Final Report

AMPC
AUSTRALIAN MEAT PROCESSOR CORPORATION

Remote Operations – Shadow Robots (Stage 2, Part A)

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Contents

1.0 Executive Summary

This project is a proof-of-concept example of robots being used to replace personnel in bandsaw meat cutting. The work has been undertaken in response to a call from AMPC for a staged programme of development work on Remote Operations/Shadow Robots. This report covers Stage 2, that is, to improve the demonstrated concept developed in Stage 1.

The objectives of Stage 2, Part A were to improve system robustness and useability by:

- Restructuring the code, improving the robot control for speed and accuracy and adding safety features
- Add operating modes, specifically semi-automated and operator-informed modes, and
- Demonstrate the system to AMPC

The system includes the following equipment:

- A robot, controller, and robot control software
- Bandsaw
- Cameras
- Object Tracking Table
- Safety equipment
- Laser pointer for remote operator guidance.
- Control Software/interfaces
- User Interface
- A simple temporary end effector – a clamp to hold the meat

The system has been successfully demonstrated to reliably cut lamb loins into chops using three different modes:

- A manual mode, where an operator moves a tracked object in an operator's workspace, allowing remote control of the robot to manipulate a piece of meat through a bandsaw by 'shadowing' the motion of the tracked object.
- A semi-automatic mode where a desired cut width is input by an operator, then the system performs multiple cuts at that desired width.
- An operator-informed mode where an operator inputs desired "cut lines" on an image of the meat to be cut and then the system automatically carries out the desired cuts.

In all three modes, the system employs 'blade protection' techniques. The system actively restricts motions that may damage the blade such as: striking the blade when returning for a new cut or deflecting the blade sideways while cutting. The current system has been shown to perform 10 cuts in 20 seconds with an accuracy of ±0.5mm from the desired cut width. Further work has been identified that would modify the robot control software to improve the cutting speed to exceed the target of performing 10 cuts in 15 seconds.

This current work has successfully proven the application of a shadow-robot concept to cutting meat on a bandsaw. There is good potential for a system like this to remove staff from dangerous bandsaw operations and reduce the risk of processing operations in general. It is our recommendation that this work continues to Stage 2, Part B.

2.0 Introduction

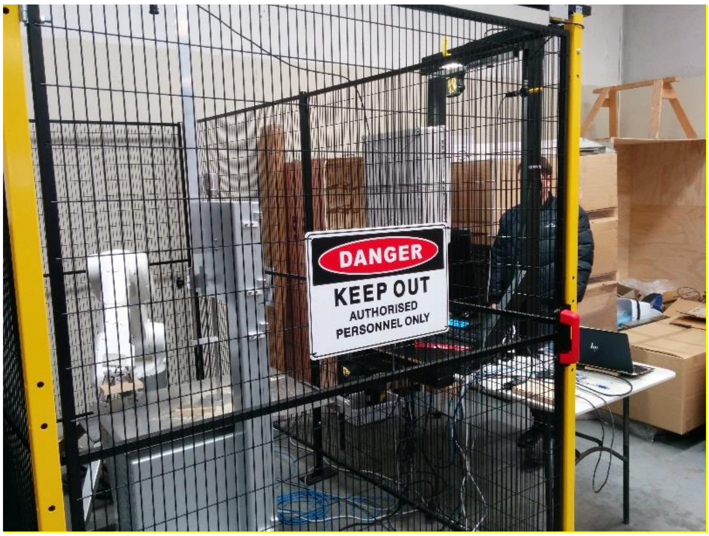
This Remote Operation – Shadow Robot project is a proof-of-concept example of robots being used to replace personnel in bandsaw meat cutting. The work has been undertaken in response to a call from AMPC for a staged programme of development work, see Appendix 1. This project fits within the Advanced Manufacturing and Safety and Wellbeing innovation themes of AMPC's 2020-2025 Strategic Plan where the goals are:

1. Removing staff from dangerous operations, via Hands-Off processing (Adv. Mft.),
2. Safety and Wellbeing, via reducing the high-risk nature of processing operations (People & Culture),

More specifically, a successful development will enable operational staff to undertake bandsaw cutting operations without having to hold onto the meat part being cut. Then once developed the concept should be considered for both boning room and slaughter floor use.

Stage 1 demonstrated the concept. This work was completed in 2021 using the following equipment and as shown in Figure 1:

- Kuka KR10 robot and controller,
- 1.5kW bandsaw
- An object tracking camera mounted over an object tracking table,
- A robot observer camera,
- Safety caging that separates the operator from the robot and saw,
- A basic clamp to hold the meat, and
- User Interface, Vision and Controls software.



