AHDB Horticulture

Project title: Application of novel machine learning techniques and high speed 3D vision algorithms for real time detection of fruit

Project number: CTP_FCR_2017_8

Project leader: Grzegorz Cielniak, University of Lincoln

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[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Raymond Kirk

PhD Student

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Signature .... Date ....12/12/2019.......................

Report authorised by:

Dr Grzegorz Cielniak

Reader

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GROWER SUMMARY

Headline

Working towards autonomous fruit harvesting and accurate long-term yield forecasting.

Background

Novel digital technologies including vision systems, robotics and autonomous systems are seen as potential game changers for the horticulture sector. Visions systems can be used to assess and sense the crop to enable better decision support; robotics and autonomous systems offer new means to drive productivity. These issues apply to all soft and tree fruit crops, but also more widely across the whole fresh produce sector. However, all picking and vision systems are dependent on the development of complex algorithms developed to identify, measure and locate fruit in real time. The development of these systems is not trivial, especially in outdoor environments where the background light level and quality can change within an instant.

Summary

This project aims to progressively implement crucial components required for robust autonomous fruit harvesting. The problem is comprised of five major milestones for fruit: segmentation, detection/classification, maturity evaluation, quality grading and finally 3D localisation and pose estimation. The challenge in this project is to achieve this whilst minimising computational requirements to identify fruit and maximising processing speed and recognition fidelity. This project will initially focus on strawberry and be anticipated eventually to include other soft fruit crops. Recent work has focused on long- and short-term tracking of individual fruits spatially and temporally to build a map useful for yield forecasting and online harvesting applications.

Financial Benefits

At this stage, the research is focussed on delivering systems that can operate 24/7 in agri-food environments over multiple disciplines such as harvesting, dense automated agronomy and yield forecasting. With expected financial savings from lower yield forecasting error, increased daily harvesting count, reduced labour demands and better resource (chemical) use from automated agronomy applications.

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Action Points

Action points for growers will be developed in the penultimate project stages as it’s too early to provide recommendations based on the current results for growers.

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RESEARCH SUMMARY

Projects

The current study is part of a larger project called 'RAS-Berry'. RAS-Berry involves developing a vision system to detect soft fruits, primarily strawberries. The end goal of the project is to enable smarter harvesting, counting and yield estimation in-field. Vision systems can be very complex and the infrastructure of fruit harvesting environments/systems are equally as complex, navigating between speed, environmental, robotic and seasonal constraints. Many current approaches in literature fail to work reliably in commercial 'real life' environments, since they have been tested/developed exclusively in lab environments.

The University of Lincoln is lucky enough to have access to the Riseholme campus where 'real world' conditions are simulated on site. This enables the development of algorithms and approaches more suited to widespread commercial application. Such as the approach I am currently working on. As aforementioned the complexity of the proposed system is great, and with the current direction of the research community, a lot of data is required to be able to develop algorithms/approaches that can robustly solve the problem. Especially with the advent, popularity and great advances being made within the Deep Learning domain.

Many processes in agri-food environments impose temporal restrictions, for example harvesting berries; the optimal time to harvest soft-fruit is when field heat is as low as possible, ensuring minimal damage occurs to them from plant to supermarket shelves. Providing a yield estimation at the start or middle of the season is another example of a time limited operation. Traditional processes have been restricted in areas such as this by availability of labour and unpredictability of soft fruit growing. This project will address these challenges by developing robotic systems to decrease cost and increase efficiency of agri-food environments.

We design our robotic systems with continuous operation in mind and see this as the primary benefit of implementing these systems in an argi-food environment. By utilising autonomous mobile robotic platforms (primarily Thorvald, Figure 1) we can digitise a wide variety of tasks and increase daily efficiency and lower energy use.

Specifically, this project will focus on the digitisation of soft-fruit harvesting, fruit counting and yield estimation, through machine learning, deep learning and computer vision. Computer vision in combination with deep learning allows us to gain deeper insight into the

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environments our systems will operate in, for example we can train a detector to separate berries into maturity classes and only harvest ripe Class 1 berries.

