IMPROVING ROBOTIC WELDING IN THE SHIPBUILDING INDUSTRY

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SUMMARY

The integration of robotic welding systems into some areas of the shipbuilding industry can present problems for engineers. The low level of repeatable welds within some ships means that, although the quality and speed of robotic welding are acceptable, the generation of a program capable of applying weld has proved difficult. This paper details current methods of program generation and discusses their effectiveness. It then discusses Artificial Intelligence (AI) techniques and presents a new automated visual system which uses AI techniques to determine where to weld. The proposed system uses a combination of AI techniques working in parallel to suggest weld requirements. These suggestions are then evaluated and decisions made regarding the weld required. These parameters are then sent to a new program generator, which produces a custom robot program for use on the shop floor.

1. INTRODUCTION

1.1 BACKGROUND

VT Shipbuilding (VTS) is one of the most established military shipbuilders in the U.K. A decision by the MOD to order six new Type 45 Destroyers from BAE Systems led VTS to invest in a new £50 million site in the Portsmouth Naval dockyard. The site houses some of shipbuilding's most modern technology in the form of robotic welding, laser and plasma cutting.

These manufacturing technologies are dependant upon 3D CAD models (robotic welding) or 2D CAD drawings (laser or plasma cutting) being available for programming the automation equipment offline. The 3D CAD models are particularly labour intensive and are generally only produced from 2D CAD drawings. This means automation can be sidelined in preference to manual welding operations.

Although the superstructure of a warship tends to be complicated, it can be a complexity of scale. A warship's superstructure can be described as a complicated object made from a large number of simple objects. This is because the vast majority of the structure is made from either metal bar (of varying sizes and shapes) or metal plate. In general, additional items are cut from metal plate.

1.2 ROBOTIC WELDING

Reasons for introducing robotics into welding operations include:

- Manufacturing Efficiency.
- Quality.
- Health and Safety.

Manufacturing efficiency is the most compelling of the factors governing the adoption of robotics. This is due to the potential reduction in labour costs and potential increase in factory throughput. Within the UK it appears to be becoming more difficult to find skilled welders; this means that effective robotic welding may become more important.

It may be debatable whether robotic welding is of better quality than human welding but a correctly operating robotic welder should produce a consistent and repeatable weld of satisfactory quality.

Manual welding is a laborious and difficult task undertaken in potentially hazardous conditions. This is demonstrated as every year in the UK over 1000 work related accidents to welders are reported to the Health & Safety Executive. Of these incidents, approximately 300 are categorized as major injuries [1].

Robots are best used when a high level of repeatability is found within the task to be automated. This is because the time taken to generate a robot program can be much greater than the time taken for the task to be completed. The ratio between time taken to program and time taken to undertake the task is important in determining the usefulness of robotics within an application.

Robotic welding has been integral to some industries for many years but has been slow to be incorporated into the shipbuilding industry. This may be due to the low level of repeated work carried out within the industry. The low level of repeatability is particularly prevalent within the naval sector where ship sections are often unique. For example, oil super tankers are suitable for automated manufacture as they contain many similar parts and panels. A modern naval warship may have no similar panels in the entire design. So robotic welding of some ships may require new programming systems.

1.3 PROPOSED SYSTEM

This paper proposes using image capture methods combined with a decision making system that uses multiple parallel AI techniques. This system is detailed within Section 4. The proposal uses object oriented programming techniques to create the framework for the system and uses imaging software to capture and process image data.

2. ROBOT PROGRAMMING METHODS

Three methods of programming an industrial robot are discussed. The programming methods detailed are:

- A teach pendant.
- A CAD model software system.
- An operator assisted visual system.

2.1 TEACH PENDANT

Programming a robot using a teach pendant allows an operator to instruct a robot without any specialist knowledge, other the use of the teach pendant.
This method of programming is categorised as online programming as the robot is unable to perform other tasks whilst programming is being undertaken.

A teach pendant is used to move the robot to successive positions of a desired path; each position is stored. A teach pendant is a natural and easily understood method as potential collisions are obvious and an operator can observe the program path.

Due to the ease of use of a teach pendant, an operator is not required to become adept with computer programming languages. Operators can therefore be recruited who are skilled in welding rather than programming and robotics.

The online nature of this programming method means that a robot is not productive during programming. This is accentuated by the time taken to produce a program using a teach pendant. [2]

2.2 CAD MODEL

The use of a CAD model to program a robot is categorised as an off-line programming method. Off-line programming may be considered as a process by which robot programs are developed partially or completely without the use of the robot. There can be a number of advantages to this method:

- Increase in robot efficiency.[3]
- Safety of the robot programmer.
- System integration with current CAD/CAM systems. This leads to benefits in production data gathering as well as less laborious programming.
- High-level languages allow complex tasks to be described in a simple, natural way.
- Ease of simulation of programs through the combination of the CAD model and the proposed robot program. [4]

CAD models are used to generate a 3D virtual model of the ship to be built. Systems that use the CAD model to generate a program operate by applying intelligent techniques to the model.

The use of a CAD model is the method by which the robots of VT Shipbuilding are programmed. The CAD model method has a number of disadvantages. A major problem is discrepancies between the CAD model and the Real-world. The VTS system has attempted to cope with errors by re-orienting a program model to Real-world coordinates before welding starts. This does not help if a beam is misplaced. The system can adjust for minor misplacements of individual beams with a touch sensing procedure; however, this system is not always effective. This is because the robot system that performs the check is limited in how far it can check. If the misplaced beam is too close, then the end effector will hit the beam before measurement can take place.