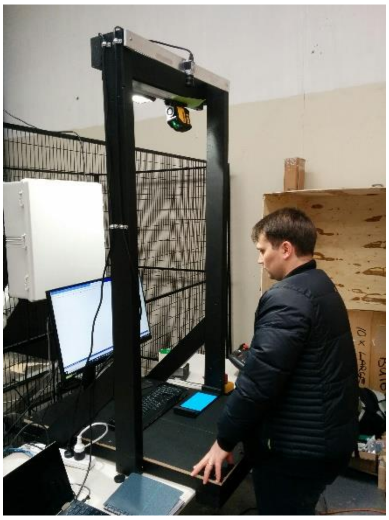


Figure 1 – Photo's of the set-up including the safety fencing within which sits the robot and bandsaw and outside the cage, the object tracking table (right).

The system set up is a robot situated adjacent to the bandsaw and the meat to be cut is held by the robot using a temporary clamp. The position of the robot is controlled by an operator who is situated at an operator's workspace out of reach of the robot and bandsaw. The operator moves a tracked object on a 2-D plane within the operator's workspace. The robot "shadows" the motion of the tracked object in real-time such that the operator can manipulate the meat to be cut by the bandsaw.

At the completion of Stage 1 the system was operated with a user interface, (Figure 2) and was demonstrated to be able to accurately cut frozen chops to a set width (Figure 3).

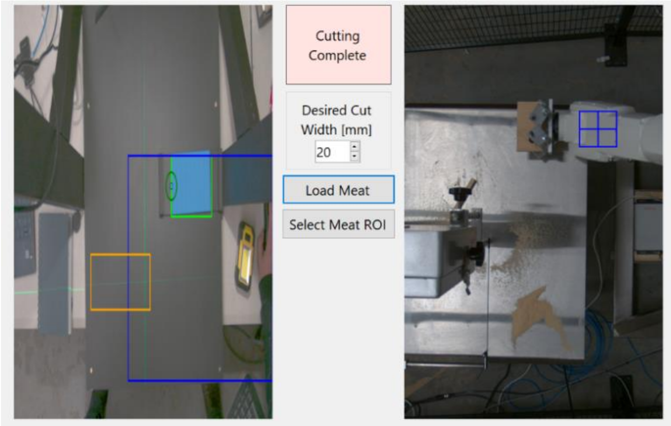


Figure 2 – Screenshot of the user interface showing the two camera images. Image on the left is above the object tracking table. The vision system is tracking the blue-coloured block.

Figure 3 – Frozen chops cut using the system**.**

A provisional patent covering this system was filed in January 2022. For further details see our Final report for Project 2021-1158.

The work reported here covers Stage 2 (see Appendix 1), that is, improving the concept. We were contracted to complete part of our proposed work so this report covers Stage 2, Part A.

3.0 Project Objectives

The objectives of this project were to improve robustness and useability of the Shadow Robot proof of concept. We did this by:

- Restructuring the code architecture, making it more module to allow ease of future feature development,
- Converting the control of the robot to the robot sensor interface for improved control, responsiveness, and speed
- Developing a referencing system for the meat being held by the robot
- Modifying the code to prevent a path coming backward through the blade, and
- In addition to the manual operating mode, developing semi-automated and operator-informed operating modes.

These improvements were demonstrated to AMPC.

4.0 Methodology

4.1 Code Architecture

Using the learnings from Stage 1, we converted the code to a more modular structure. The primary motivation for the software architecture redesign was to create a system that can be easily adapted to new applications that may require different tracking, operational, and control requirements. By creating a modular software architecture, new operating modes, methods of tracking, and robot control can be developed, tested, and implemented seamlessly without effecting how other aspects of the system operate.

The new software architecture consists of the following three main components:

Tracking - This interfaces with the camera system, performs image processing, and applies a selected object tracking algorithm. It outputs a tracked object position and orientation and passes this to the operating mode component.

Operating mode - This applies a coordinate transform to the tracked position to produce an equivalent position and orientation in the robot coordinate system, then applies application-specific logic to the robot coordinate position to check that the position (and orientation) is valid and modifies the position (and orientation) if necessary. Once a valid robot coordinate position and orientation has been determined, the valid values are passed to the robot control component of the system.

Robot control - This component establishes and handles communication with the robot controller and passes valid position commands to the robot and allows for a range of different robot control and communication options to be used e.g. the robot sensor interface.

4.2 Robot Sensor Interface

In our proof-of-concept system we interfaced the vision system with the open-source communication system JOpenShowVar. This was sufficient as a proof-of-concept, but some key drawbacks were apparent resulting in lag. In addition, the robot motion was not smooth.

