Cooperative Research Centre
for National Plant Biosecurity

Final Report

CRC300023

Smart Trap Scoping Study

Scoping the potential of spectral imaging and digital shape/pattern recognition technologies for automatic detection of EPPs

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16 December 2008

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1. Executive Summary

The aim of this project was to undertake a scoping study to assess the suitability of digital shape and pattern recognition techniques to differentiate different, but related insect species with the overall goal of eventually developing an automatic detection system for Emergency Plant Pests (EPPs) to be deployed into traps. Three pairs of insect species from each of the following Orders, Diptera, Coleoptera and Lepidoptera, were used as model systems. A dataset of over 400GB of images of the model insects was acquired using hyperspectral cameras in the near infrared, visible and UV. The effectiveness of existing state of the art recognition methods was tested on the insect imagery dataset and compared with performance on two published standard datasets. The algorithm achieved an average of approximately 90% recognition for the target model insects investigated using shape and 'colour' image descriptors. A subsequent analysis identified the three most significant bands (out of 77 spectra outside the visible range) to use for classification and achieved recognition rates of up to 95% for pseudo-colour data. We have also commenced the development of methods to recover descriptors using any number of bands and including the use of texture as a queue in addition to shape and spectral response. We expect that this additional information, together with the flexibility of selecting any number of bands, will increase significantly the recognition rate of the model insects investigated. A preliminary benchmark and evaluation of the whole system comprising our descriptor, classifier and band selection steps has also been undertaken. The recognition rates obtained in our experiments indicate that the development of an automatic detection system to deploy in a 'smart trap' is feasible. The next phase of this work will require expertise in trap design, wireless technology and sensors networks to develop a prototype trap with an auto-reporting semi-automated system for field testing.

2. Aims and objectives

This project undertook a scoping study to assess the suitability of digital shape and pattern recognition techniques to differentiate different, but related insect species that could be deployed into novel traps.

The project objectives were to:

1. Assess the suitability of UV and hyper-spectral sensing to differentiate between related but different species of fruit flies, moths and beetles.
2. Assess the suitability of digital shape and pattern recognition to differentiate different species within the above groups.
3. Determine the feasibility and estimate cost of developing an automatic detection system suitable for insect traps, based on the most promising technology identified in objectives 1 and 2.
4. Conduct a preliminary analysis of options to develop auto-reporting insect traps and identify future research directions.

3. Key findings

A summary of the methods is included in Appendix 1.

3.1. Objectives 1 and 2

Obj. 1 — Assess the suitability of UV and hyper-spectral sensing to differentiate between related but different species of fruit flies, moths and beetles.

Obj. 2 — Assess the suitability of digital shape and pattern recognition to differentiate different species within the above groups.

A dataset of over 400GB of images of the model insects was acquired using hyperspectral cameras in the near infrared, visible and UV with a range of optics ranging from standard mainstream lenses to dissecting microscope lenses. The dataset was then analysed to extract descriptive image features.

A benchmark was conducted to test the effectiveness of existing state of the art recognition methods and compare the performance of algorithms on both published standard datasets (flower images and GATECH dataset) and the model insect imagery dataset. These methods include a set of local image descriptors, colour and shape features (Fig. 1). For our hyperspectral model insect imagery, we selected, as an alternative to colour data, multiple bands which satisfied a statistical criterion based on the 'sharpness' of the image, i.e. contrast and the discrimination between target model insects. We also tested the available UV data making use of shape and local image descriptors. In these experiments, the recognition rates for both, the hyperspectral and UV imagery were of the order of 90%. The project provided conclusive evidence that shape can and should be used in conjunction with spectral signatures to enhance robustness of recognition tasks. In our experiments, the best results were always achieved through the use of shape as a cue for the recognition process.

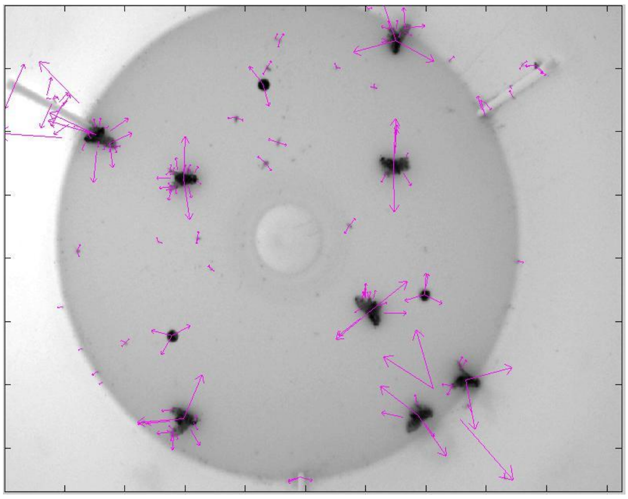

Figure 1. Image showing the use of Scale Invariant Feature Transform descriptors on one of model insect species.