The production of the robot program from the CAD model takes place away from the shop floor and can take a considerable length of time. The production line nature of the plant at VTS means that the whole manufacturing process can be delayed due to waiting for the robot. Therefore if there is a problem with the robot program then the robot is bypassed.

A lack of transparency within this programming system means that an operator has little or no control over the path of the robot [4]. It also means that until the panel to be welded is within the robot's workspace, problems with the program cannot be determined. This is because the simulation system can only simulate the positional elements of a program and not how the robot will respond to the program. For example, if a program asks the robot to rotate too far on one axis then it will pass the simulation but may fail at runtime.

2.3 OPERATOR ASSISTED VISUAL SYSTEM

Systems have been developed that use an image to assist with the robotic program generation. These systems provide an operator with an image of the work piece and the operator then selects the start and end positions of each weld. This system sits somewhere between off-line and on-line programming in that the initial program cannot be generated whilst the robot is working, however, once the first program is being run by the robot, further programs for subsequent welds can be generated without interruption of the robot. There is also a substantial downtime period whilst the images are collected by the system.

This method solves the problem of CAD model to Real-world discrepancy. The cost is that an operator must enter the required welds manually. This is acceptable if the operator is only dealing with one robot however, the method limits the possibility of one operator monitoring multiple machines.

3. ARTIFICIAL INTELLIGENCE TECHNIQUES

AI techniques are discussed that will be tested for use within the proposed system detailed in Section 4.

3.1 FUZZY EXPERT SYSTEMS

Fuzzy Expert Systems (FES) use fuzzy logic to handle the uncertainties generated by incomplete or partially corrupt data. The technique uses the mathematical theory of fuzzy sets to simulate human reasoning. Humans can easily deal with ambiguity (areas of grey) in terms of decision making, yet machines find it difficult [5,6].

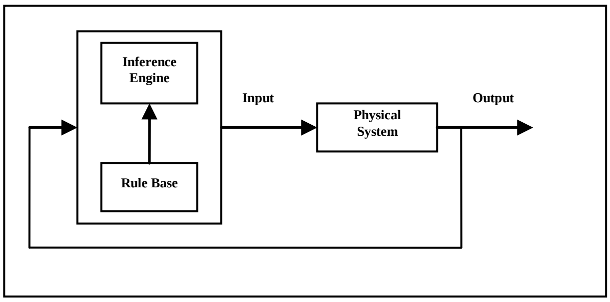

Figure 1 – A Fuzzy Logic Controller

Figure 1 shows the architecture for a fuzzy logic based controller as described by *Yen et al* [7].

Bloch [8] stated that there are a number of reasons why imprecision was inherent to images. These were:

- Imprecise limits between structures or objects.
- Limited resolution, numerical reconstruction methods.
- Image filtering.

Fuzzy Logic is well suited to this area. Applications in structural object recognition and scene interpretation have been developed using Fuzzy Sets within Expert systems [8].
FES are suitable for applications that require an ability to handle uncertain and imprecise situations. They do not have the ability to learn as the values within the system are preset and cannot be changed.

3.2 RULE BASED SYSTEMS

A Rule-Based System (RBS) is where the knowledge of the system has been described in terms of IF…THEN..ELSE. Specific knowledge can be used in order to make decisions [6]. Figure 2 shows the basic structure of an RBS as presented by Negnevitsky [9].

Sometimes called a Knowledge-Based System (KBS), the aim was to capture human knowledge and model it within a computer system. The KBS achieved this through the use of four main components [10].

- Knowledge base.
- Inference engine.
- Knowledge engineering tool.
- Specific user interface.

RBS are good at representing knowledge and decisions in a way that is understandable to humans. Due to the rigid structure of the rule-base they are not so good at handling uncertainty and are poor at handling imprecision.

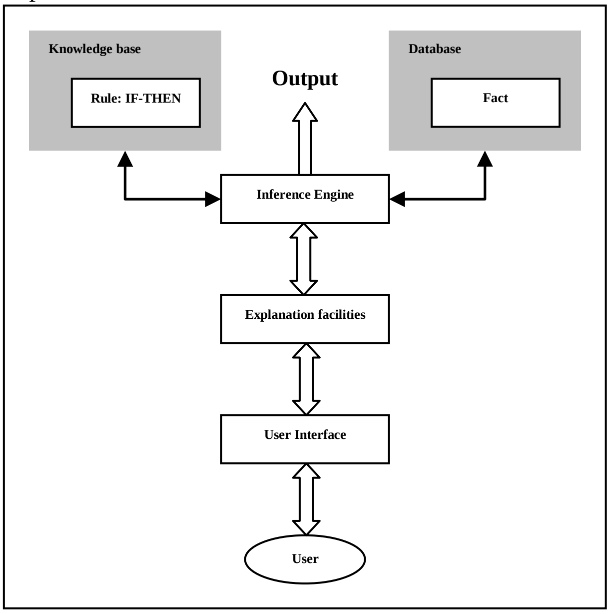

Figure 2 – A Rule-based Expert System

3.3 CASE BASED REASONING SYSTEMS

The concept in Case-Based Reasoning (CBR) is to adapt solutions from previous problems to current problems. These solutions are stored within a database and represent the experience of human specialists. When a problem occurs that a system has not experienced, it compares with previous cases and selects one that is closest to the current problem. It then acts upon the solution given and updates the database depending upon the success or failure of the action [11]. CBR systems are often considered to be an extension of Rule-Based Systems. As with Rule-Based Systems, CBR systems are good at representing knowledge in a way that is clear to humans, however, CBR systems also have the ability to learn from past examples by generating additional new cases.

