Studentship Project: Annual Progress Report OCT/2022 to OCT/2023

Student Name:	**Philip Johnson**	**AHDB Project Number:**	**SF/TF 170/a**
Project Title:	**Design and Control of a novel low-cost soft robotic gripper for soft fruit harvesting**		
Lead Partner:			
Supervisor:	Dr Marcello Calisti		
Start Date:	01/10/20	**End Date:**	01/10/24

1. Project aims and objectives

- Design a soft robotic end effector for soft fruit picking
- Develop novel soft robotic technologies which can be used in the end effector
- Fabricate the end effector
- Control and test the end effector

2. Key messages emerging from the project

- Shear thickening fluids (STFs) can be a used to create effective variable stiffening mechanisms in soft robotics.
- STF joints can achieve upwards of 6x stiffness variation, based on the speed of actuation.
- Blackberries can be harvested with 95% success rate with a soft robotic gripper.
- Blackberry shelf life is improved by picking with soft gripper vs human hand.

3. Summary of results from the reporting year

The project work and results can be split into two main sections. The first section concerns the development of a soft gripper for blackberry harvesting. This year we developed a design for a ‘closed structure’ cylindrical soft gripper for the harvest of cane fruits such as blackberries and raspberries. To support this design process, we collected a set of ‘blackberry detachment force’ data with 250 individual points [Figure 1]. The gripper is made of soft silicone rubber and works using pneumatic air channels to inflate around the fruit and apply gripping force. We have tested the prototype gripper extensively, gripping blackberries in real farm polytunnels and glasshouses [Figure 2]. We also collaborated with EPFL CREATE lab to test our gripper on a sensorised ‘physical twin’ of a raspberry [Figure 3]. This work allowed us to compared the force applied by our gripper design with that of a human hand applying force. The results reveal that the gripper is able to harvest blackberries with a comparable level of force to a human hand and that it harvests real blackberries with a ~95% success rate. We further evaluated the gripping success rate using highly varied experimental cultivars grown at NIAB East Malling with consistent results. Furthermore, after an industry inspired shelf-life trial, we found that blackberries picked with the gripper had a much-improved shelf life (30-150%) and quality across 8 metrics measured one week after picking [Figure 4].

Figure 1: Collecting blackberry detachment force data (Clock House Farm UK)

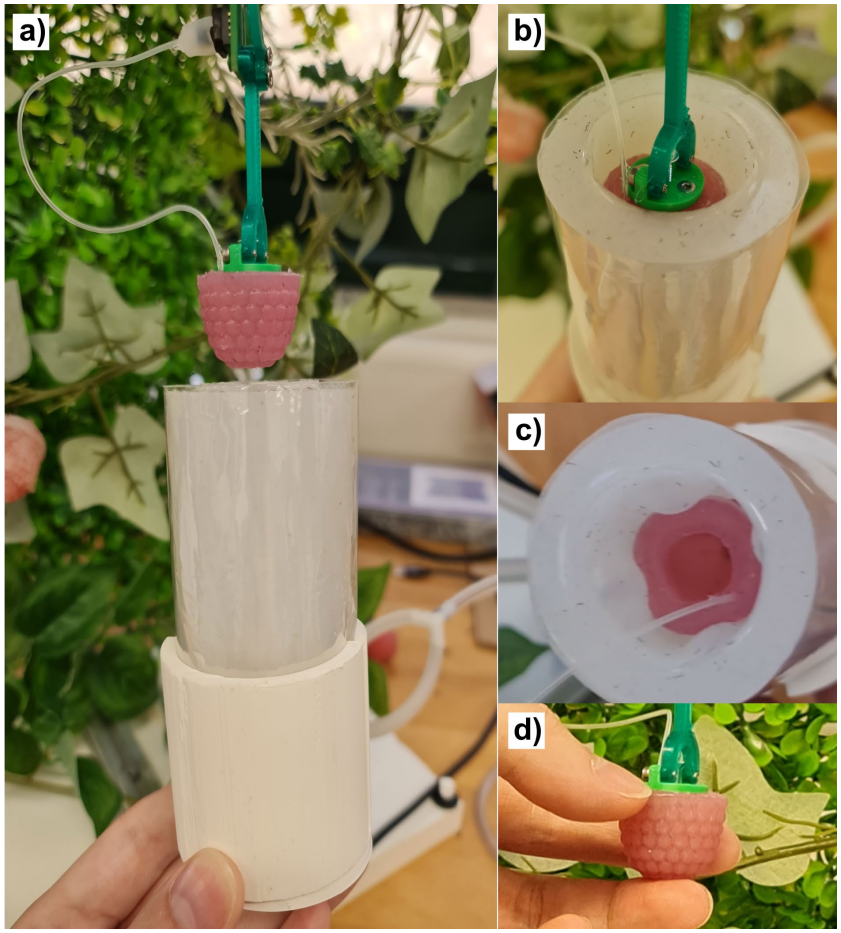

Figure 2: Gripping the EPFL 'sensorised berry' a) - d) assorted images of berry and gripper