To address the drawbacks we switched to using the robot sensor interface (RSI). The key advantage of the RSI approach is the ability to control the robot in real time.

The RSI was successfully implemented and integrated into the new software architecture, markedly improving the responsiveness and smoothness of the robot's response to the tracking.

4.3 Referencing & System Protection

To operate the system safely and accurately the meat (clamped to the robot arm) needed to be referenced. A photoelectric sensor was installed near the bandsaw table to detect the edges of the piece of meat. The referencing was used to restrict the motion of the robot so as to prevent the operator inadvertently contacting the blade in an unsafe way e.g. contacting the blade from any direction other than the cutting direction.

With the automatic updating of the "blade protection boundaries", the operator does not need to spend any time resetting the system parameters when a new piece of meat is loaded. Therefore, the operator can focus solely on the desired cutting actions for each piece of meat and the overall cycle time for performing the task is reduced. The automatic referencing provides the system with the ability to have tight tolerances in "blade protection boundaries," ultimately reducing unnecessarily large movements to ensure clearance with the blade after a cut. Furthermore, the automatic referencing is a fundamental step for future developments.

4.4 User Interface

The User Interface was updated to include:

- a live feed of the tracking table and the robot camera,

- indicators of the cut width in the current position and when the meat is in the blade region
- cut width selection and
- buttons for **Load Meat** to initiate the referencing process, **Allow Position Control** to start and stop control, **Select Cam ROI** to adjust the tracked region of the operator table and **Select Blade Position** to register the blade with a selected position on the operators table,

4.5 Operating Modes

Manual mode

The manual mode allows the operator to manipulate the meat in a two-dimensional plane to perform straight cuts at any width by moving the tracked object. The system utilises the previously outlined ‘system protections’ which will prevent the operator from entering the blade from any direction other than the cutting direction. Furthermore, once the meat is in contact with the blade, sideways motion that would deflect the blade is not possible.

Semi-automated mode

The semi-automated mode works by the operator selecting a desired cut width through the user-interface and then pressing the “Go” button to begin the cutting sequence. The semi-automated algorithm will then calculate a series of robot waypoints that correspond to cuts that have the desired cut width. The robot will then step through these waypoints to perform the cuts until it can no longer satisfy the desired cut width and will then hand control back to the operator by switching to manual mode.

Operator-informed mode

The operator-informed mode makes use of the operator’s expertise and decision making to decide what cuts to make for each piece of meat. The system then performs the desired cuts for the piece of meat safely and efficiently without requiring additional input from the operator. In this mode, once the operator has indicated the desired cuts, the operator is free to perform other duties (such as determining the cuts for the next piece of meat or even operate a second system) while the desired cuts are being executed by the system automatically.

With the current configuration, the operator-informed and semi-automated modes will perform 10 cuts in 20 seconds with a cut width accuracy of ±0.5mm from the desired cut width. However, with some further work to the robot control software, we are confident that the cutting speed can be improved to exceed the target of performing 10 cuts in 15 seconds.

5.0 Project Outcomes

Stage 2, Part A has been successfully completed. The restructured code, robot communication through the RSI, safety improvements and different operator modes have markedly improved the control and accuracy of the shadow-robot cutting system. Further, the addition of selectable operating modes:

- increases the useability and permits the speed of the robot to be utilised, and
- allows personnel knowledge and experience to be put into cutting by the shadow-robot.

We are not aware of similar systems and so with the support of AMPC a provisional patent has been filed.

In the process of completing this work we have focused on the very simple application of cutting lamb chops, a simple 2D cutting task. Next we seek to move to 3D cutting and for this we welcome industry input.

6.0 Conclusions / Recommendations

This work has successfully improved the application of a shadow-robot concept to cutting meat on a bandsaw. So there is good potential for removing staff from dangerous bandsaw operations.

It is our recommendation that this work continues to Stage 2, Part B, specifically 3D cutting and material handling considerations.

7.0 Future Work

This project has been informed by AMPC's theme on a page, see Appendix 1. This roadmap highlights the work ahead to get to a commercial product. Most immediately there is a need to advance to 3D cutting and to consider clearing the cut meat etc (i.e. Stage 2, Part B). Beyond that is the following: Stage 3 – Gripper Development, Stage 4 (a-f) - boning room & slaughter floor application (in processor facilities) and Stage 5 – Adoption.

The proof-of-concept equipment is just that and has some limitations on the weight/arm-extension such that at this time. We're probably limited to lamb-based cutting use. The system could easily be sized for processing larger/heavier cuts e.g. beef manufacture. The controls and software code would translate with ease.

8.0 Appendices – AMPC Remote Operations R&D Theme on a page