Development of a robotic system for harvest of blackberries.

Dates: **15 July 2024 – 18 July 2024**

Names of GCRI grant recipients: **Marcello Calisti**

Locations of where the work took place: **NIAB, East Malling and Clockhouse Farm, Maidstone.**

Executive Summary and highlights

An extensively lab-validated robotic arm equipped with a soft gripper for blackberry harvesting has been deployed to blackberry farms for testing and refinement. The experiments demonstrate the feasibility of the approach and identified technical bottlenecks to be addressed for the effective employment of the robotic arm in autonomous harvesting.

- Researchers demonstrated the feasibility of autonomous berry picking with a soft material gripper and low-cost robotic arms.
- Researchers validated these steps of the automatic picking process, i.e. identification of the berry, calculation of the pose, approaching of the berry with the robotic gripper, ingestion of the berry, detachment of the berry, and release.
- Researchers identified key technological bottlenecks for deployment of autonomous picking robots of blackberries cultivated in polytunnels.

Background

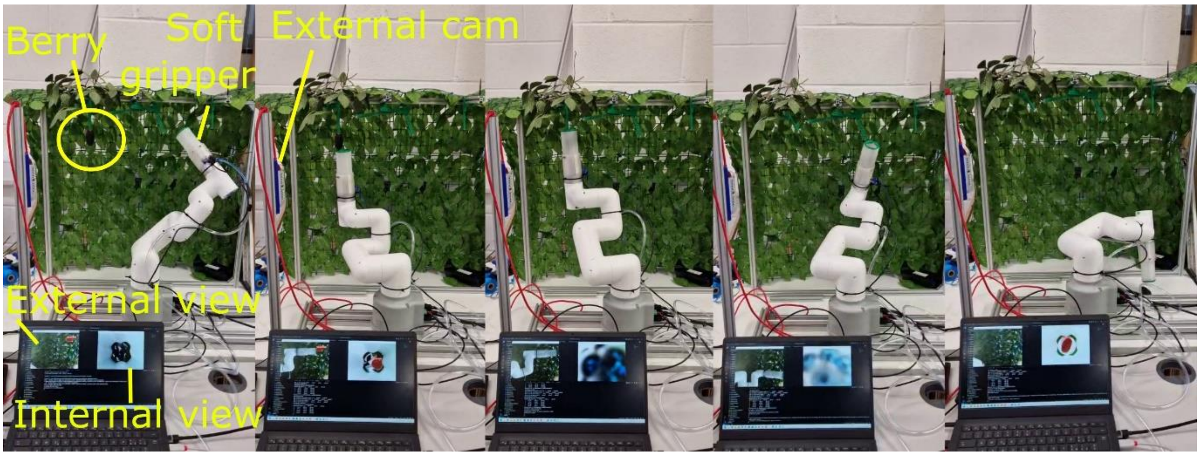

Figure 1: The robotic arm equipped with a soft gripper, controlled by an external laptop, a realsense camera, and a USB camera (inside the gripper). The picture shows the views from the external and internal cameras (for user feedback on the laptop), while the arm moves autonomously toward the plastic berry, aligns to the main axis of the fruit, and ingests it within the gripper. The gripper then inflates and detaches the berry, and eventually it collects it on the table.

A blackberry soft gripper [1], developed within the context of a Collaborative Training Partnership (CTP) for Fruit Crop Research, supported in part by Berry Gardens Ltd. and in collaboration with NIAB, has been integrated into a small robotic arm equipped with an external RGB-D camera and an internal camera to achieve autonomous harvesting. This work, carried out in collaboration with the University of Trento (UoT) within the context of an Erasmus+ visiting student agreement between UoT and the University of Lincoln (UoL), demonstrated excellent results in a lab setting with physically replicated blackberries.

By taking as a reference Figure 1, from left to right, you can see the arm in the lab setting while it is initiating the movement, then moves the end effector (gripper) below the berry, aligning it according to the commands informed by the external camera. At this point, the arm moves the gripper linearly following the principal axis of the berry and ingests the berry with the soft gripper. The gripper inflates, and the arm moves away, detaching the berry from its magnetic base. Eventually, the gripper deflates and the plastic berry is collected on the table.

With the goals of validating the approach, gaining field experience, and refining the current robot, Dr. Marcello Calisti and Dr. Charles Withfield decided to test the robot within the polytunnels of NIAB, and at the polytunnels of Clockhouse Farm. Support for such activities have been requested and granted by the GCRI.