3.4 HYBRID SYSTEMS

The purpose of a hybrid system is to combine the desirable elements of different AI techniques into one system. For example, FES are poor at learning due to the fixed nature of the values needed. This can be improved by the creation of neuro-fuzzy systems. Neural networks have the ability to learn which enables the fuzzy systems to learn.

4. PROPOSED SOLUTION

A solution to the weld programming problems detailed in Section 2 is presented. Sub-Section 4.1 explains the current system in place at VTS and discusses how additional systems may be integrated with existing systems.

The proposed system is discussed within sub-Section 4.2. Software systems required, image processing systems and the use of multiple artificial intelligence techniques to make decisions are discussed.

4.1 EXISTING SYSTEM

The existing system at VTS is shown in Figure 3. The system consists of two software systems working in series to construct viable robot programs. The first system, the CAD model interpreter, accepts a CAD model and determines the welds required. This data is fed to the Program Generator which re-orientates the weld requirements in line with the actual real-world orientation of the panel. The program generator then sends any programs sequentially to the robot (normally one program per weld line). Additional software systems could be incorporated into the existing system at the point where the robot programs are sent to the Robot System. This is because the transmission protocol at this point is standard TCP/IP and any programs to be sent can be viewed as text files.

4.2 PROPOSED SYSTEM

The proposed system in Figure 4 shows that data will be gathered from an image. This data will then be combined with the data contained within a CAD model. The Multi-Intelligent Decision Module will then use multiple AI techniques to suggest a required weld. This weld requirement will then be displayed for the operator to check. If the operator rejects the suggestion the system will learn from that rejection and suggest a different requirement. Assuming the operator now accepts the requirement, the system will generate a compatible robot program by using the program generator and post-processing systems.

4.2 (a) Software Systems

In the same way that the construction of the superstructure of a ship is broken into smaller elements such as sections, units and panels; the weld requirements can also be sub-divided. Figure 5 shows that a Panel is considered the largest practical part. This is intuitive as the factory system is such that Panels have specific documentation. It has therefore been proposed that each Panel be made up of a collection of one or more Jobs. The inclusion of this layer allows collections of Welds (the next layer) to be logical grouped together in order to improve production efficiencies. The final layer is that Welds are collections of Points. This is where the anatomy concept falls back into line with the real-world. Any linear weld can be described by determining just two points, the start and end. All the other points that are required can be extrapolated from these two points.

When creating the software systems to generate a required robot program, it was decided that an object oriented approach would reduce the development time. Object oriented technique offers easier handling of complexity within software and allow changes to be simpler during debugging. Figure 6 shows the hierarchy of OOP when compared to Rock's Level model [12], it can be seen that a weld or welds are made up of a robot program. That program is constructed from a number of actions. OOP will be the object of a further paper at the conference.

Actions are made up from one or more Commands, these Commands may include, for example, Weld (turns the weld on), LinearMove (moves the end effector in a linear movement) or any other command that may be required. When used, Commands are linked to one or more Instructions which are required to carryout the Command. This is the lowest level of the programming and generates script that can be interpreted by a robot controller.

Figure 7 shows some of the different positions that the end effector must move through to successfully weld. The touch sense points allow the robot to determine the precise location of the part to be welded in relation to the end effector. This is important as the end effector must be positioned within 2mm of the correct weld start point to achieve satisfactory weld quality.

4.2 (b) Image Processing Systems

The image processing systems involved detecting edges, line identification and geometric data generation. This data can then be used to identify the different objects within the image. A software package named 'WiT 8.3' by Dalsa Coreco has been used to reduce development time of the image processing system. This software has a graphical interface which is used to create and test algorithms. The final algorithm can then be exported as a VB.net compatible function for inclusion within a .net framework software package.

Figure 8 shows the iGraph (a graphical representation) output of the algorithm created within WiT. The image is read, converted to greyscale and then put through a low pass filter. The low pass filter removes some of the noise in the image and reduces the occurrence of small random edges. The image is then operated on by an edge tracing function which uses a Prewitt edge detection algorithm and then collates any edges into a collection of geometric lines. These lines are then overlaid onto the filtered greyscale image for viewing.

