An Adaptive Agent-Based Distributed Expert System for Pest Management

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Abstract

This paper describes the architecture of the Integrated Pest Management Expert System (IPMES) project that is being developed by the University of Otago and HortResearch. The project develops and applies new learning techniques to building intelligent systems. The overall intention of this project is to develop an adaptive decision support system for pest management based on information integration. It will be designed for use by ENZAFruit New Zealand (International) (ENZA), HortResearch, packhouses, and the growers/orchardists themselves.

1.Introduction

The potential benefits of applying expert systems to integrated pest management has been identified for several years (e.g. [8]). With the introduction of Integrated Fruit Production (IFP) to the pipfruit industry by ENZA and HortResearch [10], the need for expert system technology to support its implementation and use has been highlighted.

IFP emphasises human and environmental safety in a continually improving fruit production system. It aims to minimise the negative impacts of agrichemical use and therefore requires an integrated system that manages information for the refinement of IFP pest management recommendations.

The complex of pests Table 1 which attack pipfruit orchards in New Zealand have been managed historically by calender schedules of broad-spectrum insecticide applications but with the introduction of IFP, a new level of complexity has been added to orchard operations.

Under IFP, growers are required to justify all spray applications based on either pest phenology or the levels of insect pests in their orchards. When intervention is required, it encourages the use of selective products which maximise survival of beneficial species, especially natural enemies. To achieve these objectives, growers must be able to recognise pest and beneficial species, monitor the pest levels, and make applications of the most suitable chemicals when these levels exceed predetermined thresholds. Full record keeping is essential for the success of the programme. The orchardists manage this processes by dividing their orchards into management blocks, often of a single cultivar, and these blocks provide the basic sampling units to which all data relates.

Pest Group	Pest Species	
	Common name	Latin name
Leafrollers	Lightbrown apple moth	*Epiphyas postvittana*
	Greenheaded leafroller	*Planotortrix excessana*
		Planotortrix octo
	Brownheaded leafroller	*Ctenopseustis herana*
		Ctenopseustis obliquana
Fruit borers	Codling moth	*Cydiapomonella*
Cutworms	Noctuid	*Graphania mutans*
Scale insects	San Jose scale	*Quadraspidiotus perniciosus*
	Oystershell scale	*Quadraspidiotus ostreaeformis*
	Greedy scale	*Hemiberlesia rapax*
	Latania scale	*Hemiberlesia lataniae*
	Oleander scale	*Aspidiotus nerii*
	Mussel scale	*Lepidosaphes ulmi*
Mealy bugs	Obsure mealybug	*Pseudococcus viburni*
	Citrophilus mealybug	*Pseudococcus calceolariae*
	Longtailed mealybug	*Pseudococcus longispinus*
Aphids	Woolly apple aphid	*Eriosoma lanigerum*
Midges	Appleleaf curling midge	*Dasineura mali*
Mites	European red mite	*Panonychus ulmi*
	Twospotted mite	*Tetranychus urticae*

Table 1: The major insect and mite pest complex attacking New Zealand apples

The development of expert systems is timely to address data analysis, interpretation, integration, and management of the large number of cultivar blocks that constitute the IFP programme within New Zealand. This has risen from about 500 blocks on 88 orchards in 1996/97 (the first year of implementation) to about 5300 blocks over 700 orchards in the 1998-99 season. With increasing fruit industry commitment to IFP, there is the potential for ongoing data management of over 10,000 blocks per annum when IFP if fully implemented by 2001. HortResearch plays a key role in the management and analysis of the IFP data which benefits both the growers and ENZA itself.

Although there are several IFP databases that exist, they are a combination of hardcopy and electronic repositories with few linkages between them. It is the objective of the IPMES to integrate these datasets and provide decision support at all levels from the orchardists to IFP programme management.

The architecture of the IPMES is being designed to be flexible, adapt to the user's requirements, able to be extended at a later date, and incorporate the wishes of the people who will be eventually using this system. In the following sections, each component of the IPMES will be described in detail finishing with a diagram of the overall system

2.General Architecture of a Adaptive Agent Based Distributed Expert System

Traditionally the architecture of conventional expert systems had a fixed structure of modules and a fixed rule base. Although they were successful in very specific areas, this particular architecture resulted in little or no flexibility for the expert system to adapt to the changes required by the user or the environment in which the expert system operated.

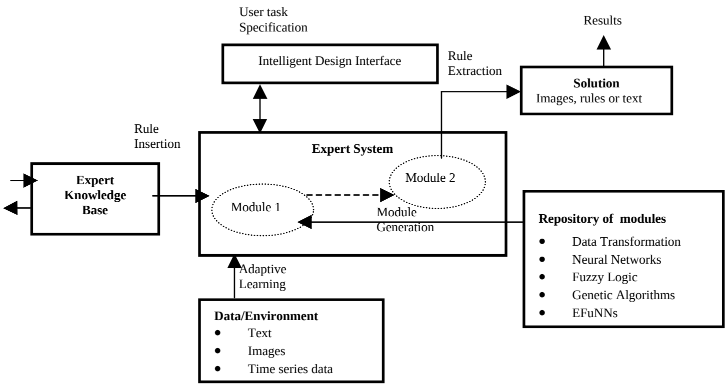

Figure 1: A block diagram of an on-line adaptive expert system.

