Final Report

AMPC
AUSTRALIAN MEAT PROCESSOR CORPORATION

# Shadow robotics

## Remote Operations - Mimeo Shadow Robots (Stage 3+)

| Project Code | Prepared by | Date Submitted |
|---|---|---|
| 2023-1039 | A FitzPatrick, B Webster, & C Eatwell | 30/01/24 |
| | Published by | Date Published |
| | AMPC | 30/01/24 |

# Contents

Contents 2

1.0 Executive Summary 3

2.0 Introduction 4

3.0 Project Objectives 5

4.0 Methodology 6

4.1 Identify Applications 6

4.2 Progressing the Existing Shadow Robot Platform 6

4.3 Installation, Commissioning, and Trials 10

4.4 Conveyor Packing Trial Scope 11

5.0 Project Outcomes 12

5.1 Conveyor Packing Trial 12

5.2 Remote Operations 14

5.3 General System Performance 14

5.4 Hock Cutting 15

6.0 Discussion 16

6.1 Progress on Objectives 16

6.2 Key System Features 16

6.3 System Performance 16

6.4 System Improvements & Future Work 17

7.0 Conclusions / Recommendations 17

8.0 Acknowledgement 18

9.0 Bibliography 18

# 1.0 Executive Summary

The objective of Stage 3+ of the Shadow Robotics initiative was to leverage the prototype system from prior development work (Stages 1 and 2) to design, build, install and test a pre-production system in a meat processing plant on at least one application.

After a workshop, two applications were chosen: the picking of lamb cuts from a conveyor and lamb hock cutting. To meet the requirements of these applications the existing industrial robot, a machine vision camera and proprietary Mimeo software were extended and complemented by:

- appropriate end effectors:
    - compliant gripping devices for picking,
    - industrial hock cutter for cutting,
- further machine vision and user interface work,
- a generic robot base and mounting that minimised floor space, and
- a safety system to enable a low intrusion installation into existing processes.

Site trials were conducted in October and December of 2023. The October site trip covered installation in the two locations at the targeted processing. For the conveyor-picking boning-room application, after commissioning the system was evaluated for pick rate, ease of install and remote usability. For the hock cutting, slaughter-floor application it was deemed too risky to production to progress commissioning without further modifications to the plant. December trials focused on refinements to conveyor picking for different cuts e.g. orientation and gripping.

The trials showed the system was easy to install, required minimal floor space, did not intrude into walkways, could be operated remotely (even internationally), and is safe to operate around other staff members. Between 10-20 different people operated the system through a remote interface. The rate of successful picks from the lamb trial was 79% (excluding operator error) at an average of 11.6 picks per minute.

The pick rate during the in-plant trials was less than the 30 parts per minute from controlled trials in the workshop prior to going to site. The main contributor to the difference was the more complex operating environment (in the workshop we managed the flow of product). In the trials priority was given to demonstrating key features and general functionality of the system in a production environment. Nevertheless, the trials provided useful preliminary performance metrics that will be used to guide future refinements of the system.

During Stage 3+ of the Shadow Robotics initiative, the prototype multifunctional workshop system was developed into a pre-production unit. Key features of the shadow robot system are:

- remote operation through a website on any internet enabled device,
- mobile robot base with a small footprint,
- quick and easy installation without the need for permanent fixings and major site modifications,
- a core system adaptable to different applications (picking, cutting, trimming),
- operator assisted capabilities,
- conveyor/chain tracking/mapping,
- custom lens design for wider field of view,
- fully Wi-Fi with wireless camera tracking,
- custom workspaces and collision avoidance,

- plug and play design (only air supply and domestic power required),
- fenceless robot operation around operational personnel, and
- washdown.

The system is now further down the path of commercialisation.

The user-operated, shadow robot system has the potential to be used in routine production. Mimeo plans to implement several improvements to the system to advance the application of operator-informed, conveyor picking and packing.

# 2.0 Introduction

The Australian Meat Processor Corporation (AMPC) put out a request for shadow robotic solutions for the meat industry in 2020. The primary motivation for implementing shadow robotics was to remove operational staff from potentially dangerous devices or tasks. The ultimate goal would be to have operational staff remote from the processing facility, thus creating a safer working environment. Additional benefits to using shadow robotic systems would be the added precision of industrial robots and the potential for yield increases due to sub-millimetre accuracy and machine learning integration, and the robot can be used to remove the physical demands of some tasks.