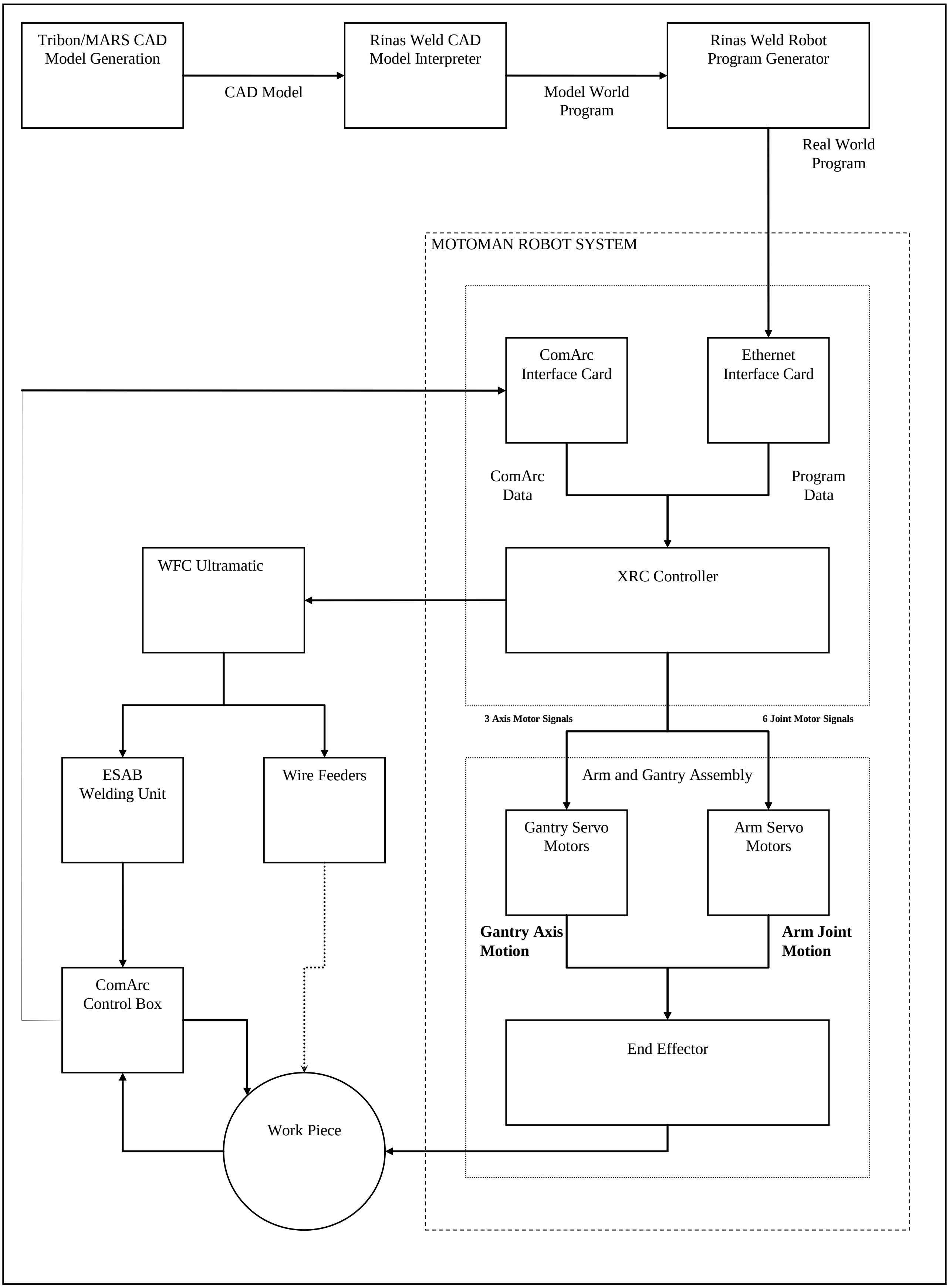

Figure 3 – Existing RinasWeld/Motoman System

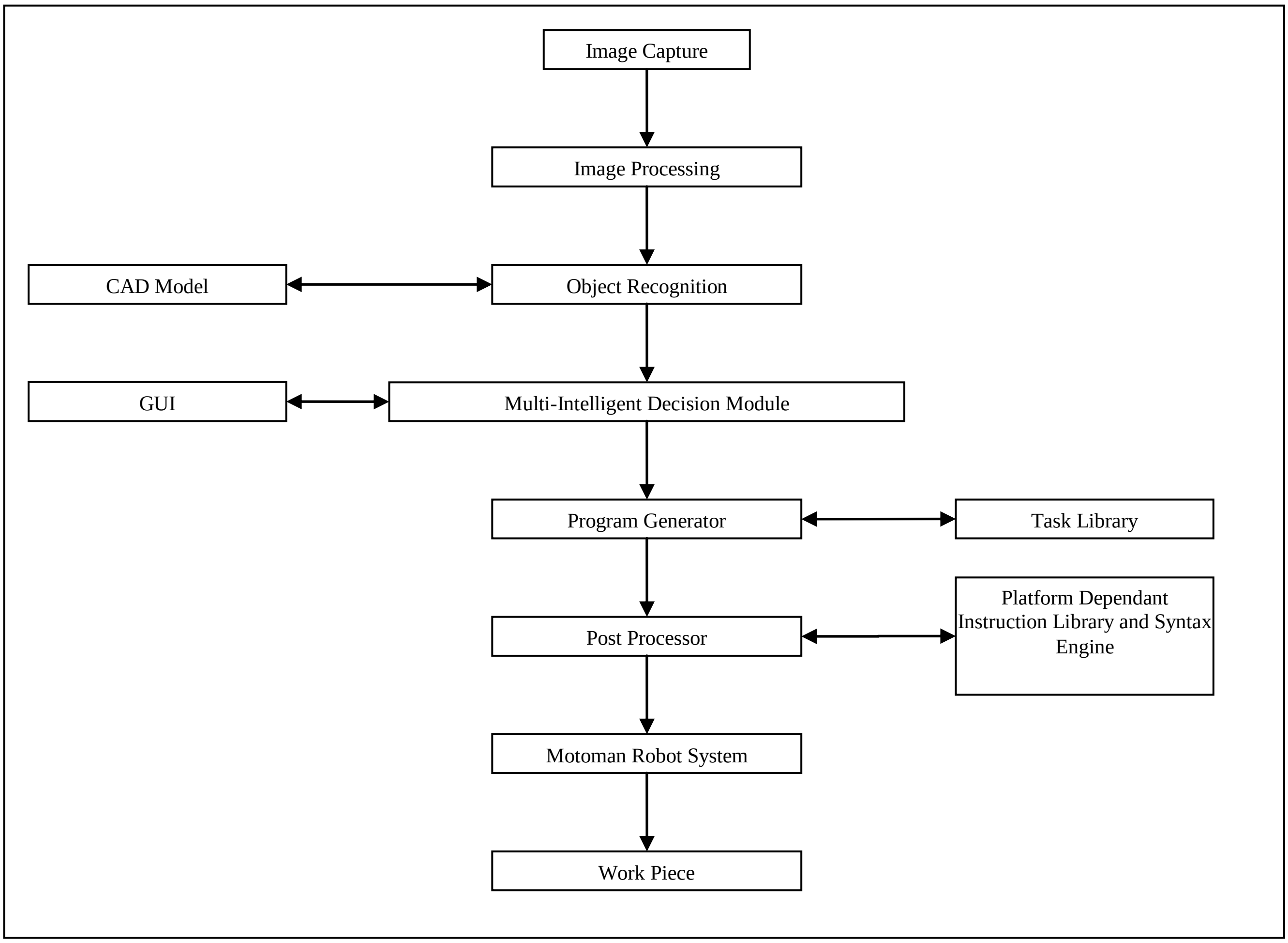

Figure 4 – Proposed System Flow Diagram

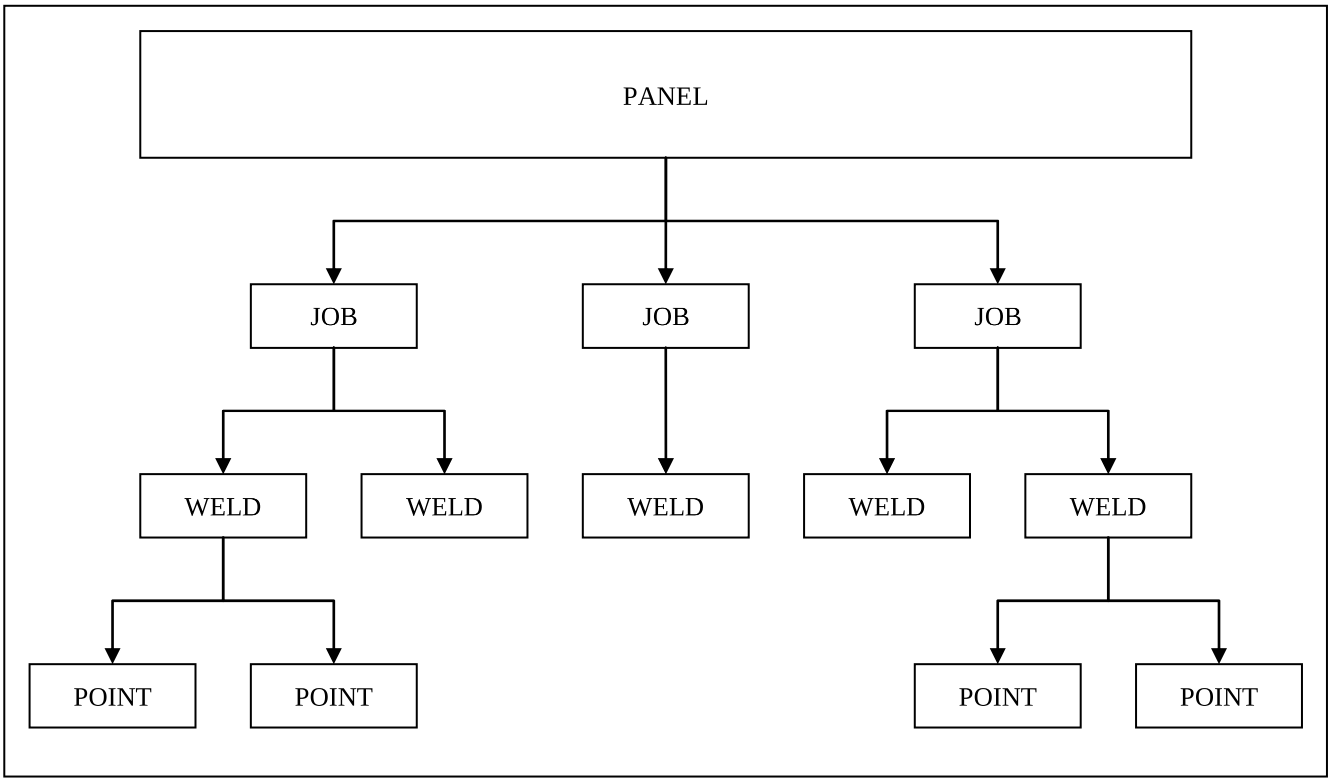

Figure 5 – Hierarchy of a Ship Panel

