Studentship Project: Annual Progress Report
Sept/2022 to Dec/2023

Student Name:	**Katherine James**	**AHDB Project Number:**	**SF/TF 170/a**
Project Title:	**High-throughput phenotyping of fruit traits for automatic strawberry harvesting**		
Lead Partner:	Berry Gardens		
Supervisor:	Grzegorz Cielniak and Daniel Sargent		
Start Date:	01/10/2021	**End Date:**	31/12/2025

1. Project aims and objectives

Strawberries are a berry crop of major economic importance, grown commercially throughout the temperate and subtropical zones of the world. Labour, or rather the lack of it, poses a huge challenge to the soft fruit industry. In a survey conducted by British Summer Fruits, the industry body representing 95% of all British grown soft fruits), a loss of £36.5 million was reported in 2021, equating to 7709 tonnes of fruit, solely due to berry waste from lack of labour (British Summer Fruits Members' Survey, 2021).

A promising technological solution to these labour problems is the introduction of fruit-picking robots (Ducket et al, 2018). Considering the strawberry industry alone, a substantial amount of research has been conducted towards developing strawberry harvesters, spanning both academic institutions and commercial start-ups around the world (Kondratieva et al, 2022).

Automated phenotyping of strawberry plants has the potential to revolutionise the breeding process by supplying high-throughput, quantitative measurements which are infeasible to complete through current manual methods (Zheng et al, 2021). Furthermore, different plant architectures have the potential to pose a greater or lesser challenge to automated harvesters and capturing this through a complexity measure as a phenotypic trait during selection has the potential to result in future varieties which simplify the harvesting task.

The objectives of this PhD centre around developing and evaluating methods for automated phenotyping of strawberry and linking these phenotypes to measures of structural complexity.

This will be approached through four objectives, as follows:

O1. Determine the current status of automation of relevant phenotypic traits and the potential for automation of unautomated traits

O2. Investigate and implement algorithms necessary to conduct standard holistic and component phenotyping tasks

O3. Investigate how structural complexity can be linked to both phenotypes and harvest success

2. Key messages emerging from the project

In the first year, we conducted and published a review to establish the current status of automated phenotyping in strawberry (James, 2022). This review highlighted that very little research has been done into automating the phenotyping of strawberry, as the only traits which have been automated relate to fruit and phenology, and research has not been focussed on the automation of traits such as peduncle length or truss complexity.

Access to relevant datasets (annotation rich 3D point clouds of strawberry) is also a challenge. We collected a dataset in the first year of this project to address this, but even a high-quality dataset poses challenges to phenotyping methods which must be considered by developers.

Existing algorithms for computing phenotypes from point clouds are lacking or require careful consideration to determine if the extracted phenotypes are biologically relevant.

3. Summary of results from the reporting year

In this, the second year of the PhD, the focus of work has been distributed across two themes; skeletonisation (converting a point cloud to a thin representative structure through its centre) and complexity.

Theme 1: Skeletonisation

Existing skeletonisation algorithms suitable for the skeletonisation of plant structures in 3D were identified to be those of Xu (2007), Huang (2013) and Magistri (2020). The former produces plant graphs that branch too much, the second produces highly fragmented graphs. While the third produces reasonable skeleton points, these are often not centred within the stem in the cases of occlusion on one side and topological connections go awry if using the same classes as the authors (leaf and stem).

Our own research into skeletonisation has consisted of development and refinement of our variant of unsupervised k-means clustering, in which a clustering is performed around k cylinder centres. This results in a set of skeleton points, at the top and bottom of each cylinder, forming a small segment which can then be connected using least cost. Initial results show that this method does not beat the state of the art, although it has some benefit in that exploiting the cylindrical prior means that the skeleton is more centred in the case of missing points.

It has also been necessary to consider how skeletonisation can best be assessed for phenotyping, as current measures are often subjective. To this end, we developed a library allowing for computation of several quantitative measures relevant for plant graph matching in 3D. This allows for quantitative comparisons between skeletonisation algorithms, to assess developed methods against existing ones.

Theme 2: Complexity

Towards developing measures of complexity that link phenotypes to ease of harvest, we first produced a synthetic dataset using L-Systems in LPy. This allows for each phenotypic trait to be varied in a controlled way, facilitating exploration of the effect of each trait on complexity measures. For each berry in the synthetic dataset, we computed a measure of the display of that fruit - how ‘reachable’ it was. Investigations were then performed using an existing spatial complexity measure, the box dimension, but this was found not to correlate well with the reachability score. Further research will focus on improving the synthetic dataset to avoid collisions between organs and in creating our own metrics to correlate phenotypes with reachability.

4. Key issues to be addressed in the next year

- Publication of dataset and phenotyping benchmarks
- Conclusion of skeletonisation research
- Further exploration of complexity and linking this to phenotypes

- Exploration of challenges to phenotyping in non-laboratory conditions

5. Outputs relating to the project

(events, press articles, conference posters or presentations, scientific papers):

Output	Detail
Review paper in New Phytologist Foundation Journal	James, K., Sargent, D., Whitehouse, A., & Cielniak, G. (2022). High-throughput phenotyping for breeding targets – current status and future directions of strawberry trait automation. Plants, People, Planet, 4 (5), 432–443. doi:10.1002/ppp3.10275.
TedXBrayfordPool Talk	"How agri-robotics will change the food you eat" A TedX talk presented on 3 September 2022 at TedXBrayfordPool. Abstract: Agricultural robotics and artificial intelligence are changing how we farm, from day-to-day practices to selecting new crop varieties. In this talk, Katherine James gives an overview of how agri-robotics is changing the way we interact with crops, how this will change the crops themselves and, ultimately, how this will allow humans to focus more on things which require the 'art-of-being-human'.
CTP Summer/Winter presentations	Bi-annual meeting at which a presentation of research highlights is given.
Research visits	Visted the Universities of Bonn, California-Davis and Wageningen and gave presentations on my research, along with my research group.

6. Partners (if applicable)

Scientific partners	
Industry partners	Berry Gardens (Richard Harnden)
Government sponsor	

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