My research to date has developed a method to minimise the impact of luminance (variability of lighting conditions on model performance over multiple days) through the use of single-stage detectors with bio-inspired modifications at the input level (Figure 2). This method was developed leverage the benefits of continuous deployment of the robotic platforms in a commercial setting enabling fruit harvesting 24 hours a day, a major benefit of fruit harvesting on a robotic platform. Variable conditions in farming conditions affect our model performance, so using bio-inspired features we managed to show we can be more invariant to these changes. We published this paper at Sensors journal (https://doi.org/10.3390/s20010275), the model architechture is contained in Figure 2 below. We achieved a performance of 0.793 (F1) in this paper and a near real-time frame rate. More in-depth evaluation can be found in the paper.

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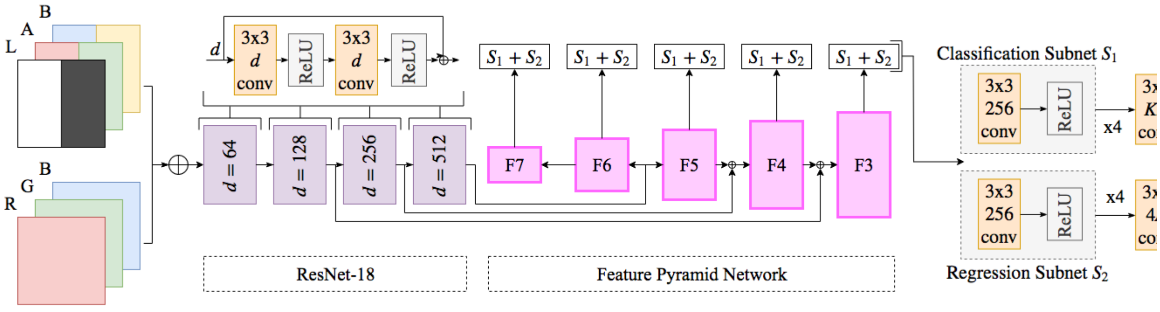
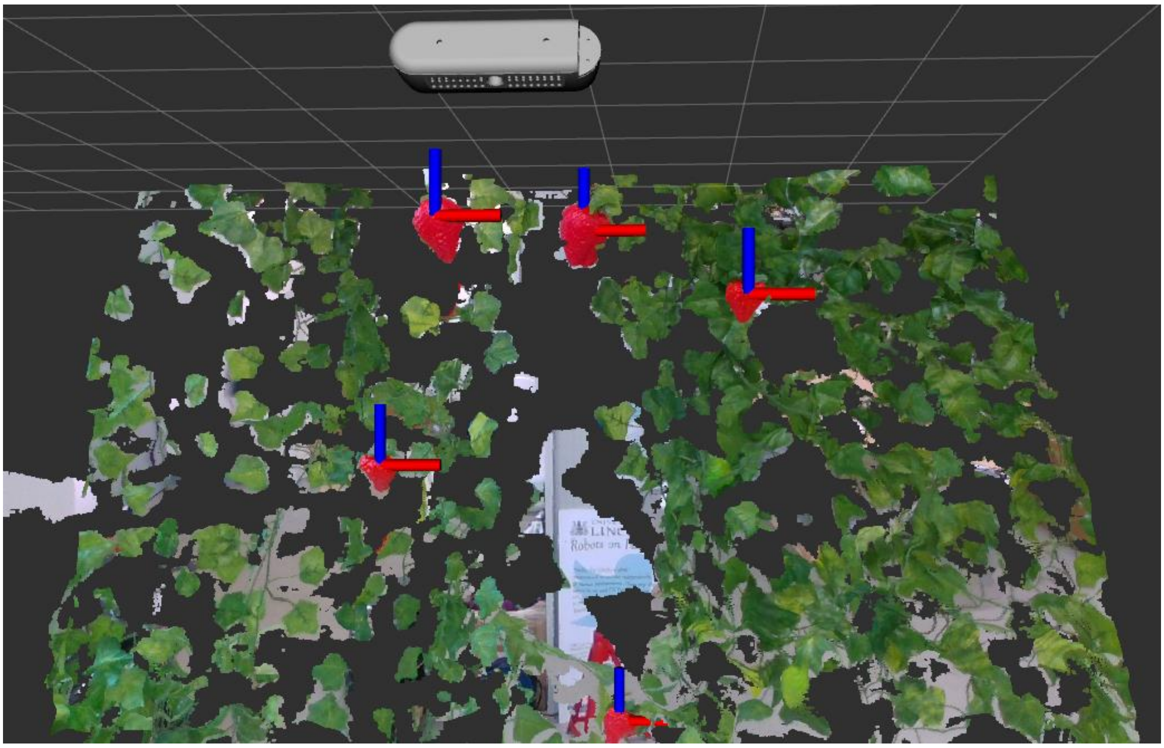