The purpose of the work presented here was to progress the previous development of a proof-of-concept shadow robot system (Mimeo Industrial Ltd., 2022a; Mimeo Industrial Ltd., 2022b; Mimeo Industrial Ltd., 2022c) to a production prototype system trialled within a meat processing facility. The previous work on a shadow robot system had yielded a prototype system that would monitor the real time motion of an operator (using a tracked object held by the operator) and "shadow" the operator's motion using an industrial robot arm. Figure 1a shows a photograph of the proof-of-concept system where the robot is being used to cut a chine bone on a bandsaw by holding the meat. Figure 1b shows a photograph of the same system holding a kebab knife and being used to slice cheese. The current work would take this proof-of-concept system and (with additional development) apply it to two applications within a processing facility. Thus, progressing the shadow robot system down the path to full implementation within a production environment.

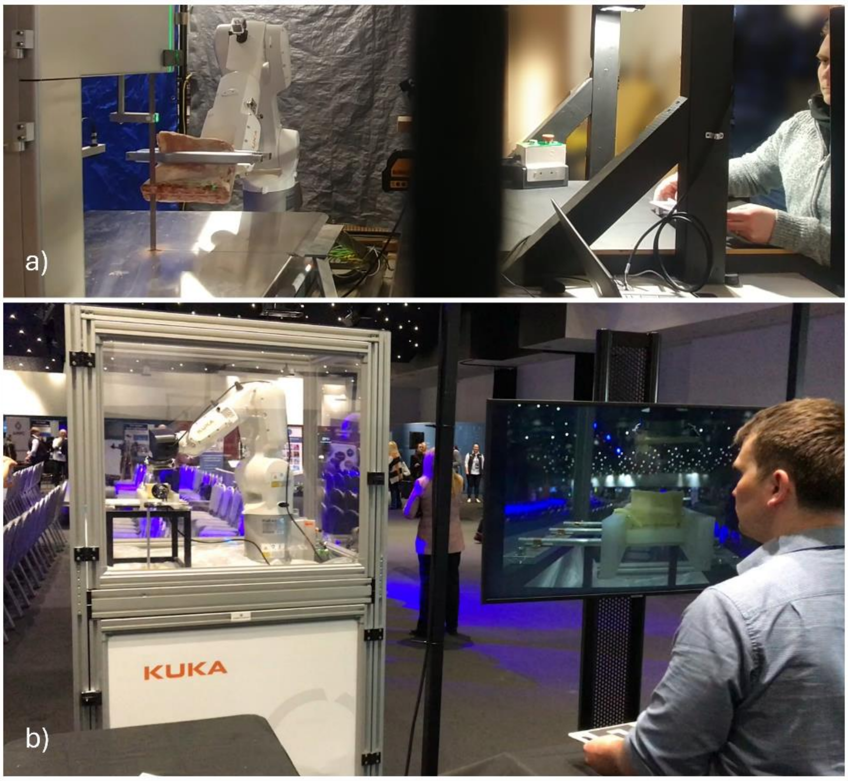

*Figure 1: Photos of the shadow robot system being demonstrated during Stage 2 to perform a) a chine cut and b) trimming.*

## 3.0 Project Objectives

Leveraging the work completed in Stage 1 (Mimeo Industrial Ltd., 2022a) and Stage 2 (Part A & Part B) (Mimeo Industrial Ltd., 2022b; Mimeo Industrial Ltd., 2022c), in Stage 3+, of the Shadow Robot development project, the objectives were to:

1. Work with the industry to identify applications with a good return on investment.
2. Continue the development of the shadow robot platform by adding:
    a. an end-effector and
    b. a conveyor-picking/in-feed singulation system
3. Progress the shadow robot platform and tailor for two specific applications, effectively giving us a production prototype.
4. Test a production prototype on site.

At the end of the project, we were to have the building blocks for an early version (1.0) of a commercial system. That is, we would have designed, built, installed, and tested a production prototype in a boning room for at least one specific application. This progresses the shadow robot system down the path to commercialisation.

# 4.0 Methodology

## 4.1 Identify Applications

Mimeo conducted a site visit to JBS Foods Australia's Brooklyn processing facility in January 2023 to scope potential applications for deploying the shadow robot technology. A site walkaround and subsequent demonstration workshop with JBS employees was conducted. From these exercises, several processing tasks were identified as possible shadow robot applications. Each possible shadow robot task was weighted by considering ease of development, hardware and installation cost, employee desires, and potential yield improvements. The top six weighted tasks were then reviewed by Mimeo, JBS, and AMPC. Two of the top six tasks were selected for concepting:

1. packing of individual lamb cuts off conveyor into cartons (conveyor packing) and,
2. lamb hock cutting.

A summary of the two chosen applications is as follows:

<u>Conveyor Packing:</u> Conveyor packing proved to be a popular choice of task. A shadow robot system would enable an operator to concentrate on identifying the meat products and their location on the conveyor while the robot handles the physical picking and packing. This system would offer a labour saving by allowing a single operator to identify multiple different meat products that would have otherwise been handled by two (or more) different operators. This application also provides the opportunity for machine learning algorithms and development to full automation.