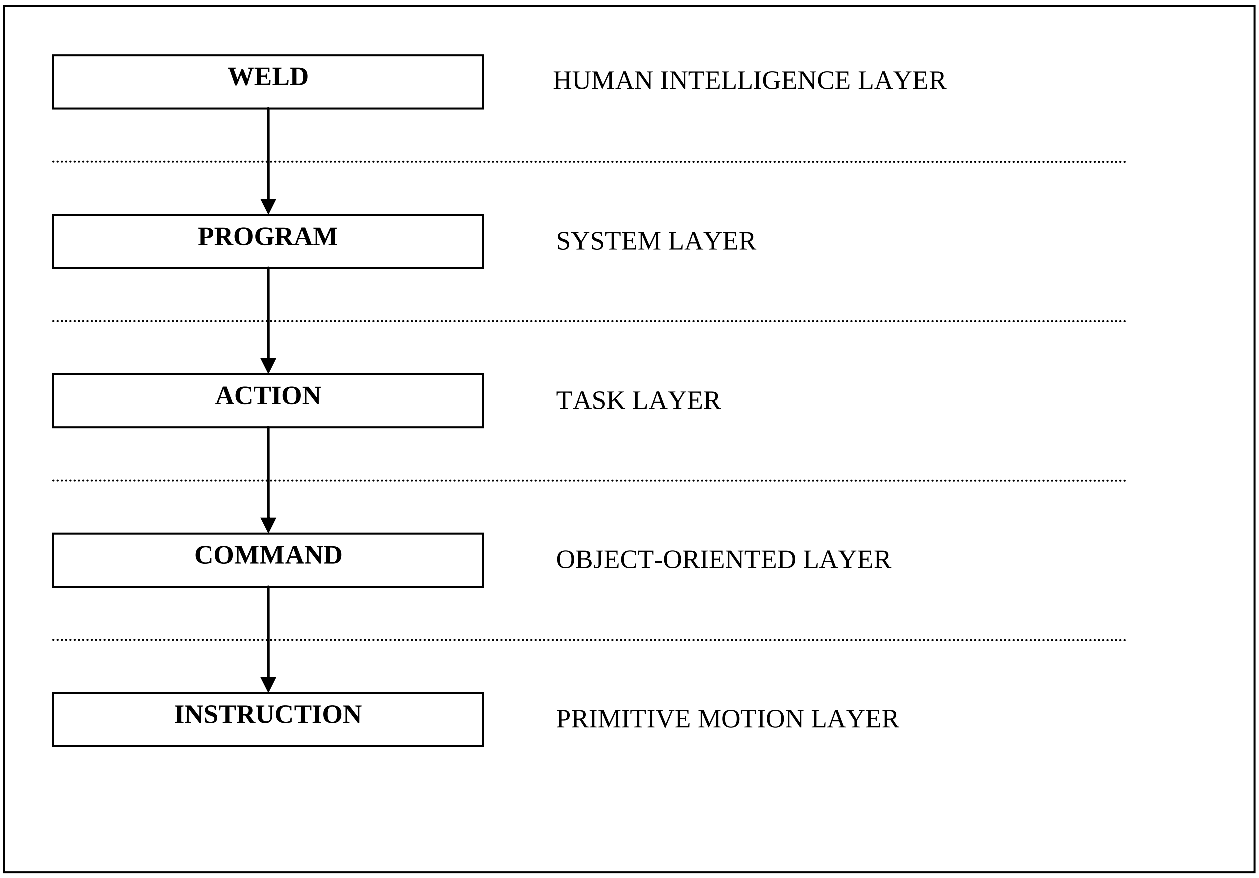

Figure 6 – Software Hierarchy for Software System

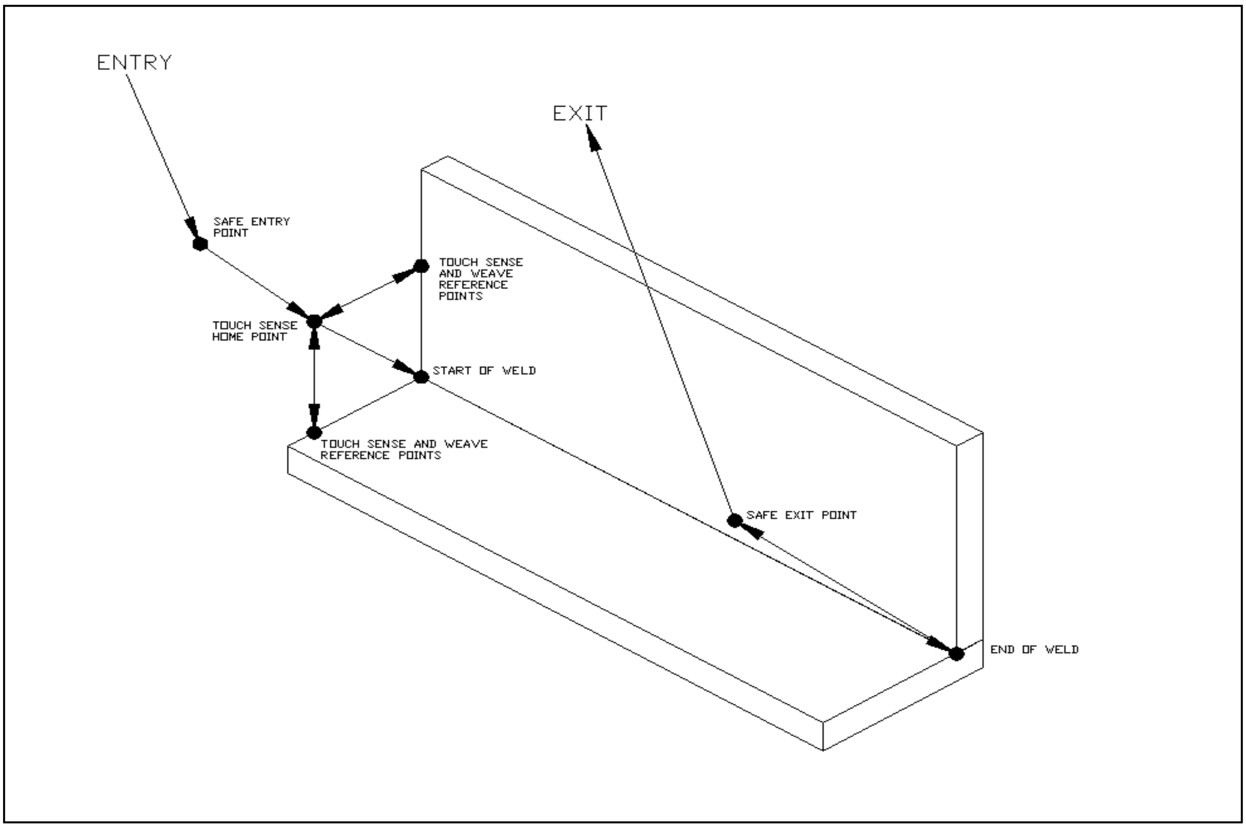

Figure 7 – End Effector Path Diagram

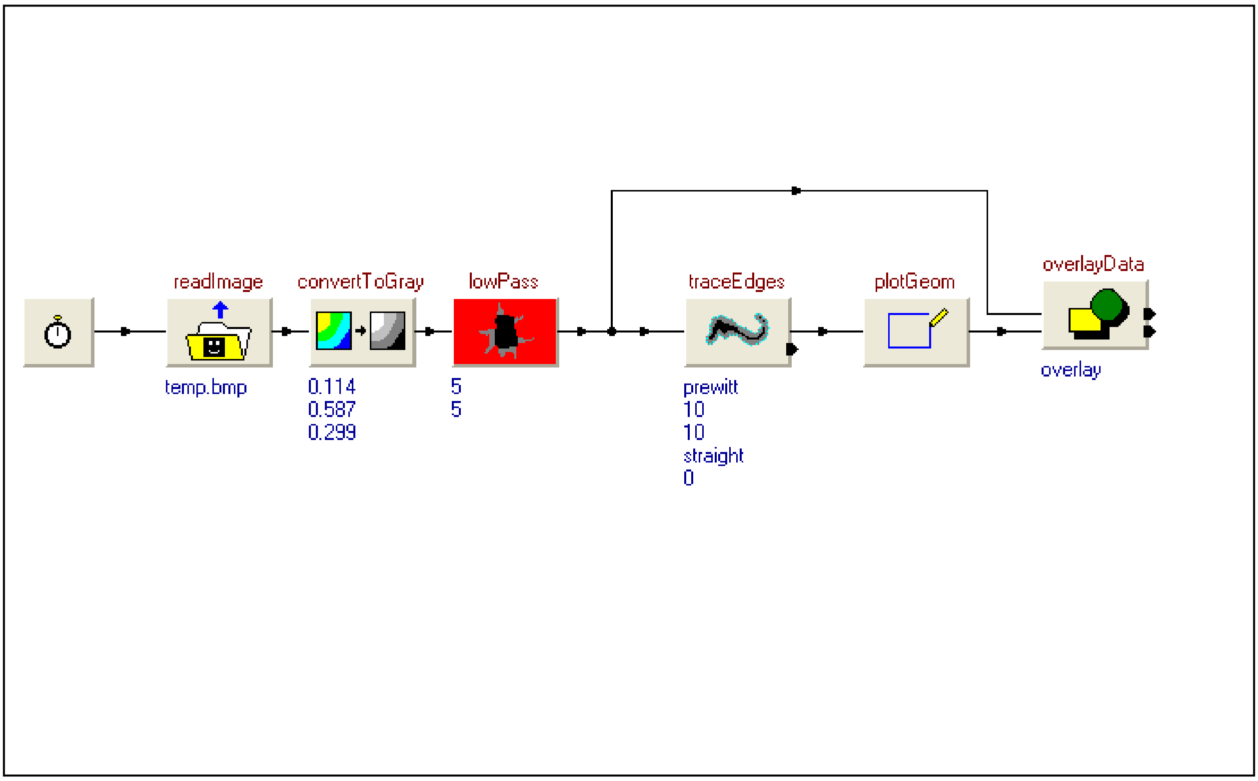

Figure 8 – Visual Representation of Edge Detection Algorithm

4.2 (c) Multiple AI techniques concept

The many different methods of implementing AI each have their own strengths and weaknesses. Some effort has been made in combining different methods to produce hybrid techniques with more strengths and less weaknesses. The Neuro-Fuzzy system which seeks to combine the uncertainty handling of Fuzzy Systems with the learning strength of Artificial Neural Networks is an example of this.