To address these deficiencies, we propose an Intelligent Agent-Based Expert System (AGES) that consists of a series of modules which are agent based and generated "on the fly" as they are needed. Figure 1 shows a general architecture of an AGES that is under development. The *User* specifies the initial problem parameters and task to be solved. Intelligent agents then create *Modules* that may initially have no rules in them or may be set up with rules from the Expert Knowledge Base. The Modules then combine the rules with the Data from the Environment to form the Expert System. The *Modules* are then trained with the *Data* from the *Environment*. The rules may be extracted for later analysis, or aggregated and re-inserted into new *Modules* for re-training or testing. Once the *Modules* have been trained, they are tested with new *Data* from the *Environment* and the results extracted. These then form the solution to the problem and may be further interpreted by another set of *Modules*. The *Modules* will dynamically adapt their ruleset as the environment changes since the number of rules is dependent on the data that is being presented to the *Module*. *Modules*(agents) are dynamically created, updated and connected. They will be destroyed if necessary at a later stage of the operation of the IES. This general architecture for an adaptive expert system has been applied to the problem of orchard management and is referred to as the IPMES.

3.Sources of Information

To understand fully how the IPMES is to function, one must become aware of a number of important sources of data that are required to implement a system of this type. Figure 2 contains the information flow of the pest management data about the fruit from orchard to packhouse to ENZA that is used in the decision-making process.

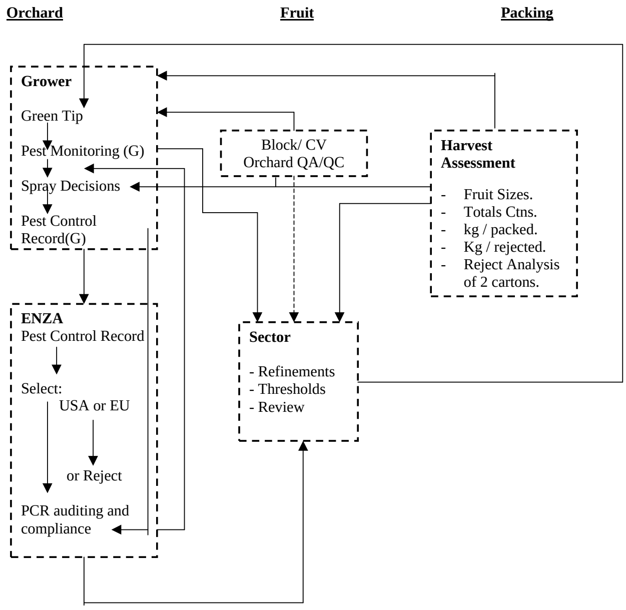

Figure 2: Information flow of the pest management data

Starting at the Grower (G) information at either the orchard or cultivar (cv) block level is recorded on spray decisions made throughout the season i.e. the pest monitored, the justifications for spraying, the choice of product used, and the date of its application. This information is supplied to ENZA as the grower's Pest Control records (PCR) which may affect decisions about the apples that are produced by the orchard, such as the destination market overseas. In addition to the ENZA processes, the packhouse packing a Grower's fruit also makes a Harvest Assessment of the fruit quality by recording defects encountered during packing. This information is then passed back to the Grower and can influence the decisions made on spraying for the next season.

These Harvest Assessments are part of the Quality Assurance (QA) and Quality Control (QC) of each Cultivar Block. Pest monitoring and PCR information collected by ENZA, and fruit defect data from the packhouses, can then be used by ENZA and HortResearch to refine the thresholds for the IFP thresholds that the orchardists will use for the next season.

Of interest to the IPMES team are four specific sources of data that are (1) primary determinants of when to spray the fruit and/or (2) records of what was applied and its effectiveness. These are the records from Weather Station, PCR's, Pest Monitoring, and Pest Status at harvest.

4.The Knowledge Base for the IPMES

Making decisions on when to spray and with what pesticide are defined by the ENZA-IFP manual developed in collaboration with HortResearch. Contained in this document is detailed information on what pests the growers should be aware of, their description, and what pesticide to spray based on the time of the season and the numbers of a given pest species have been found in traps or on either the fruit or the trees. Two important issues affecting the IPMES are contained in this manual:

1. The decisions that are made are not just based on information recorded about the current season, but influenced by certain parameters obtained from the previous season, most importantly, the harvest assessment.

2. The thresholds that are in the IFP manual are not necessarily grounded on the analysis of the information acquired over the past two years but based on heuristics which translate to the values contained on the document. The IPMES could provide valuable information to ENZA about how to alter the values based on the processing of the expert system.

