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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.

Zeke Hobbs

PhD student

The University of Sheffield

Signature ....   Date. 1 April 2019

CONTENTS

GROWER SUMMARY

There are currently no changes to grower practice resulting from the project at this point.

Headline

1. Reduction in pesticide use for combatting Drosophila Suzukii
2. Automated soft fruit harvesting robots

Background

Drosophila Suzukii is an invasive species that are able to lay eggs in ripening fruits leading to a large loss of crops. Using Drosophila Suzukii vision system as a model we are able to understand better how to combat Drosophila Suzukii through creating smart materials to block key spectrums of light, reducing the need for pesticides. Also understanding how Drosophila Suzukii vision system works we are able to create automated fruit detectors for agro robotics by using the same spectrum of light Drosophila Suzukii our sensitive to, also a deeper understanding of Drosophila Suzukii brain structure will lead to faster computer fruit detectors.

Summary

1. Understanding to make smart greenhouses and polytunnels that block key spectrum of light required by Drosophila Suzukii to find fruits.
2. Saves labour costs and removes uncertainty over seasonal workers.

Financial Benefits

With only 1% of seasonal workers coming from the UK (Office of national statistics), this project will lead to agro robots that can reduce the uncertainty of seasonal workers due to Brexit.

Action Points

Currently, no changes needed by growers.

SCIENCE SECTION

Introduction

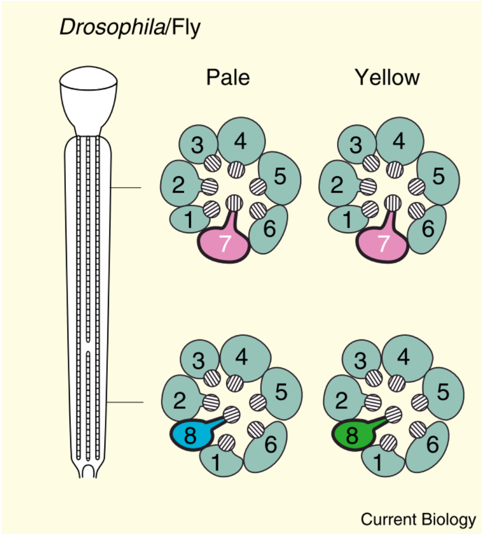

Figure 1: Ommatidia of Drosophila consisting of receptors R1-6 that are broadly tuned receptors, R7 and R8 being narrowly tuned. Having two different types of ommatidia pale and yellow. Pale being sensitive to UV and blue light and yellow being sensitive to UV and green light. Taken from Kelber & Henze (2013) in Current Biology.

As time moves forwards, fewer people are required for farming, even with a population that is growing. This is in part due to improvements in technologies such as tractors and machinery that reduce the labour force needed for crop maintenance and harvesting. This is set to continue but with data-driven processes and automated farming. One area that requires improvement for automated farming to become efficient and practical is computer object detection and object localisation. Here we look to understand Drosophila Suzukii (D.S)vision system specifically how the photoreceptors and the early stages of the optical nervous system can be used for image segmentation of soft fruits.D.S have eyes with multiple lenses known as ommatidia, and each ommatidium contains multiple photoreceptor cells that are sensitive to different spectra of light. D.S has six broadly tuned receptors R1-6 and two narrowly tuned receptors R7-8 (Figure 1). Each ommatidium can be two different configurations known as pale ommatidia where R7 is sensitive to UV at335 nm, and R8 sensitive to blue at 460 nm or yellow ommatidia where R7 is sensitive to UV at355 nm and R8 is sensitive to green at 530 nm (Hardie 1986, Kelber & Henze 2013, Jagadish et al. 2014, Behnia & Desplan 2015). Ommatidia both pale and yellow are stochastically distribution throughout the eye. However, the ratio of pale and yellow ommatidia is not even 35:64 (Wernet et al. 2015) the reason for this being unknown. Before the signals from the eye reach the first neuron in the medulla of D.S, the signals of the R7 and R8 photoreceptors interact with each other in an opponent fashion. R7 and R8 mutually inhibit each other directly creating a colour opponent process at the first visual synapses (Schnaitmann et al. 2018). This is an important discovery as colour vision has 2 main conditions to be true colour vision, possess photoreceptors with different spectral sensitivities and some means for comparing the signals from different photoreceptors (Kelber 2016). This means that D.S has at least basic colour perception. Colour opponency is key to humans perception of colour. The CIELAB colour space has been created to mimic the human vision system and is an industry standard when colour accuracy is needed (Figure 2). It uses the same process as the human eye, where red is compared to green creating the A colour opponent channel. Blue compared to yellow, which is the combination of red and green, creating the B opponent channel. Comparison of green, blue and red creates the L channel which is luminance. When converting images into the CIELAB colour space, each colour has its value in the space, and any addition or subtraction in the number is a change in colour that is perceivable by humans. As each colour has its value, the ability to compare objects in images becomes easier. Figure 2 shows a comparison between the colour opponent process in D.S and the CIELAB colour space when looking at ripe fruit and vegetation. It's seen that in the opponent spaces there is a separation of vegetation and fruits.