<u>Leg Cutting/Neck Tipping:</u> Leg and neck tipping operations occur near each other on the slaughter floor, so, there is good opportunity to perform both operations sequentially. There would be an obvious labour saving if a shadow robot system (with a single operator) was used to perform multiple tasks that are currently performed by individual operators. Furthermore, the shadow robot technology can offer yield improvements through precise motions and the use of machine learning algorithms.

## 4.2 Progressing the Existing Shadow Robot Platform

### 4.2.1 Existing Core Shadow Robot Components

As reported in previous work (Mimeo Industrial Ltd., 2022c) the existing shadow robot platform uses the following core components:

- Robot - Kuka, KR10 R1100-2
- Robot Controller - KRC5 micro with control software - KSS 8.7.
- Camera – Basler Ace a2A1920-160uc with C125-0418-5M 4mm lens.
- Control software/interfaces – in-house code using Kuka RSI (Ver. 5.0.2) to communicate with the robot.

To progress the shadow robot platform to the in-plant applications, several additional components needed to be developed. Namely,

- suitable end-effectors for the end of the robot arm to adequately perform the conveyor picking and hock cutting tasks,
- additional control software for enabling 1) part selection through a video feed of a conveyor and, 2) hock cut location through a video feed of the carcase on a processing chain,

- a suitable mobile base for the robot to enable easy installation, and
- a safety system to ensure safe operation of the robot alongside human workers.

The development of the additional components above is addressed in the following sections.

### 4.2.2 End-Effector Selection

Once the top two applications were chosen, the design for the robot end-effector was considered. The shadow robot system was to be applied in two different ways: the robot holds a tool, and the robot holds a piece of meat. Therefore, adaptability versus specificity was important to consider since a platform that was as generic as possible was desired.

The basic requirements of a tool or gripper for performing hock cutting or conveyor packing were identified as follows:

- less than 0.5 seconds actuation time,
- washdown ready or able to modified to be such,
- preferably less than 6kg to enable quick cycle times with 10kg robot (use of a counterbalance may be possible to enable heavier tools),
- actuated electrically or with minimal pneumatic supply,
- must carry a 2kg payload (applies to gripper only).

Considering the above requirements, some rapid prototyping of gripper concepts was carried out and several off-the-shelf tools and grippers were compared. As a result, two off-the-shelf products were purchased:

1. a pneumatically actuated gripping end-effector with five soft silicone fingers from SoftGripping for the conveyor packing application and,
2. a M5 hock cutter from Kentmaster powered by an air-over-oil intensifier.

### 4.2.3 Operator-Informed Machine Vision

The existing operator-informed mode was set up as a configurable option that could be switched between multiple applications cleanly. Therefore, the existing operator-informed mode forms the base of the conveyor (and carcase chain) infeed software. The software development path also includes separation of the program into separate client/server pairs to distribute processing and allow each hardware component to be standalone for installation. The configurable modes mentioned above easily allow this separation into modules while still using the base software package.

The client/server modules were developed for the operator-markup-interface that was required for both the conveyor packing and the hock cutting applications. These modules have the following basic features:

1. Allow a remote operator to markup a video feed,
2. Freeze an area of the video feed around where the operator is working to allow easy selection, and
3. Allow easy shape adjustment for tuning once in place.

Figure 2 shows two screenshots of the operator markup interface where breast pieces on a conveyor have been “marked up” (selected) for picking.

