Doctor of Philosophy
Examiner's Report

Candidate's Name:	Mr Gilbert Eaton	ID: 2795921
Title of research:	Machine vision approach to identifying and grading Strawberries	
Examiner:	Examiner 1	
Date submitted:	2020-01-16	

Criteria Questions

1. Does the thesis make an original and significant contribution to knowledge and understanding of the field of study with which it is concerned?

Criteria Response: Yes

Criteria Comments:

2. Is the standard of literary presentation in the thesis satisfactory?

Criteria Response: Yes

Criteria Comments:

3. Is the methodology applied in the candidate's research effective and appropriate for the thesis topic and the degree sought?

Criteria Response: Yes

Criteria Comments: I select 'yes' with a caveat - I have comments about the presentation of this methodology which I elaborate in my main comments

4. Does the thesis reflect competence in the survey of literature and documentation of statements?

Criteria Response: Yes

Criteria Comments:

5. Is the thesis suitable for publication as a book or in a learned journal in the form submitted?

Criteria Response: No

Criteria Comments: Not appropriate due to the nature of the thesis and the industry involvement

6. Is the thesis suitable for publication as a book or in a learned journal with modifications?

Criteria Response: Yes

Criteria Comments:

Recommendation

Recommendation Submitted**: 2.2 Award with Minor Additional Work**

Recommendation Definition: *The candidate should be awarded the degree, subject to minor revisions being completed as follows: additions to arguments, review of literature, interpretation of findings and any typographical, referencing or formatting errors as specified in the General Report Form completed to the satisfaction of the Chairperson of Examiners.*

Recommendation Comments: I have provided my comments as a PDF report. There are also comments in the supplied thesis PDF file (approx 100 comments).

CONFIDENTIALITY

The University's normal practice is to provide the candidate with copies of the examiners' reports with the examiners' identities expunged. A candidate will be informed of the name of the examiner responsible for each report after the examination is finalised.

Doctor of Philosophy
Examiner's Report Form

CANDIDATE'S NAME:	Gilbert Eaton	ID: 2795921
TITLE OF RESEARCH:	Machine vision approach to identifying and grading Strawberries	
EXAMINER:	Examiner 1	

Gilbert Eaton Thesis Review 15.1.2020

Overview

The thesis describes the development of a strawberry grading system. The Strawberry Quality Assurance system developed in this thesis has a number of novel components, including physical hardware (inc lighting, imaging and electronics), and software (inc image processing, machine learning). This is all developed in an industrial setting. It is worth noting the approach is now in a production environment, having already assessed >1/4 million punnets of strawberries.

In the below comments, I have provided a summary and review of each chapter, followed by bullet points to highlight corrections I believe would make the chapter stronger. But first, I'll give my general impression and major comments.

General comments

I'd like to begin by saying I enjoyed reading the thesis very much, and the final system would seem to be very impressive. It is very well written in general, and clearly a large amount of novel development work has taken place.

I believe the thesis could be improved by clarifying a few sections describing experiments more fully, rather than brief text stating that a test has taken place, culminating in some final parameters to use, or positions to place equipment etc.. I recognise the strong engineering component to the work, but feel as this is a PhD thesis, it would be strengthened with more evaluation described throughout the development process. I should stress, I think this has been done by the candidate, but just not *presented* clearly here, so I hope addressing the comments below will not be too much work. I also note that Chapters 6 and 8 do go into more evaluation detail, but it would strengthen the earlier chapters of the thesis a lot to present existing experimental work more clearly where possible.

- Clarifying **evaluation methods**; **presenting experimental results** (even if for "preliminary tests"). A number of times experiments are referred to which don't seem to be clearly described with reported results. Perhaps it is the concept of "an experiment" which differs between my expectation and that presented in the thesis, but I would like to see a clearly described methodology and presented results (even if for a short experiment this is only half a page of text and one table or some example images)
    - To add, it seems clear from the implications in the text and the success of the final result that this experimentation *has been carried out* (e.g. optimising the pneumatics on p152) but in a thesis a clear description of *how this was evaluated* and a table or graph of the results are expected.
    - For example, on p.156: "The experiments show the 930nm−980nm range has…" What are the experiments exactly? They are hinted at, and some images are

displayed, but the process is not described clearly enough in my opinion. And on P166, the thesis presents results of a 500+ image test set (which is great!), but the process is not described clearly enough.