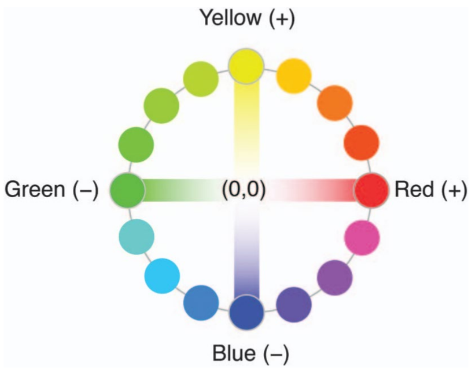

Figure 2: Depiction of the CIELAB colour space taken form Shevell & Martin(2017).

Materials and methods

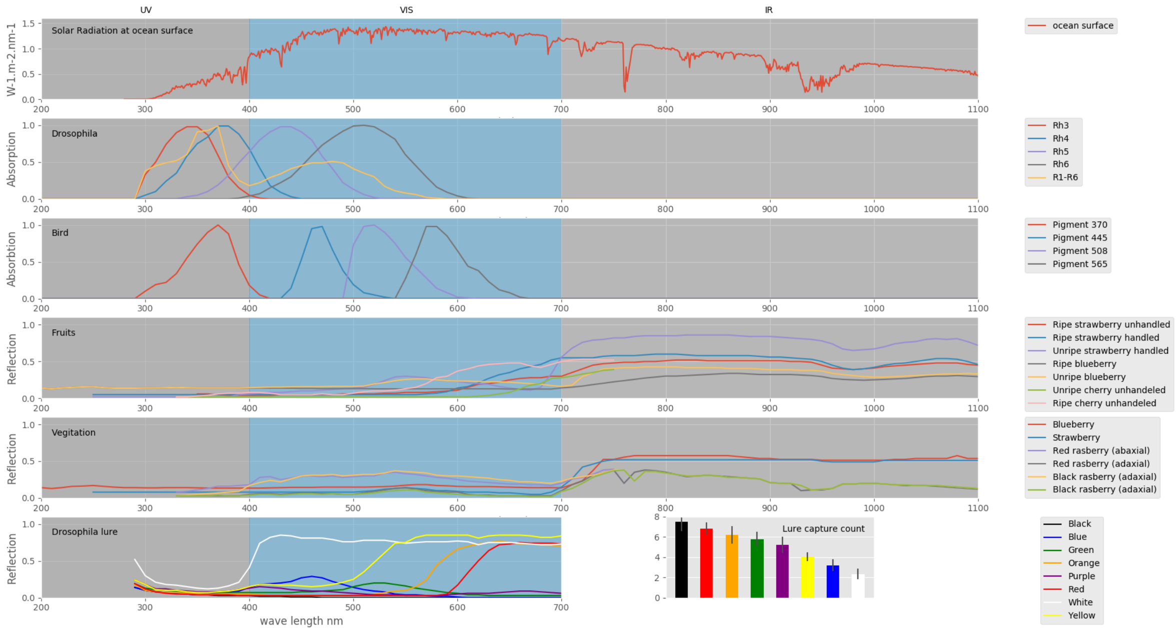

Figure 3: Data taken and modified from and for Cherry's Zude et al. (2011), Strawberry's Wahab et al. (2017) and Blueberry's Yang, Lee & Williamson (2012), Drosophila lures Rice et al. (2016).