Dr. Withfield organized the field experiments and logistics concerning NIAB and Clockhouse, while Dr. Calisti organized the part concerning robot transportation from Lincoln and technological logistics.

Mr. Fabio Taddei Della Torre participated in the activities as the visiting student who, during his six-month period, developed the vision and control part of the system. He was also responsible for collecting the data, refining the algorithms, and executing the experiments in the polytunnels, with the supervision and collaboration of Dr. Calisti and Dr. Withfield.

Activities undertaken

Dr. Calisti and Mr. Taddei Della Torre arrived at NIAB on the afternoon of July 15th and, with Dr. Whitfield, carried out a logistical inspection of the NIAB polytunnel and planned the activities for the following days.

Figure 2: Top row of the image: the light variability was significant during the experiments; the two images show how the light condition changed dramatically from one moment to the next one. Below, it can be seen on two berries how the robot aligned with the wrong axis of the berry, due to the lack of a clearly elongated shape.

On the morning of July 16th, Mr. Taddei and Dr. Calisti collected preliminary data and images from the plants growing within the polytunnel at NIAB, assembled the robot on the moving platform, and prepared the hardware for the field experiments. After an early testing phase, they spent the morning adapting the vision and kinematic algorithms of the arm to the field conditions and to plan the experiments. In the early afternoon, extensive testing of the blackberry robotic system was carried out on selected berries, analyzing seven different stages:

1. identification of ripe berries by the vision system,
2. calculation of the correct pose of the berry,
3. approach of the berry by the robotic arm,
4. centring of the berry using the internal camera,
5. ingestion of the berry by the soft gripper,
6. detachment of the berry from the stem, and
7. release of the berry.

Three issues immediately arose from this first field experiment (see Figure 2). Firstly, the extreme variability of light conditions significantly impaired the identification of the berry, despite the additional data collected in the morning. This significantly influenced the internal camera, which was tasked with centring the berry with the gripper. The second issue was related to the variety of blackberry used for picking: the lab tests were based on the Driscoll's Victoria® variety available at Clockhouse Farm and replicated with a 3D-printed model in our lab. Victorias® have an elongated shape with a clear principal axis, which was used as an assumption for the algorithm. Lacking this feature, the algorithm struggled to recognize the pose of the berry. The third and final issue was that the serial approach conceived for automatic picking without manual intervention was prone to a total-fail/total-success outcome. In other words, if one point of the serial process failed for some reason, it was impossible to test the subsequent steps. This was a factor that occurred in the lab but at such a rare frequency that it did not pose a real problem: however, in farm such issue resulted as a strong limitation, especially since these initial failures impacted the steps 1 to 3 of the autonomous harvesting process. During the evening, we worked to fix the first issue (related to illumination, by adapting the threshold and partially retraining the YOLO algorithm), hoping to proceed smoothly with the next steps of the serial process.

On the second day of experiments, the morning of July 17th, we restarted the experiments at NIAB with the modified vision algorithm for the detection of the berry. The detection rate improved dramatically, achieving similar performance to that obtained in the lab, but the pose calculation of the berry (needed to align the gripper to the berry for ingestion) was still not working. Due to the time constraints of the visit and the availability of the commercial farm, we decided to test the current state of the algorithm directly at Clockhouse Farm, and we moved all the equipment to the polytunnel facility at Clockhouse.

The elongated shape of the blackberry at Clockhouse's polytunnel immediately improved the calculation of the appropriate pose, with approximately half of the attempts correctly calculated. Lighting conditions at dusk forced the interruption of the field trials, and an evening post-experiment briefing was conducted. During the post-experiment briefing, it was decided to modify the serial architecture of the system and to allow the user to select the principal axis of the berry after a first automatic attempt. Such user intervention was a mitigation strategy to increase the number of berries that could be ingested during the trials and to bypass potential interruptions of the automatic algorithm.

Figure 3: The improved vision algorithm detected correctly most of the berries (top left image), but the berry was still not detected with the internal camera (top row, right-bottom image). Although the algorithm aligned correctly the gripper with the berry (bottom row, central image) during the ingestion stage even small discrepancies prevented the ingestion (bottom row, right image).