We subsequently scoped the use of discriminative band selection for classification to maximise the separation between target model insects and minimises inter-class distance between specimens of the same species. The statistical approach developed in the project permitted analysis of information provided by each band and evaluation of the impact of reducing the number of bands and resolution in order to produce a more efficient sensor. Following this approach, we identified the three most significant bands (out of 77 spectra outside the visible range) to use for classification and achieved recognition rates of up to 95% for pseudo-colour data. This significant reduction in the number of bands required to achieve high level recognition rates will facilitate the use of cheap sensors or multiplex light inside traps.

We have also commenced the development of methods to recover descriptors using any number of bands and including the use of texture as a queue in addition to shape and spectral response. We expect that this additional information, together with the flexibility of selecting any number of bands, will increase significantly the recognition rate of the model insects investigated. We have also performed a preliminary benchmark and evaluated the whole system comprising our descriptor, classifier and band selection steps.

Based on our present developments and recognition rates, it is feasible to expand the methods developed so far and include them into a future prototype trap design. It is worth noting, however, that any recognition rate achieved in the field will depend not only on the computational power and performance of the methods employed, but also on the design of the trap itself.

Additional objective — Determine if a simple classifier can be generated to differentiate dyed and non-dyed Queensland and Mediterranean fruit flies with a UV camera.

UV imagery was proposed as a possible option to differentiate between dyed and non-dyed fruit flies as part of sterile fruit fly release programs. The sorting of dyed and non-dyed flies caught in traps is currently done manually by exposing insects to black light. Unfortunately, we were not successful at separating dyed from non-dyed fruit flies in our experiment using UV images. The use of a calibrated Xenon illuminant instead of a traditional black light during image acquisition with the UV camera may explain this. It would be worth examining the use of a black light further as a design option for a prospective prototype.

3.2. Objective 3

Determine the feasibility and estimate cost of developing an automatic detection system suitable for insect traps, based on the most promising technology identified in objectives 1 and 2.

The recognition rates obtained in our experiments indicate that the development of an automatic detection system to deploy in a 'smart trap' is feasible. It remains an open question as to what the design should be for such a system and, therefore, this should be an important objective of a subsequent phase to develop the technology. Estimating a cost quantum is, at this stage, an approximation exercise, but it would be of a comparable size to that required in this scoping study.

3.3. Objective 4

Conduct a preliminary analysis of options to develop auto-reporting insect traps and identify future research directions.

We envisage the use of wireless technology and sensors networks to produce an auto-reporting semi-automated system. We also envisage bringing together expertise and skills available in the CRCNPB and NICTA. Along these lines, NICTA does have expertise in technology relating to wireless signal processing, whereas CRCNPB collaborators can be drawn in to the task of trap design. See section 5 for detail on future research directions.

4. Implications for stakeholders

Insect trap grids are the first defensive array in place against incursions of EPPs. These grids are designed to detect an exotic pest incursion before it has spread too far, making eradication much cheaper to undertake. Over the last 10 years, the need for early warning trapping grids has significantly increased due to more stringent demands by importing countries to demonstrate pest area freedom. The recent Papaya fruit fly incursion in Queensland, with its eradication cost of $40 million, demonstrated the consequences of not having an effective early warning grid in place. Early warning insect trapping grids for EPPs however, are expensive to monitor in remote areas due to travel costs, whilst in urban areas inspection costs are considerable because grids are larger due to higher risks of incursion.

'Smart traps' that integrate an automatic detection system with reporting capabilities will:

- provide a surveillance hardware for real-time early warning of EPPs,
- save large sums of money by reducing needs to monitor existing grids regularly,
- allow the deployment of more extensive trapping grids in urban and remote locations,
- ensure earlier warning of EPP incursions, which in turn will reduce costs of subsequent eradication,
- increase Australia's capacity to safeguard its plant industries.

'Smart traps' comprising an automatic detection system and auto-reporting capabilities would have a high potential for commercialization, both nationally and internationally.

The significant cost savings that can be achieved by using 'smart traps' and the automatic and continuous monitoring capabilities of such traps should bring rapid adoption among State agencies and plant-based industries involved in early warning networks for EPPs.