*Figure 2: L*a*b*Fruits: A Rapid and Robust Outdoor Fruit Detection System Combining Bio-Inspired Features with One-*

The current study has implemented two-stage architectures such as Hybrid Task Cascade RCNN (Kai Chen 2019) and Mask-RCNN (Kaiming He 2017) for two reasons; 1) they are fast becoming the standard; and 2) due to the fact they learn pixel level representations of each object, rather than just learning it's bounding box co-ordinates. Utilising more filtering and SOTA approaches accuracy has been improved up to 90% on some datasets. Example images are shown in Figure 3. These pixel-level features allow us to more accurately locate the position of each berry in a real-world situation. We have now translated our Hybrid Task Cascade model to a cartesian 3 degrees of freedom robotic arm and have shown an average picking rate of 3.1s per berry in laboratory conditions.



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Future Work

For harvesting applications, our naive pick-by-detection strategy was in-effective for dense cluster and highly occluded examples (Harvester pictured in Figure 4), so now we're focusing on dealing with these edge cases. Furthermore, these experiments brought us to the realisation that static detection (detection at a single time point) of produce in-field is not sufficient for intelligent control of harvesting systems, yield estimators, disease control and forecasting systems. Moving forward we're collecting a large scale strawberry dataset that will provide data suitable for training many different types of artificially intelligent systems, including temporally tracked single berries, dense spatial capture of berries in-row on a mobile platform capturing both environmental data and localisation data (for tracking) and finally alternating camera-views and sensors for generalising to viewpoint and providing quality depth maps used for machine learning of shape and quality attributes of berries. This type of dataset has already been used to develop a fruit counter. As demonstrated on Countryfile (https://www.bbc.co.uk/programmes/m0009vj0) the fruit counter uses 'instance segmentation' detection and a Bayesian tracker (statistical inference utilising Bayes' theorem to predict where objects are based on prior observations) to count berries within a fruit row.

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Figure 4: Strawberry harvester mounted on the Thorvald platform harvesting berries using the object detection aproaches mentioned above.

We hope to now mitigate some of the pitfalls of static detection techniques and attempt to develop our own short-term tracking system robust to the environment, using the Bayesian tracking results as a baseline. Tracking information will allow us to more accurately harvest berries using an automated process, enabling us to correct the harvest strategy in real-time and allow us to calculate daily fruit count estimates with much greater accuracy. In my future work I will use deep association of image features to enable short-term tracking of objects, this will enable more accurate measurements of intrinsic qualities of produce and provide a base for fruit counting and automated harvesting. This is a necessary component of an end-to-end vision system for produce.

Knowledge and Technology Transfer

Since starting the project I have been involved in numerous smaller projects that have involved high level commercial software implementations. I have also worked closely with industry/academic partners such as Garford Farms Machinery, SAGA Robotics, Thorvald and NMBU.

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I have built up connections with many UK and Norwegian strawberry farmers who assisted me in detailing specifics of the problems at hand. They have also given me access to their farms for future experiments.

While on the project I have spoken numerous times publicly for presentations such as LGM and at conferences. I presented my recent work at the Berry Gardens Annual Research Conference in December 2019, showcasing the major advantages of smart computer vision based agri-tech solutions. I will present in February at the Institution of Agricultural Engineers (IagrE) presentation evening.

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