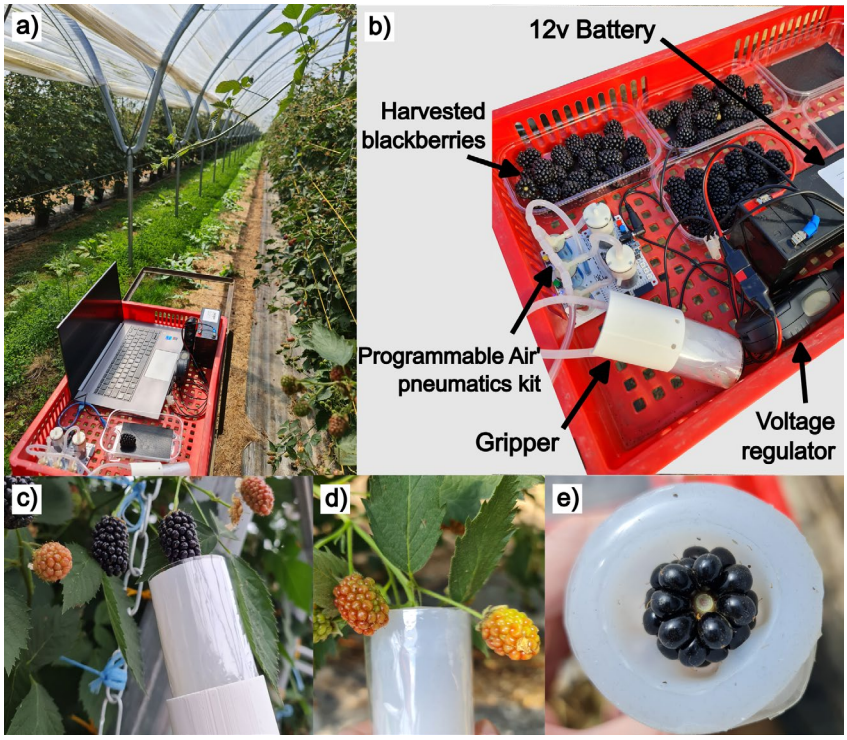

Figure 3: Images from gripper testing. a) Polytunnel with gripper equipment b) Diagram of equipment used c) Gripper with ripe blackberry d) Gripper enclosing blackberry near unripe fruit e) Blackberry inside gripper cavity

Figure 4: Shelf life metric results for Gripper picked vs Human picked blackberries

The results collected so far for the blackberry gripper have been recently submitted pending review as a conference paper for next year's IEEE ICRA conference. In the past month further development on the prototype has taken place which will progress towards a planned journal submission next year.

The second section of work is focused on novel soft robotic technology which can be used to enhance grippers for soft fruit harvesting as well as other applications. This technology is based on 'Shear thickening fluids' (STFs) which can be included in soft robotic mechanisms to introduce 'variable stiffening' properties. These properties allow soft robotic devices to apply higher forces when required whilst retaining desirable flexible and gentle characteristics. The results collected last year (included in last AHDB report) were accepted as a conference paper at the IEEE Robosoft conference 2023 and presented in April. Building on

this outcome, we have planned a second phase of work, securing an Interdisciplinary Research Grant of £1000 for the purchase of advanced materials. We are also building ties and collaborators with The Bridge advanced materials lab and computational physics group here at Lincoln to bring additional expertise to work involving the STFs. In the last month we have investigated the modelling of STFs to inform the design of improved mechanisms and experiments. The next steps will lead to a larger contribution aimed at journal publication.

Finally, this year I was also involved in co-writing a mini review paper entitled 'The Adoption of Robotics in Pack Houses for Fresh Produce Handling' which has been published in the Journal of Horticultural Science and Biotechnology. This work draws together literature findings related to the handling of fresh produce with soft robotic technology. I also made a minor contribution to a soon-to-be-published review of soft robotics in agriculture entitled 'Soft Robotics for Farm to Fork: Applications in Agriculture & Farming'.

4. Key issues to be addressed in the next year

The first key focus area for next year will be refining the gripper that we have developed and using it with a robotic arm to develop basic control and vision systems for autonomous berry harvesting. We will mount the gripper on an existing robot arm and add two camera sensors for detection of the fruit and robot navigation. We will conduct a series of experiments to investigate the performance of the gripper in realistic harvesting scenarios similar to agricultural robots developed for Strawberry and Tomato harvesting. This will represent a key outcome for this project and aim to develop our prototype into a well-rounded solution for cane fruit harvesting.
The second key focus area will be the next phase of work with STF-based soft robotic mechanisms, building a model for their behaviour, and ultimately producing more advanced mechanisms which can be integrated with grippers and other devices. Ideally, we will use this technology with the blackberry gripper to enhance picking and grip strength while also enabling softer and more delicate designs.
Finally, an additional point to address will be the fabrication of a sensorized blackberry physical twin. This work will build on the open-source raspberry physical twin equipment produced by EPFL CREATE lab. The device will be produced to support the testing of agricultural grippers in this project and beyond. This work will ideally allow high quality testing of agricultural grippers outside the growing season when access to real fruit in farms is not possible.

5. Outputs relating to the project
(events, press articles, conference posters or presentations, scientific papers):

Output	**Detail**
Conference Paper	P. H. Johnson, M. Rai and M. Calisti, "Fabrication and Characterization of a Passive Variable Stiffness Joint based on Shear Thickening Fluids," 2023 IEEE International Conference on Soft Robotics (RoboSoft), Singapore, Singapore, 2023, pp. 1-6, doi: 10.1109/RoboSoft55895.2023.10122061
Journal Paper	Barry J Mulholland, Pardeep S Panesar & Philip H Johnson (2023) The adoption of robotics in pack houses for fresh produce handling, The Journal of Horticultural Science and Biotechnology, DOI: 10.1080/14620316.2023.2247835
Journal Paper	Soft Robotics for Farm to Fork: Applications in Agriculture & Farming' (Awaiting Publication)
Conference Poster	IEEE Robosoft Conference 2023
Workshop Presentation	EPFL Switzerland Workshop: Workshop on Soft Robotics and Embodied AI for Food and Home Applications
Conference Poster	Lincoln College of Science research showcase
Conference Poster	AUC Future Agricultural Researchers PhD Conference 2023

Conference Poster	Agri-TechE REAP Conference 2023

6. Partners (if applicable)

Scientific partners	N/A
Industry partners	Berry Gardens Ltd
Government sponsor	UKRI (BBSRC)