5. Recommendations

5.1. PhD project

A PhD project built on the work done as part of the 'smart trap' scoping study was initiated in March 2008 (student Pattaraporn Khuwuthyakorn funded by the CRC and NICTA). This project aim to develop the statistical and computational techniques required to recognise and identified EPPs in real-time on-board automatic insect traps. The project will explore kernel methods and optimisation techniques that can be utilised for the purposes of discriminant learning and classification. These are novel technologies that could greatly enhance efficiency of early warning trapping networks. Moreover, these methods are applicable to pattern recognition settings relevant to the use of spectral imaging and digital shape/object recognition technologies for automatic detection of EPPs. The following issues will be investigated:

1. Which are the features that should be extracted from the data set to achieve optimum recognition between targets and what is the best method for their recovery.
2. What is the best way of capturing the structure of the extracted features and which technique is better suited to perform classification.
3. How can domain knowledge be included into the classifier to provide a means for robust classification of the EPPs.

5.2. Prototype development and testing

This scoping study has established the feasibility of developing 'smart traps' using a classification system based on spectral imaging and pattern recognition combined with auto-reporting capabilities. Thus, we envisage the next phase of this work to be the development and testing of a prototype trap to demonstrate the potential of the technology and attract a commercial partner.

We propose the following objectives for the next phase:

- Thorough benchmarking and evaluation of the whole system, with our descriptor, classifier and band selection steps. This may include further data acquisition if necessary.
- Improvement of the recognition methods to make them fully deployable in the field. This would include the use of multiplexed light and other options based upon cheap camera sensors.
- The preliminary design of a self-standing trap for an economically and socially significant EPP, such as fruit flies.
- The basic design of a means to enable auto-reporting through wireless networks in a scalable manner.

We propose the following timeframe:

- Month 1-8: Benchmarking of a preliminary concept system.
- Month 6-18: Improvement of recognition methods for deployment in field tests.
- Month 1-18: Preliminary design of a self-standing trap with a wireless, self-reporting option.
- Month 18-24: Field tests and basic design for an on-board wireless link-up.

6. Abbreviations/glossary

ABBREVIATION	FULL TITLE
CRCNPB	Cooperative Research Centre for National Plant Biosecurity
NICTA	National ICT Australia
EPP	Emergency plant pest

7. Appendix 1

7.1. Model insects

The following pairs of insect species from three different Orders were used as model systems for the study:

Diptera:
Queensland fruit fly (*Bactrocera tryoni*)
Mediterranean fruit fly (*Ceratitis capitata*)

Coleoptera:
Confused flour beetle (*Tribolium casteneum*)
Five-spined bark beetle (*Ips grandicollis*)

Lepidoptera:
Codling moth (*Cydia pomonella*)
Oriental fruit moth (*Grapholita molesta*)

The Macadamia bark beetle (*Cryphalus niger*) was originally selected as one of the Coleoptera model insects. During preliminary investigations, it was found to be too small for high quality images to be acquired with the types of camera/lens used. Consequently it was replaced with the slightly larger confused flour beetle.

Pupae of the two moth and two fly species were obtained from colonies maintained by our collaborators and reared to adults under optimal conditions at CSIRO Entomology. These adults were separated according to sex before processing.

Adults of the confused flour beetle were obtained from a rearing colony maintained at CSIRO Entomology. Five-spined bark beetle adults were obtained from a large piece of bark infested by the insect sourced by a collaborator and placed under optimal conditions for emergence. It was not possible to separate with morphological characters the beetles according to sex.

7.2. Image acquisition to build initial dataset

Several images of each of the model insect species were acquired to recover a characteristic representation of the species and build a dataset for subsequent analysis. Freshly-emerged adults of each model species were placed in groups of five to ten individuals in vials, which were then transferred to a freezer at -20ºC for up to 1 hour to immobilise/kill the insects before acquiring images. Images from a large sample of individuals (a number that varied from 30 to 100 depending on species) of each model species were acquired at 77 different spectra outside the visible range using hyperspectral and near infrared cameras mounted on a dissecting microscope.

7.3. Development of algorithms and methods for classification

We developed a set of novel statistical and structural pattern recognition to recover stable features to reliably classify the model species, by exploiting the spectroscopic properties of insects, such as absorption patterns and shape. The effectiveness of the techniques developed in separating the two related insect species within each order were statistically assessed.