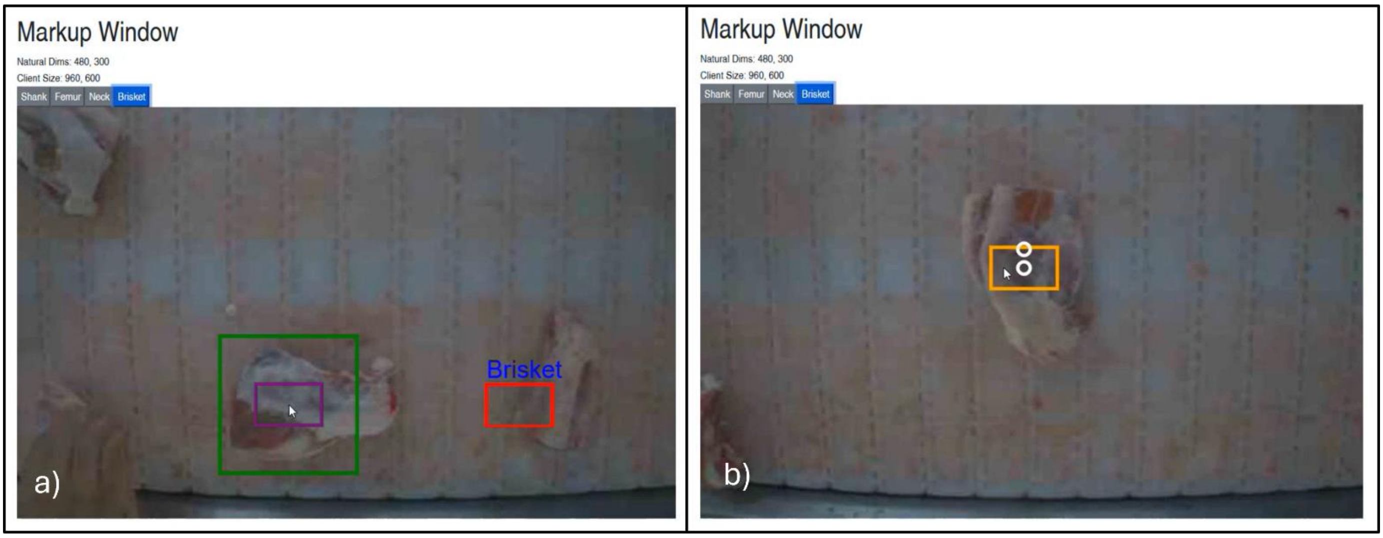

*Figure 2: Screenshots of the operator interface markup screen showing a) a "marked up" (selected) breast piece and a breast piece currently being selected (upon clicking the screen, a fixed area appears around the markup chosen so the user is free to markup at their leisure while the rest of the conveyor belt moves), and b) a selected breast piece where the markup shows the handles that can be used to rotate the markup.*

### 4.2.4 Robot Base

An in-house designed robot base was fabricated in accordance with requirements identified during a preliminary site visit to the processing plant. The major drivers of the design were as follows:

- anything in the rooms on-site must be food grade if in contact with food,
- minimise footprint (especially in conveyor packing to not impede adjacent walkway and work areas),
- mobile/easily moved platform for quick installation and moving between locations,
- freestanding (i.e. does not require bolting down or other invasive installation procedures), and
- can house robot controller (to limit the number of connecting cables, ideally just power, air supply, and a data cable is run to the robot base).

The stainless-steel base concept that was produced consists of two main components: an outrigger base frame, and a pedestal doubling as the robot controller cabinet. Figure 3 shows a photo of the shadow robot system where the pedestal cabinet base and outrigger legs are visible. Also visible in Figure 3 is the in-house designed vacuum pad system that provides stability to the overall assembly.

*Figure 3: Photo of the shadow robot and associated base where the pedestal cabinet and outrigger legs are visible.*

### 4.2.5 Safety

The safety system of the shadow robot was designed to incorporate AIRSKIN®. AIRSKIN® is an add-on pressure sensing system that will detect collisions and allows people to work safely alongside industrial robots. By utilising the AIRSKIN® safety system, the shadow robot can be deployed safely in a fenceless manner which reduces the required footprint for operation within the processing facility. Figure 4 shows a photo of the shadow robot with the AIRSKIN® system installed.

*Figure 4: Shadow robot with AIRSKIN® safety system installed.*

## 4.3 Installation, Commissioning, and Trials

Prior to shipping the shadow robot to the processing facility, development and testing of the system for each application was conducted in the workshop. The purpose of this work was to develop, test, and improve the system to a functional state in an emulated environment before launching into tests in the production environment.

Site trials were conducted on two separate week-long visits to the processing facility (October and December 2023). The goal of the October visit was to install, commission, and trial the shadow robot system for each of the two applications (conveyor packing and hock cutting). After completing the October visit, a return visit for December was planned with the goal of recommissioning and trialling the shadow robot system for the conveyor packing application after implementing improvements to the system.

The October trial was conducted over 6 days. The installation and commissioning at the conveyor packing location was carried out over one and a half days, highlighting the adaptability and ease of installation of the system. The design of the shadow robot system allowed for the robot to be wheeled into position and installed by no more than two people. The system was then operated and evaluated over four days. Evaluation of the system each day led to minor improvements. In December, the system was reinstalled in the conveyor packing location in the boning room over one day and some hardware improvements were implemented. Over the next four days trials were conducted to test improvements relating to remote performance, part selection, orientation and gripping.

Figure 5a shows an image of the shadow robot being wheeled to the conveyer packing location by one person. Figure 5b and Figure 5c show images of the shadow robot installed and operating at the conveyor packing location respectively.