D.S can see UV light, so images with UV and RGB data is needed. With limited UV images,pseudo-images needed to be made containing UV data. In order to create these images, UV reflection data was gathered (Zude et al. 2011, Wahab et al. 2017, Yang, Lee & Williamson2012, Rice et al. 2016) and can be seen in Figure 3. As images of fruit are easy to find in the RGB colour space images were taken of cherry's, strawberries and blueberries then segmented by hand (Figure 4). Now with RGB images hand segmented, we can now make UV images from the data previously collected. This is done by traversing every pixel in the original image and creating a fourth channel of data for UV. Populating the UV channel from the graphed data in Figure 3 the segmentation mask dictates the pixel class, ripe fruit, unripe fruit, sky and vegetation. A sample pseudo UV image can be seen in Figure 4. In order to test if there is any validity in detecting fruits with UV and RGB images an existing method for detecting vegetation is alive or dead is used. This method was initially used on satellite's and compared near inferred light (NIR) to red light (R) the method is called normalised difference vegetation index (NDVI) where NDVI=(NIR−R)/(NIR+R). The closer the value of NDVI is to +1, the more chlorophyll the vegetation has whereas the closer to -1, the less chlorophyll the vegetation has. We use a modified version just by the changing colour bands used. To find the best bands for detecting ripe fruits, unripe fruits, vegetation and sky, a brute force approach is used. Testing all channels against each other and seeing what two channels gives the most accurate results. From this we can test if just focusing on the ripe fruit is better than detecting sky, unripe fruit and vegetation and then removing that from the original image, leaving behind just the ripe fruit in the image. If the value of the modified NDVI formula is less than zero or equal, then we take this as not the object we are looking for. If testing for sky if the value is zero or less, then this is a false value. If the result is greater than zero, we count this a correct classification. With the brute force method, we are looking for the bands that give the highest modified NDVI values when calculating. After brute force comparison of different channels is done and the best values found the modified NDVI is tested on real-world UV and RGB images of fruit (Figure 5).

Figure 4: Left RGB camera images. Center hand segmented ground truth image sky (blue), vegetation (green), ripe (red) and unripe (purple) fruits. Right, generate Pseudo UV image.

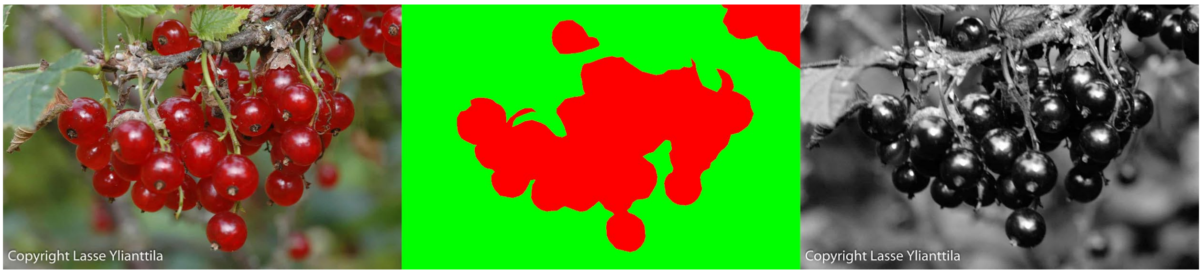

Figure 5: Left RGB camera images. Centre hand segmented ground truth image vegetation (green) and ripe (red). Right UV image. Images were taken from UV4plants.org (Ylianttila).

