construction and testing of an entire robot hand was constrained by time. Therefore the area of the non-anthropomorphic configuration of an entire hand was confined to design, with a single prototype finger being constructed for testing. An early prototype of the robot hand was constructed which will include the prototype finger and three other digits without actuation. Testing will occur on the components of the finger and the concepts behind the two thumb, two finger robot hand configuration.

1.3 Structure of Thesis

The research and development for this work takes the project from the literature review, feasibility study and design concept stage through the design and development stage and up to the testing of the prototype robot hand and the analysis of the concept of PTIRH. The structure of this thesis reflects this design process.

Chapter One provides an introduction and scope for the research. Reasons for research and development into robot hands are given with an emphasis on the definition of intelligent robotics.

Chapter Two reviews the literature on robot hands and relevant background topics to robot hand research. As robotics is a bringing together of many different types of technologies and skills, so too is robot hand research, with an added emphasis on human hand physiology. The state of the art is examined, with a particular emphasis on learning from the successes and avoiding the problems.

In chapter Three the design goals for Production Technology's Intelligent Robot Hand are given. The reasons for the choice of sensors and air muscle actuators are given. The design of a servo pneumatic valve to use with the air muscles is explored. The mechanical design process for PTIRH is described and a final design chosen. The implementation of the design into a prototype robot finger and an early prototype robot hand is discussed.

Chapter Four evaluates the results of testing on the prototype intelligent robot finger and gives the analysis of the PTIRH concept. The success of the robot finger is discussed, along with the servo pneumatic valve, the air muscles and sensors. The prototype hand is used to demonstrate grasps possible with the two thumb, two finger configuration.

Chapter Five concludes the thesis.

Chapter Six has suggestions for future work in the research and development of intelligent robot hands in the Department of Production Technology at Massey University.

Relevant experimental data and design drawings for the hand are included in the appendices.

1.4 The Reasoning Behind Building Robot Hands

As robotic systems become integrated into flexible manufacturing systems there is a need for robots to become more universal in their application. In order for the true flexibility of robots to be realised, end effectors need to become less of a tool to do one particular operation and more of a device to use a tool. Other applications have a need for universal robotics also. NASA has identified that remote dexterous manipulators are critical to the successful maintenance of space stations [1].

A common universal end effector design is anthropomorphic in nature, although other configurations have been proposed. In the Production Technology Department at Massey University design and development is proceeding on an intelligent robot hand that will be able to perform many different functions. This intelligent robot hand will have a configuration of two fingers and two thumbs.

An intelligent robot hand is a step towards a universal end effector for a robot arm that has the same functions as a human hand (often resembling a human hand) and can grasp and manipulate objects in a manner similar to a human hand. An intelligent robot hand is part of a closed loop with its controller and has sensors to give information to the controller. An intelligent robot hand is intended to be as universal as possible so it can be used for any task with little or no reprogramming, understanding the change in task through feedback from sensors. The intelligence of a robot can also reduce the need for other equipment, such as part orientation guides, or controllers in a robotic work cell [3].

Intelligent control systems for robots can take a programmed motion and alter it in response to environmental conditions in the work place [4]. Intelligent robots can communicate with their operators or other computer-based systems, integrate and fuse information from sensors and model their environment. The ultimate intelligent robot would be able to repair itself. At the current state of the art, the level of intelligence of intelligent robots is primitive at best but will improve with advances in micro-actuators, parallel processors and smart sensors. Even the addition of a simple sensor and a control system to use the feedback can make a robot manipulator more intelligent than one without the sensor and control system.

There are three basic reasons [5] for utilising intelligent robots:

1. Technical - improving the quality of the product, reducing the waste from the process and increasing flexibility in the process.
2. Economic - cost benefits of robots that can work non-stop, which result in improved utilisation of other equipment and the freeing up of trained people for jobs which can not be done by robots.
3. Social - taking humans out of jobs that are dangerous, unhealthy, boring and arduous.

Sixty percent of parts in robotic assembly can be handled by manipulators with two fingers. Another twenty five percent can be handled by three fingered manipulators and the remaining parts require handling by four or more fingers [6, 7]. Therefore it is concluded that a manipulator based on a human hand, "the finest machine ever created" [8], will be able to handle all parts involved in robotic assembly.

Current robot hands of four or five digits are considered by some researchers not to be suitable for assembly operations because of their slow movement, low reliability and bad positioning accuracy[9]. However, other researchers say that more fingers will be an advantage. Jacobsen et al [10] believe a greater number of fingers results in even more versatile hand designs, finger redundancy permits more flexibility in grasping and manipulations are easier. Tanie [11] holds that increasing the number of fingers up to a maximum of five will allow the capability to accommodate change in object shapes. Alexander [12] believes that with more than five fingers even more complex tasks than those already possible could be performed. Any multi-fingered robot hand will certainly need to be fast moving, reliable and accurate, while taking advantage of the redundancy and grasp options available with more fingers.

The human hand is very versatile; as well as being a powerful tool itself, it is able to use an almost unlimited range of other tools. Some researchers [13, 14] consider this a disadvantage in robotics, believing that a multi-finger approach will complicate the assembly process, be expensive and that it would be a mistake to assume the human hand is the ideal gripper as the manufacturing world is much more restricted than the one for which the human hand is designed. They point out that the human hand often has to use pliers, tweezers or gloves to be able to pick up certain objects.

There is no doubt that a multi-fingered manipulator will be more complicated, and hence costly, than the standard two jaw grippers. That the manufacturing world is a subset of the human hand world is no problem, rather an advantage, as the world view needed for a robot hand is therefore reduced. The present two fingered robot grips could be compared to a person using only pliers to do every task.

The human hand makes a good starting point to begin to build more versatile, universal grippers. The 27 degrees-of-freedom a human arm and hand have are matched by state of the art hands connected to state of the art robot arms. However, the number of grasps and manipulations, and the variations, that the human hand can perform is impressive and can not begin to be matched by the robot hands of today. The grip most often used by robots at present is a simple pinch and the opposition found in a human hand is one of its most important features. Any robot hand must include this ability.

There is no reason why the human hand could not be improved upon. For example instead of fingernails, screwdriver blades could be installed - people sometimes use their fingernails as screwdrivers which can result in a broken nail. The Utah/MIT Dextrous Hand project researchers are considering mounting the thumb centrally on their hand so that the hand could become right or left handed with a shift of the thumb. It should also be possible to control a hand so that it can perform grasps and manipulations unlike those of a human.

As well as the control challenges associated with having multiple robot limbs interacting together, the development of robot hands helps with understanding in areas of intelligent sensors, the development of tactile sensors, the effect of different hand configurations and how the various components of an intelligent hand work together to produce an optimum universal robot hand.

Much work has been carried out on anthropomorphic grippers. The reasons for this are simple. Firstly, all researchers have extensive experience with their own hands to compare with the robot hand performance. Secondly, the natural human hand provides proof that an anthropomorphic geometry, properly controlled, can perform many useful grasps and manipulations, as well as providing a means of communication. Thirdly, as well as being used as robot end effectors, anthropomorphic grippers are being used as prosthetic hands. However, with prosthetics form and appearance is often more important than function.

The intention here at the Department of Production Technology is to make a hand similar to the human hand in strength, speed, usefulness, dexterity, accuracy, range of motion, controllability and sensitivity.

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