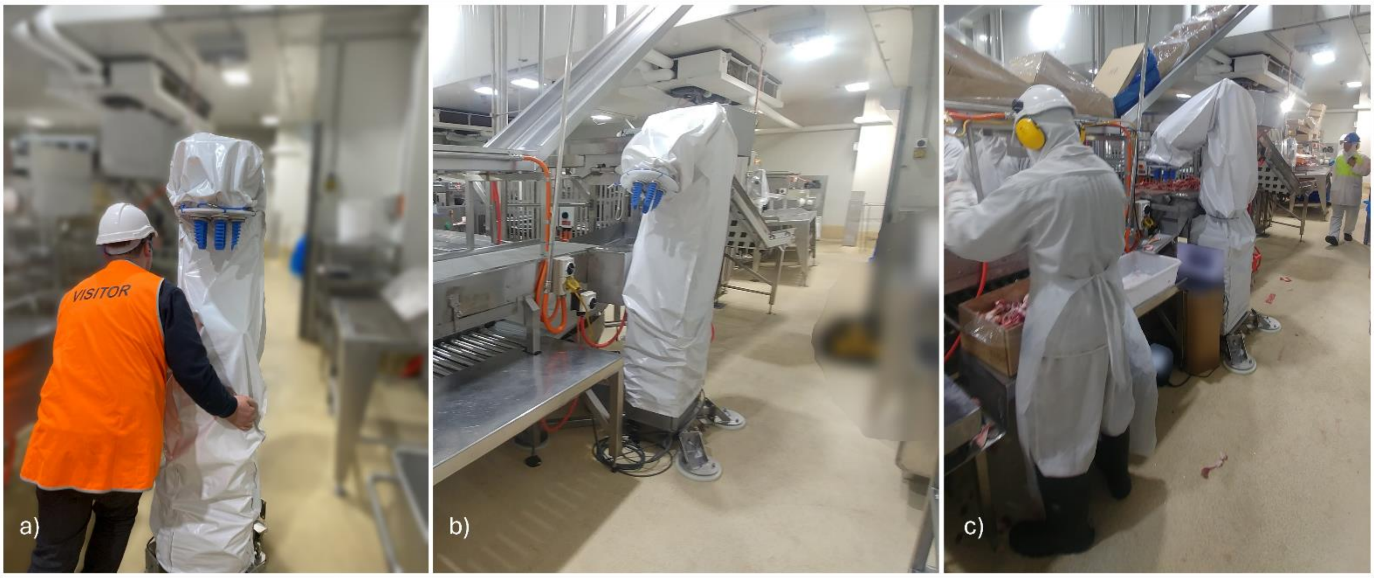

*Figure 5: Photos of the shadow robot a) being wheeled to the conveyor position by one person, b) installed by the conveyor ready for operation, and c) during production.*

The installation at the hock cutting location was performed and commissioning began over one day. However, the risk associated with the hock cutting trial could not be minimised to a satisfactory level during commissioning (further explanation can be found in Section 5.4). Therefore, it was decided that the hock cutting trial would not progress during the remainder of the visit.

## 4.4 Conveyor Packing Trial Scope

The primary purpose of the trial was to demonstrate the shadow robot system (through the application of conveyor packing) operating in a production environment. The scope of the conveyor packing trial focused on the first step in packing i.e. selecting and picking parts, as detailed here:

1. Operator uses User Interface (UI) to make ‘target’ selections on a live video feed of the conveyor.
   - The target selections are of parts to be picked by the robot.
   - The centre point of the selection corresponds to the centre point of the robot gripper.
   - The operator can do this locally (within the boning room) or remotely (from outside the boning room).
2. Demonstrate the system’s ability to pick at least one specific part (e.g. shanks, femurs, breast pieces, or necks) when singulated on the conveyor.
   - Assess ability of gripper to pick each type of part from conveyor (i.e. can the gripper pick up and hold onto each of the part types or not).
   - Evaluate pick success of parts generally (e.g. number of successful picks versus number that were dropped).
   - Optimising the effective pick rate (parts per minute) was not within the scope of the trial. However, the trial would provide preliminary performance metrics from the production environment.
3. Robot performs a pick motion at the target location selected by the operator.
   - Pick motion occurs when selected location moves within the workspace of the robot.
4. Robot moves picked parts to a drop off location over an outfeed chute.

    - Parts are simply released once robot is at the drop off location (i.e. organised packing into boxes was outside the scope of the trial).

It is worth noting that since maximising the effective pick rate (parts per minute) was not a primary outcome for the trial, the speed of the shadow robot system was not optimised for the trial. Furthermore, the trial framework included only picking singulated parts in the trial, with spacing of at least 200 mm or four parts within 1 metre (a limiting factor on the maximum achievable pick rate).

# 5.0 Project Outcomes

## 5.1 Conveyor Packing Trial

The installation and commissioning of the shadow robot system went smoothly for the lamb conveyor packing location. The goal was to complete the installation and commissioning within one day and this was achieved. Over the next four days the system was used to pick a range of parts from the conveyor, noting that organised packing into boxes was outside the scope of this trial.