Results

After testing all band combinations, the bands used for modified NDVI are as follows. Sky requires UV and red channels, Vegetation green and blue channels, unripe fruit red and green channels. Ripe fruit detection is the same as unripe fruit using red and green channels for detection. Figure

6 displays the best and worst of both methods of just detecting ripe fruit and detecting sky, unripe fruit and vegetation, then removing that from the original image. As seen in Table 1 removing the sky, unripe fruit and vegetation is slightly better than just detecting ripe fruits. This result is also seen in the few real-world images.

Image	Fruit Detection	Image - Sky - Veg
B_1.png	0%	64%
B_2.png	5%	78%
B_3.png	3%	69%
B_4.png	3%	15%
B_5.png	1%	64%
S_1.png	95%	73%
S_2.png	45%	8%
S_3.png	71%	12%
S_4.png	24%	4%
S_5.png	76%	46%
C_1.png	86%	81%
C_2.png	80%	54%
C_3.png	72%	57%
C_4.png	31%	48%
C_5.png	46%	52%
Average	42%	48%

Table 1: Image segmentation accuracy using intersection over union as a measurement of accuracy.

Figure 6: Left original RGB images, Centre modified NDVI output for detecting ripe fruit and right the implementation of modified NDVI (original image - sky -veg = fruit). This shows the worst and best of both methods.

Discussion

Although modified NDVI does not give highly accurate results that we seek using the sky, unripe fruit and vegetation detection and then removal that data from the original images, in the worst case display parts of the fruit and the best case gives very nice segmented images. With additional processing of the image, this could be a good input into further processing steps. One way that this could be used is as an input to a deep learning model, by using the pixel clusters of detected ripe fruit and expanding that out in set circle size. Reducing the amount of information in the image and therefore being able to reduce the size of a neural network. Giving you a faster model allowing for real-time detection but an accurate detector because of the deep neural network.

Conclusions

We can see that using different channels of data to find fruit is possible. However, there is still a need for more prepossessing before more accurate segmentation can occur. Next, we will look at D.S colour opponency as more information is encoded in the data that comes from colour opponent channels. In Figure 7 it is seen that ripe fruits and vegetation are segmented out when comparing the values in the CIELAB colour space and the D.S colour space, whereas when compared to RGB colour space the data combines into a single clump.

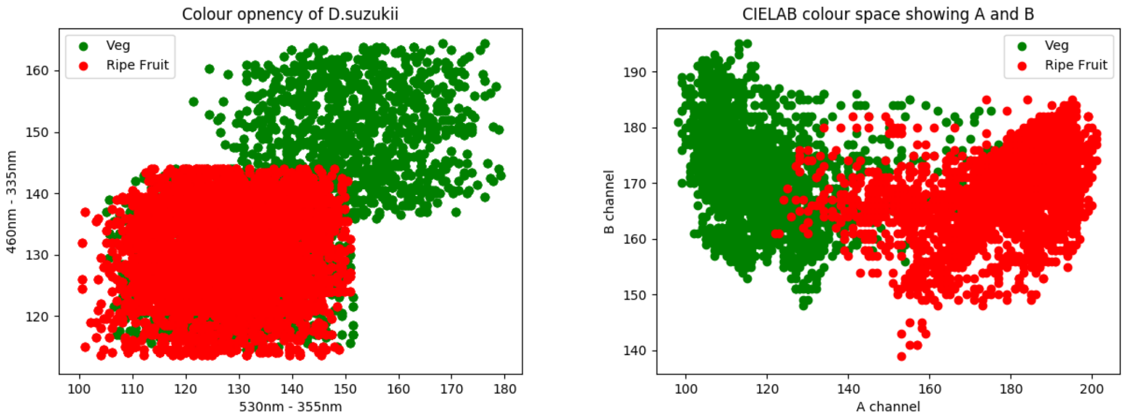

Figure 7: Left D.S colour opponents from pseudo-images, right CIELAB colour opponents from RGB of pseudo-images. Comparison of Ripe fruits and vegetation in opponent spaces.

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