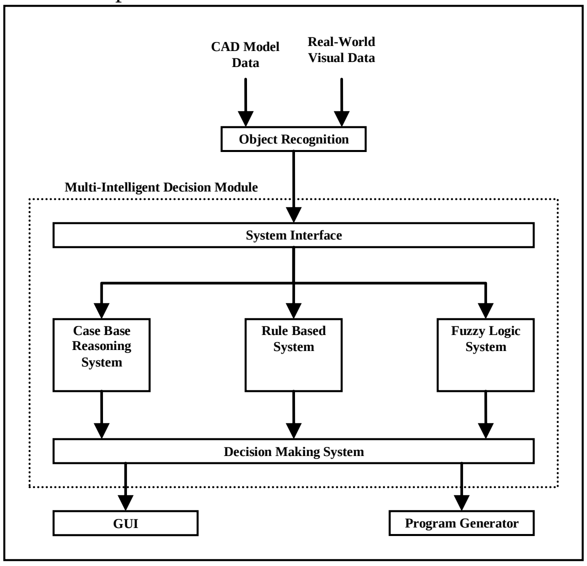

Figure 9 – Multi-Intelligent Decision Module Diagram

This paper proposes a system of using multiple AI techniques to decide on weld requirements for a job.

The system will combine the Real-world visual data captured through the image processing algorithms with the data provided by the CAD model. It will then use this combined data to present differing AI systems with the same information. These systems will then make weld requirement suggestions to a Multi-Intelligent Decision Module (Figure 9). This module will evaluate the suggestions and determine the optimum weld path. The suggestions will be passed to the existing robot program generator.

5. CURRENT PROGRESS

The current state of the research is that the robot program generation systems have been created and tested. These systems have been used to produce consistent straight line welds. A simple edge detection system has been created using the WiT software. Figure 10 shows the initial image. The weld piece was positioned on white paper in order to improve the contrast for the figure.

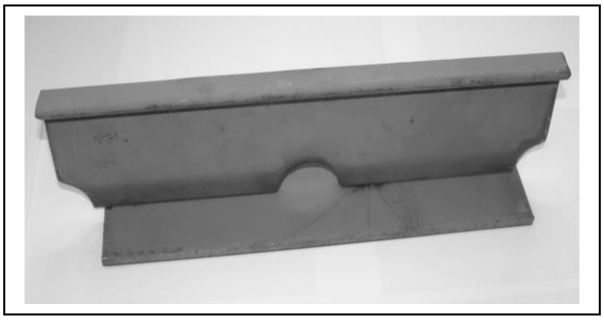

Figure 10 – Photograph of a Weld Part

Figure 11 shows the edges as detected by the algorithm created during this research. The edge detection in this instance is good as the object can be identified from its perimeter detail. There is also detail present that has been caused by corners between metal pieces. This shows that the edge detection is not reliant upon a high contrast. The external perimeter detail is more defined than the internal detail.

The work surrounding the AI systems is in the early stages and will be taken further over the next six months. During this time the multi-intelligent decision module framework will be created and combinations of AI techniques tested. The AI techniques to be tested will include Rule-based, Case-based and Fuzzy systems.

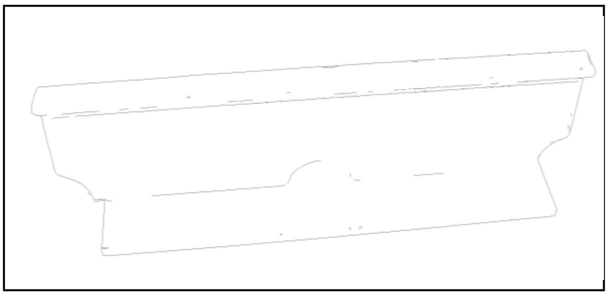

Figure 11 – Image output from Edge Detection Algorithm

6. FIGURES

7. CONCLUSIONS

This paper discussed some of the difficulties surroundings automation within the shipbuilding industry. Within Section 1 it is stated that current techniques for robotic welding are not well suited to the naval shipbuilding industry and that new methods which can cope with low levels of task repeatability are required.

This hypothesis is developed further within Section 2 as the present methods of robotic programming are discussed. The teach pendant method is described as being labour intensive and unsuitable for low levels of repeatability. Programming via a CAD model is shown to be poor at coping with differences between the CAD model and the real-world model. The final method discussed is a visual system which requires operator input to determine weld positions. Whilst this method has none of the disadvantages of the other systems, the operator involvement means that multi-robot installations would be less efficient.

Section 3 discusses some of the Artificial Intelligence techniques that could be used within an intelligent system to determine weld requirements. Any created system would need to be able to handle the uncertainty of unidentified objects within the image; however, when all objects are positively identified there should be little doubt as to the weld path.

The paper suggests that a combination of systems (CBR, FES and RBS) could offer the necessary uncertainty handling whilst still returning a correct weld path when all factors are known.

A proposed system is presented within Section 4; this system uses image processing techniques in combination with a CAD model to provide a model to a multi-intelligent decision module. This module then uses different criteria to determine the best weld path. Once the weld path has been determined then the program generator and post-processor can be used to send a compatible program to the robot controller.

Section 5 contains information about progress so far and discusses further research to be undertaken over the next six months.

8. ACKNOWLEDGEMENTS

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