The user-operated, shadow robot was able to pick each of the lamb products that regularly came past its location. These were femur bones, neck pieces, breast pieces, shanks, fat caps, and trimmings. Figure 6 shows images of successful picks of four of the lamb products: lamb shank, neck, breast piece, and a femur bone.

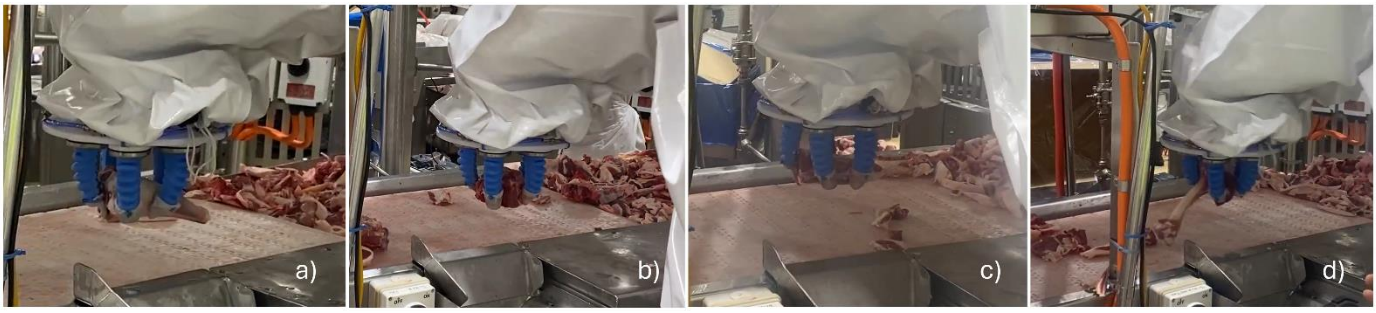

*Figure 6: Images of successfully picked lamb products by the shadow robot. a) shank, b) neck, c) breast piece, and d) femur bone.*

During the trials, several videos were taken of the system in operation to collect information on the preliminary performance metrics. Note, the trial had a primary focus on determining what singulated products can be picked, giving a preliminary assessment of the pick rate. This reduced the maximum possible value regarding pick rate per minute. Table 1 presents the preliminary performance statistics from 37 videos that were analysed after the October site visit. Of note are the following metrics:

- Pick success rate (from recorded sessions)
    - excluding significant operator selection errors (e.g. misclicks) averaged 79%
    - Overall average 68%
- ‘Successful picks per min’ (from recorded sessions)
    - average 11.6 (maximum recorded 18.2).

    Note workshop trials indicated 30 picks per minute was possible with an experienced operator and smaller shanks, indicating the necessity for further gripper development.
- ‘Selections per min’ (from recorded sessions)

- average 17.2 (maximum recorded 25.5).

Again, this number is lower than in the workshop (40 ppm), partially due to environmental constraints and partially due to self-imposed restraints i.e. restricting flow of parts to assess grip performance.

One observation during the trial was that some products were being dropped after an initial pick up. To reduce the number of dropped parts, some glove fingertips were attached to the gripper fingers to increase friction between the fingers and the picked part. The glove fingertips did prove to increase the pick success rate. Therefore, concepts for increasing the friction/changing the surface texture of the gripper fingers will be a focus of future work.

*Table 1: Preliminary performance statistics from 37 analysed video recordings during the site trial.*

| | **Total (from 37 videos)** | **Average per min of video recording** | **Average per recording** |
|---|---:|---:|---:|
| Pick attempts | 585 | 17.1 | |
| Successful picks | 382 | 11.2 | |
| Skips | 32 | 0.9 | |
| Obvious selection errors/ moved targets | 78 | 2.3 | |
| Drops (Orientation/Position misalignment) | 4 | 0.1 | |
| Drops (Strength/Friction/Height) | 75 | 2.2 | |
| Drops (Other) | 14 | 0.4 | |
| Total success fraction | | | 0.68 |
| Success fraction excl. skips/selection errors | | | 0.79 |
| Selections per minute | | | 17.2 |
| Success pick rate per minute | | | 11.6 |

Success of picking in the in-plant trials was less than controlled trials conducted in the workshop (in advance of going to site); increasing the success pick rate (picks per minute) was not the priority, rather demonstrating the key features and general functionality was. Not unexpectedly, the trial yielded preliminary performance metrics including a pick rate of 11.6 parts per minute which was well less than the “workshop” pick rate of 30 parts per minute. The two main reasons for this disparity were: artificially restricting the flow of product to assess grip performance, and not attempting to pick all parts during times of high product volume flow.