The third and last day of experiments started directly at the Clockhouse polytunnel on July 18th. The improved algorithm for lighting conditions, the elongated shape of the Driscoll Victoria®, and the user verification allowed a consistent and perfect initial alignment of the gripper with the berry. However, the internal camera still suffered from difficulties in detecting the blackberry and refining the alignment (see Figure 3). This step was deemed necessary, also in the lab, to compensate for the low accuracy of the manipulator itself and because of normal inaccuracies in the pose and position calculation. Moreover, being the gripper only marginally larger than the berry, the best possible centring was necessary to perform the ingestion. In the afternoon, after failures in fixing the internal camera issues in the field, we proceeded with a teleoperated approach, which resulted in sporadic successes in the ingestion. Once ingested, the gripper inflated and the berry was properly detached, quite robustly even in case of partial ingestion (e.g. with the berry partially inside, and partially outside the gripper). At the end of the experiments, additional videos were taken of the actual polytunnel to improve the training of the YOLO algorithm employed for the detection by both the external and internal cameras. The experiments concluded at dusk.

Knowledge gained

The experiments confirmed the effectiveness of the gripper which, with rare exceptions due to the prototyping nature of the technology, always actuated properly and gripped berries even in sub-optimal conditions (e.g. partial ingestions). The vision algorithm for the external camera, after initial refinement, worked to a sufficient standard for the automatic detection of the berry. The pose calculation was partially satisfactory, and the user in the loop provided an appropriate solution to move to the next stage of the harvesting process.

The inexpensive robotic arm employed, costing around £700, demonstrated an insufficient level of accuracy and similarly low quality of the built-in libraries. Especially on the edge of the workspace, the dexterity of the arm was insufficient for a perfect straight ingestion motion that, paired with the low quality of the refined centring, resulted in a high level of failed ingestions. However, the arm was always capable of reaching the commanded position, and when the internal camera worked to refine the alignment, it was sufficient for ingestion despite the mentioned limitations. Similarly, the processing time for the control algorithm was excessive due to the low quality of the libraries employed. This limitation cannot be overcome with the current hardware.

Regarding the integration of the different components, although the algorithm worked as expected in laboratory conditions, it showed practical limitations in terms of testing in the field. Especially in terms of the serial process, the lack of verification steps and options for manual intervention was a significant drawback for the field experiments.

In conclusion, the work carried out with the support of GCRI was a necessary step to improve the existing automatic blackberry harvesting solutions. Although the success of the whole algorithm was disappointing, the individual components demonstrated high potential for improvement. Thanks to extensive hands-on testing, issues were addressed during refinement stages, directly during the visit. The field experience reported here demonstrated once again that a huge discrepancy exists among simulation, lab conditions, and field conditions, and that the real deployment of robotic solutions can only be achieved by increasing the time spent in the field under actual conditions.

Next steps

The results highlighted a clear way forward and the steps required to improve the harvesting solution. Thanks to the additional data collection at dusk, YOLO algorithms for the detection by the internal and external cameras will improve the performance of berry identification. Moreover, tailored training that includes the stem will further refine the calculation of orientation, even in the presence of non-elongated berries.

A bespoke arm with ideal kinematics should be developed specifically for berry harvesting. The commercial solutions, although multi-purpose, are incapable of negotiating the perfect approaching kinematics needed for blackberry harvesting. With the appropriate development time, a bespoke manipulator can be developed for less than £1,000 and with better performance than the arm used in these experiments.

Eventually, shared autonomy should be considered a priority. A fully autonomous picking system, no matter how perfect, will require a user in the loop at least during the development stage. The lesson learned here is to develop a teleoperated solution first and to build upon it the autonomous steps to gradually reach full autonomy. This will allow for separate testing of the control and mechanical parts of the system and speed up the whole system diagnostic.

Personal statement

I am extremely thankful for the generous support of the GCRI Trust. Without the financial assistance for travel and the invaluable insights gained from the field experience, the progress of the developed system would have stalled, and the actual impact on the industry would have been very limited. This experience also informs the way forward in developing robotic systems for the field and invites early and extensive field testing both to understand the problems and limitations and subsequently to improve the developed solution.

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References

[1] P. H. Johnson, K. Junge, C. Whitfield, J. Hughes, and M. Calisti, “Field-evaluated Closed Structure Soft Gripper Enhances the Shelf Life of Harvested Blackberries,” *Proc. - IEEE Int. Conf. Robot. Autom.*, pp. 9382–9388, 2024, doi: 10.1109/ICRA57147.2024.10610387.