- I have marked chapter by chapter comments below relating to these evaluation points in red, to help address them. I am hoping the candidate has these results to hand and can relatively easily amend the sections mentioned.
- I think this will make an already impressive thesis much stronger, bringing the scientific method used more into the foreground.
- Most other comments are quite minor.

The following are some general minor comments:

- Figures taken from other sources should have a citation included in the legend
- Some figures come out low quality in the PDF (low DPI). Worth fixing for the final version.
- It feels like there is quite a lot of repetition between sections, especially describing the technicalities of the electronics for example. This isn't a major problem, but the candidate may want to consider streamlining some sections if work has already been described, and refer back to it instead.

Chapter 1

Excellent introduction to the project. Clear specification of the existing production system, and how the new development will enhance the quality assurance process. Very clear specification of requirements and what needs to be done. Clear consideration of the importance of difference types of error on the outcome of the system.

Chapter 2

Good consideration of literature related to image-processing and machine learning approaches to detecting defects. There seems to be a very thorough exploration of existing systems and the data analysis approaches they used.

- It would be helpful to have a paragraph defining hyperspectral data (and contrasting with multispectral and RGB). The term seems to be used on p28 without much introduction for the reader so far (EDIT just got to the later section 2.4 defining the terms – can you link forward to this from the earlier references?) Also in this section, you might want to provide more detail on hyper versus multispectral versus normal colour imaging, especially in terms of number of samples throughout the spectrum range.
- Fig 2.5 Add citations for where the figure came from to the legend, so readers are clear of the source (and that it is not yours)
- Section 2.7 Intro. It would be helpful to provide a few sentences introducing deep learning more ie. how it is a neural network approach, and how its different from older ANNs
- On p53 you introduce ReLU without introducing what an activation function actually is. Also, the definition of ReLU isn't quite right (negative values are set to 0, not negated). The benefits of ReLU also aren't clearly expressed.
- Network architecture p54. I think these need annotations to explain why you are listing them. What is they key point of each example?

Chapter 3

A thorough exploration of challenges with imaging the strawberries is presented. This includes an exploration of different options for lighting, camera selection, positioning of the punnet etc. Software development for the main application is described, and seems well thought out. Challenging issues with timing are resolved using a multi- threading approach in order to manage the multitude of tasks which must be accomplished in the time it takes one punnet to pass through the system. A broad consideration of the physical system components is presented.

The only issue I have with the chapter is a lack of rigorous evaluation. For example, the image analysis ideas are presented, but not clearly evaluated. I suspect more evaluation has been done than is present here, and it would be good to add in some results so choices in implementation can be justified more robustly. As a minimum, I'd like to see some tables of results for the image analysis section, or at the very least a page of example output images, both good and bad, as well as a clearer description of the full algorithm.

- On a first read, I thought the polarizer was not well evaluated. Later I read Chapter 4 and noted some evaluation in this chapter. I think it will be clearer for the reader if you point out here that further consideration of the polarizer happens in Ch 4.
- Fig 3.15 P 95. You state in the text above many iterations of the GUI have been developed to arrive at this figure. Wouldd it be possible to include some snapshots of the GUI Development as an appendix, with some annotations as to what worked and what didn't at each step?
- Clarify use of saturation on p. 100 (See highlighted text and comment)
- P102, with the circular nature of hue, does red wrap around to 360 or does it really start at 0?
- P102. Could you provide more example output images demonstrating that your approach works? It would also be good to see some numerical analysis of the thresholding approach. It is hard to tell how well it works, and as you mention at the end of the section, it does have problems which need addressing. Are these addressed later in the thesis? Hard to tell at this point - please provide a pointer to a future section if they are addressed later.
- P113. Section 3.4.5 Image Processing. You need to describe in detail the algorithm here that you are using. You mention the approach, show a screenshot, and present a few select results. This section needs to much more clearly show the final method, and tabulate some results (or at the very least present more output image examples – good and bad). The text about the size of the test set is also very confusing, and I am unsure if this work has happened or if it is to do in the future?