A significant portion of the data that contributes to the statistics of Table 1 included sessions where parts were periodically placed on the conveyor in a controlled manner to provide semi-consistent spacings. This was done to ensure consistency of selection by the operator so the grip performance of the end-effector could be assessed with minimal chance of inaccurate operator selections. Furthermore, by not attempting to pick all parts during times of high product flow volumes (due to the limited scope of the trial system to pick a maximum of four parts per metre) the theoretical maximum pick rate was reduced below 30 parts per minute. With future refinements, the achieved pick rate will be improved through a combination of increased grip friction, increased robot motion speeds, part buffer zones, and software features to optimise target locations and motion paths.

## 5.2 Remote Operations

The site trials proved the remote operation capability of the shadow robot system. The system (located in a processing facility in Melbourne, Australia) was successfully used with remote operators located in an office environment both within the facility and in Christchurch, New Zealand. Figure 7a shows an image of an operator using a tablet within the boning room to make part selections in real time. Figure 7b and Figure 7c show images of two different operators using a touch-screen laptop in an on-site office to make part selections in real time.

*Figure 7: a) image of operator using tablet within the boning room, b) and c) images of two different operators using the system remotely from an office onsite but outside of the boning room.*

Over the course of the trial, several different people (between 10 – 20) used the operator interface to make part selections. All of those who used the system found the interaction to be intuitive and were quickly able to make accurate selections (resulting in successful picks). The simplicity of the operator interface appeared to contribute to the ease of use for the operators. It was also noted that imprecise placing of the selection target by the operator (e.g. placing selection on one edge of a breast piece rather in the centre of it) would cause unsuccessful picks. Hence, the overall success rate of the system in its current form has some dependence on the precision of the operator.

## 5.3 General System Performance

In general, the shadow robot system performed very well in the production environment. In particular, the trial demonstrated several design features that contributed to the success of the trial. Namely,

- the ease of transport and installation of an industrial robot system into the processing facility,
- the adaptability provided by the software design to enable fast commissioning of application specific parameters,
- the safe operation of an industrial robot alongside human workers without the need for physical guarding, and
- the novel method of providing stability through vacuum feet.

However, there were several areas for improvement identified:

- grip success (as noted earlier, increasing the friction between the gripper and the picked product increased grip success),
- keeping up with “waves” of product (the volume of product on the conveyor was not always constant, therefore the picking speed of the system would need to be increased or a suitable buffer system implemented to ensure no product gets missed during times of high volume on the conveyor),
- box packing (the trial excluded box packing from its scope, nevertheless, packing into boxes is a necessary step to fully implement the shadow robot platform in this location),
- camera field of view (the current camera setup results in a relatively narrow field of view for the operator which increases the chance of imprecise selections during times of high product volume on the conveyor),
- manage/avoid unexpected parts/objects on conveyor (occasionally, large parts/objects would come down the conveyor that would obstruct the workspace of the robot and effectively stop any picking while they cleared the workspace),
- washdown bag – gripper interface (the interface between the washdown bag and the gripper was found insufficient), and
- optimisation of robot paths for efficiency and to avoid collisions of parts with conveyor surrounds.

## 5.4 Hock Cutting

The steps taken to setup the robot system in the hock cutting location produced some useful learnings about the complex and restricted working environment. The initial setup highlighted several areas where more time would be needed to address issues such as those outlined as follows:

1. Safety of operator at adjacent neck tipping station. The shadow robot hock cutting needed to occur further upstream than the existing cutter, so the adjacent neck tipper would be forced to perform their operation earlier than normal and likely have to reach outside of their normal workspace. Furthermore, for the initial trial, the hock cutter did not have additional guarding. Physical barriers were going to be used to stop access to the area where the tool was working. However, it was determined that barriers were likely going to restrict the neck tipper’s workspace and may inhibit them from performing their task effectively.
2. Potential collisions with existing plant in the event of a breakdown and subsequent triggering of the hock cutting safety breakaway mechanism. If a tool breakaway was to occur, there was a chance the tool would rotate out of the way of the hock to be cut but collide with the hind leg of the carcass behind the tool. This would result in a stoppage of the entire production chain while the shadow robot system was reset.

As a result, the decision was made to defer the trial of this application and as an alternate, focus on additional trials of the conveyor packing application.

# 6.0 Discussion

## 6.1 Progress on Objectives

The project successfully met the objectives. Mimeo worked with a processor to identify several potential shadow robot applications, the shadow robot platform was further developed to incorporate two end-effectors and conveyor picking/carcase chain software, the system was tailored for two applications (conveyor packing and hock cutting), and a prototype system was tested in a processing facility for at least one specific application (conveyor packing).

Unfortunately, the second application (hock cutting) did not progress past installation in the facility (as an alternate, all agreed to extending the work on picking from the conveyor). However, as mentioned in Section 5.4, some useful learnings were gained regarding the specific application and the implementation of shadow robot systems on the slaughter floor in general. Since the flow of carcasses through the room is the same regardless of location, a trial of a shadow robot installation on the slaughter floor will require extensive testing to ensure effective integration into the line without disrupting carcass flow.