We also used statistics to develop algorithms and methods for the classification of the model insects within each group, using bands or 'colours' at which difference is more evident. The research was divided into two strands: 1) the recovery of a representation of the target which is characteristic of the model insect under study, and 2) the incorporation of domain knowledge into the classifier. This was important since the design of a classifier that is robust to varying photometric conditions and is capable of recognising moving insects at medium resolutions depends greatly on the image features upon which the recognition process is based upon.

Finally, but not least, the dataset and data acquisition process required a number of pre-processing and denoising steps. We developed processes to archive the data on a server for future reference and pre-processing it for testing.

7.4. Image acquisition to test classification system

Another cohort of adults of each model insect was obtained either by rearing or emergence from field collected material. Aged (or recently dead) adults from rearing colonies were selected whenever possible, or alternatively freshly-emerged adults were placed in a crowded environment within small containers for a few days to ensure that they were not in impeccable conditions and thus closer to specimens that would be trapped in the field. The live insects were transferred to a freezer at -20ºC for several hours to kill them before acquiring images.

Images (in the visible and infrared ranges) of these insects, in groups of single species mixed or not with debris or in mixed groups of the closely-related species, were acquired to test the robustness and accuracy of the classification and identification system developed (detailed protocol in Appendix 2). The images were acquired using a setting reminiscent of field conditions, with the hyperspectral and trichromatic cameras mounted on a high-oblique viewpoint above a trap supplied by one of the collaborators.

In addition, imagery of dyed and non-dyed Queensland and Mediterranean fruit flies exposed to a UV light source (black light) within a trap was also captured with a UV camera (Appendix 2) to determine if a simple classifier could be generated to differentiate them in trap conditions. Black light is currently used to identify dyed, sterile fruit flies when sorting insects caught in traps.

8. Appendix 2

Detailed protocol to acquire images of the model insects in traps to test the robustness of the classification system developed.

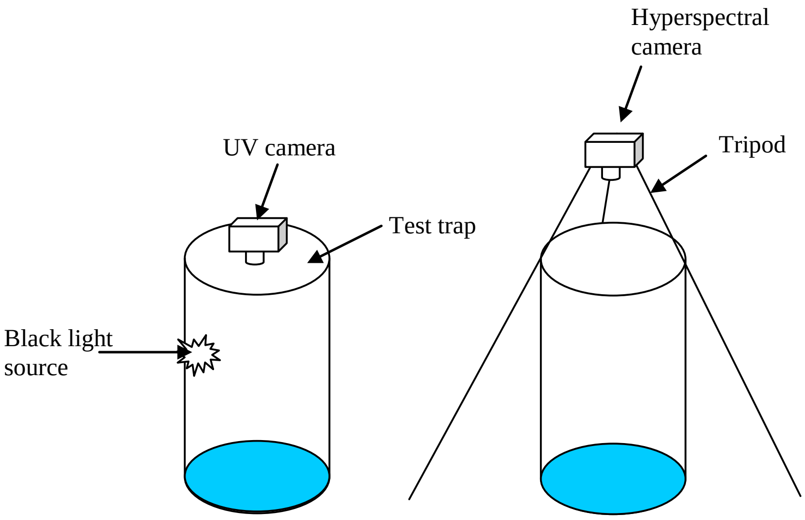

Figure 1. Schematic of experimental setting to acquire images of model insects in a trap.

Figure 2. Photographs of setting to acquire images of model insects in a trap using the hyperspectral camera (**A**, **B**) and the UV camera (**C**, **D**).

Sampling:

1- Take 10 insects from the 100 main source and place in trap

2- Acquire images (see below).

3- Remove 5 insects from trap and replace with another 5 from the original source

4- Repeat steps 2 and 3 until all insects in main source are used.

(Note: due to the lower number of oriental fruit moths available (37) samples of 8 insects were used in step one, with 4 insects being remove at a time in step 3.)

Image acquisition (visible and infrared ranges):

For each pair of related insect species (i.e. beetles, moths and 'undyed' fruit flies) and following the sampling protocol above:

1- Acquire images of groups of species no. 1 alone (Round 1).
2- Acquire images of groups of species no. 1 mixed among some debris (i.e. a couple of leaves and twigs) (Round 2)
3- Acquire images of groups of species no. 1 mixed with an equal number of closely-related species no. 2 (Round 3)

4- Repeat steps 1 and 2 but this time with species no. 2

Image acquisition (UV):

For each species of fruit flies (dyed and undyed individuals) and following the sampling protocol above (except that a black light source will be added to the trap):

1- Acquire images of groups of dyed flies mixed with an equal number of undyed flies of the same species

2- Repeat step 1 but using the other species of fruit fly.