Chapter 4

The aim of this chapter is to develop a method to create well-lit images of the strawberries, minimizing the effect of specular reflection.

- To note, this chapter seems to be directly from a paper, and refers to itself as such. I am not sure if the text could be altered in a few places to better fit as a thesis chapter rather than a paper – this would not be much work and would make the flow better.
- Related, there is quite a bit of repetition between ch 4 and ch 3…due to the nature of Ch 4 as a paper. Read both, and edit where possible to prevent this.

- P125 I am unclear what "average pixel area" is. I think this section could benefit from a rewrite to make the exact image processing steps more clear.
- P128. You conclude the chapter with "Experiments were also performed that showed that the cross-polarization technique has the ability to entirely remove of the specular reflections in most cases". I would argue the last part of this claim is not true, given the results presented. The example image (4.5b), whilst clearly improved and impressive, still has a small amount of reflection. I think to justify the "in most cases" claim, I'd like to see some results from more images (numerical and/or qualitative images), rather than just one.

Chapter 5

This chapter describes the integration of the proposed system into the industrial environment. Its nice to see some descriptions of problems which arose and how they were fixed.

- P146 The motion blur section is OK, and the results look nice, but I had a few questions marked in the text about some of the terminology used.
- P148 What is described as optic flow is actually a difference image. There is no concept of how far pixels have moved, so I would not refer to this as optical flow.
- P152 This is another example of where more experimental results would be beneficial. Final parameters of the pneumatic system are presented which are based on "initial testing". It would much improve the section if the testing was described in more detail, and results presented (presumably these exist, but are not presented here at the moment).
- Minor point. I was curious when reading this section what would happen if the conveyer systems stops after a "bad" punnet has exited the image processing station but before the ejector. Will it still be ejected correctly in this case?
- P160 please describe the two new algorithms mentioned
- P166 "A dataset of 500+ images".. This is great! A sizeable evaluation on a realistic test set has clearly taken place, but is not clearly described here. Please expand this section for more fully describe the process and results, and provide more example images.

Chapter 6

This chapter considers analysis of strawberry colour, and is presented as a published paper. Again, this means there are some repetitions from previous sections, e.g. the physical system is described again. However, this chapter does provide a much better evaluation and results section than the earlier chapters.

- Section 6.4 This is a clearer consideration of the image analysis processes developed, but would still benefit from showing the final algorithms in their own box for clarity (as a flow chart, or pseudo code, for example, as on p 221)

Chapter 7

This chapter describes a significant upgrade to components of the system, reflecting on a first set of industrial uses. Again, this represents an impressive amount of novel development work. The foreign object detection is interesting and fairly well described and illustrated with examples, including why certain objects were detected, which is nice to see.

- P221. Is algorithm 20 really algorithm 1? To note, this is exactly the kind of algorithm presentation I would like to see elsewhere in the work. Happens again with Algorithm 19 p225

Chapter 8

This chapter explores machine learning approaches to image aanalysis, including deep learning. Feature vector classification is proposed, but rather than using hand crafted features, those generated by a ResNet deep network are used. Impressive results are achieved (95%) given the similarity of the images.

This is a strong and timely chapter for the PhD, but I found there to be a number of wording issues which affected the clarity, which I have highlighted in the PDF.

- P241. Is there a reason why the training set is so small (27) compared to the test set (579)? I would normally expect this division to be the other way around.

Chapter 9

This chapter presents conclusions and outcomes and highlights the clearly met objectives and impressive performance of the final system.

Bibliography

Broad enough. Could do with checking formatting on the references to make them consistent.