Nevertheless, with reference to the project objectives, the current project has progressed the shadow robot system down the commercial path for a conveyor packing application.

## 6.2 Key System Features

The current project has progressed the shadow robot to a pre-production unit with additional features that have contributed to the success of the system. Some general key features of the system are:

- remote operation through a website on any internet enabled device,
- mobile robot base with a small footprint,
- quick and easy installation without the need for permanent fixings and major site modifications,
- a core system adaptable to different applications (picking, cutting, trimming),
- operator assisted capabilities,
- conveyor/chain tracking/mapping,
- custom lens design for wider field of view,
- fully Wi-Fi with wireless camera tracking,
- custom workspaces and collision avoidance,
- plug and play design (only air supply and domestic power required),
- fenceless robot operation around operational personnel, and
- washdown.

## 6.3 System Performance

The conveyor trials were considered successful since each of the four scope areas were able to be demonstrated. Namely,

1. various operators (approx. 10-20 different people) were successfully able to perform part selections through the UI from both within in the boning room and the remote location of an onsite office (see Figure 7),

2. the system could successfully pick each of the main four different part types on the conveyor (shanks, femurs, brisket pieces, and necks) on most pick attempts (79% success),
3. the robot reliably moved to the operator selected pickup locations on the conveyor at the correct times, and
4. the robot reliably released the picked parts at the specified drop off location.

In addition, the December site visit:

1. demonstrated the improved web interface by having an operator based in Christchurch, New Zealand, performing successful real time part selections for the shadow robot system operating in an Australian processing facility,
2. demonstrated part classification (e.g. “femur”, “shank”, etc.) by the operator (see Figure 2a where a part has been classified as “brisket”) and a unique drop off point for each of the part classifications (i.e. once a part has a classification then the software can choose the predefined drop off location that corresponds to the part classification), and
3. demonstrated the ability for the operator to change the rotational orientation of the gripper for a pick to improve pick success.

## 6.4 System Improvements & Future Work

The trials of the shadow robot system provided the opportunity to evaluate the system within a production environment. In general, the performance of the system during operation was as expected. Nevertheless, the trial also identified areas where the shadow robot conveyor packing system requires design improvements to advance to a full production system. Of note is:

- the implementation of box packing as opposed to using an outfeed chute,
- increased picking success through modified grip finger design and robot speed improvements, and
- better management of the periodic increases in product flow on the conveyor to ensure that all selected products can be picked by the system (e.g. using buffer/intermediate storage zones to optimise cycle time, or implement a multiple robot system).

# 7.0 Conclusions / Recommendations

This project took the shadow robot system from a proof-of-concept system demonstrated in a workshop to a production prototype, operator-informed conveyor picking system successfully trialled in a processing facility. The system was developed to make it suitable to enter a production environment and an operator interface where part selections could be made from a live-feed of a conveyor or processing chain was implemented.

In conveyor picking trials, between 10-20 different people operating the system through a remote interface. The system was run successfully not only with the operator situated at the processing facility, but also by an operator providing real time selection from offices distant from the processing facility.

The average successful pick rate of the system was 68% (79% when obvious operator errors, moved targets, and non-singulated parts were excluded) corresponding to a rate of 11.6 successful picks per minute. Several areas have been identified to improve the pick success of the system and will be addressed in future work.

The user-operated, shadow robot system has the potential to be used in routine production. Mimeo plans to implement several improvements to the system to advance the application of operator-informed, conveyor picking and packing.

## 8.0 Acknowledgement

Mimeo wishes to acknowledge the support of AMPC and JBS Foods Australia.

## 9.0 Bibliography

Mimeo Industrial Ltd., 2022a. *Remote Operations – Shadow Robots (Stage 1).* [Online] Available at: https://ampc.com.au/getmedia/849568c1-6295-41a7-9fe5-15b2c6f940ba/MIMEO-Final-Report_2021_1158-Jan-2022.pdf?ext=.pdf
[Accessed 18 January 2024].

Mimeo Industrial Ltd., 2022b. *Remote Operations – Shadow Robots (Stage 2, Part A).* [Online] Available at: https://ampc.com.au/getmedia/587c6ffb-ffb6-46eb-9867-7abeaf0c1e35/MIMEO-Final-Report_2022_1118-Apr-2022.pdf?ext=.pdf
[Accessed 18 January 2024].

Mimeo Industrial Ltd., 2022c. *Remote Operations – Shadow Robots (Stage 2, Part B).* [Online] Available at: https://ampc.com.au/getmedia/5d6e122f-c070-42d2-80c5-52c0fe306e3d/AMPC_Final_Report_2022_1202.pdf?ext=.pdf
[Accessed 17 January 2024].