To model these rules in an expert system requires that the thresholds themselves in each rule, which are operated at a regional or national level, can be modified to adapt to the changes in the orchard's pest management performance over time. The use of a fuzzy rule base with adaptive membership functions that are altered by evolving neural networks would provide one solution which have already been used in [2]. In this way the thresholds would be tailored to New zealand orchards or a particular region by automatically modifying the thresholds as new information about the pest levels are known nationally or regionally. Techniques similar to this have already been applied to create adaptive intelligent information systems [6, 4, 5].

5.The Functionality of the IPMES

One of the prime requisites of the IPMES is the ability to flexible in its decision-making capabilities to adapt to the various types of people that will be using the IPMES. This formed the basis of the three main stages of its functionality:

1. The ability to visualise the data about the orchard over time based on information contained in the database or to access past records of the orchard for a "What If" scenario based analysis. This would demonstrate how altering the thresholds would affect the spraying of the pesticide and in turn indicate projected pest damage in the orchard. This stage is to be purely on decisions inferred from the facts contained in the database.

2. The next level would be decision-based support of the assessed risk of the insect presence within the crop. This stage is to be based on both the historical data and current data stored in the database about the orchard.

3. The final level would be to recommend an applicable treatment of pesticide and use the rules and thresholds store in the rule base of the IPMES that are initially based on the ENZA-IFP manual.

6.Architecture of the IPMES

Figure 3 contains the architecture of the IPMES. The growers, HortResearch, and ENZA collect the data. How it is collected depends on the type of data in question. The data is then stored in the database ready for retrieval. Users of the IPMES would then access the database through the internet to update the model of their own orchard which will then be used for the purpose of data visualisation and the assessment of the risk of pest presence. The "intelligence" of the IPMES will be embodied in the ENZA-IFP knowledge base and the decision support module. These two modules will have components that alter the thresholds for the rules to accommodate the type and presence of insects within a particular orchard so that the appropriate spray decisions can be made.

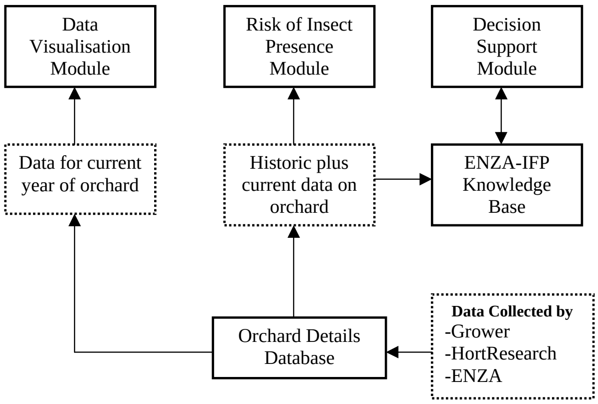

Figure 3: Initial architecture of the IPMES

7.Description and Functionality of the Modules for the IPMES

The IPMES contains three different types of modules:

- Data Visualisation Modules
- Grower Advice Modules
- Threshold Improvement Modules

The orchardists would use the Data Visualisation and Grower Advice modules with ENZA and HortResearch utilising all the Modules within the IPMES.

7.1.Data Visualisation Modules

These modules summarise the trap catches, other pest monitoring, harvest results, and pest control record information for a particular orchard block. Each sub-module for the Data Visualisation Module is described below.

7.1.1.Trap catch module

The functionality of this module is to visualise the Codling Moth (CM) and LeafRoller (LR) weekly trap catches and associated spray applications. It communicates with the Pest Control Record and trap catch databases, and the IFP Manual ruleset: Users can specify catch information and spray applications for:

1. Block/orchard versus current threshold in IFP manual.
2. Compared to previous year on the same block/orchard.
3. Compared to the district average for the same year.

7.1.2.Pest monitoring module

The functionality of this module is to visualise the scale, woolly apple aphid, mealybug, appleleaf curling midge, European red mite, and twospotted mite pest monitoring data and associated spray application. It communicates with the Pest Control Record and pest monitoring databases and the IFP Manual ruleset. Users can specify pest monitoring and spray applications for:

1. Block/orchard versus current threshold in IFP manual.
2. Compared to previous year on the same block/orchard.
3. Compared to the district average for the same year.

7.1.3.Harvest assessment data visualisation

The functionality of this module is to visualise the harvest assessment data from a particular cultivar block or orchard/block. It communicates with the harvest database. Users can specify:

1. Harvest data for an individual pest insect compared to yearly threshold - for those pests where harvest data is used for this purpose e.g. mealybug, scale, woolly apple aphid.
2. Compared to previous year on the same block/orchard.
3. Compared to the district average for the same year.

7.1.4.Pest Control Record visualisation over the season without monitoring or trap data

The functionality of this module is to visualise pest control entries over the season without the integration of monitoring or trap data. It alone communicates with the Pest Control database. Users can specify:

1. Pest Control information for each orchard/block by variety.
2. Compared to previous year on the same block/orchard by variety.

7.2.Grower Advice Modules

These modules provide advice to the grower with a range of options for orchard pest management in terms of spraying, pest monitoring, recent spray applications, update of database, and harvest date reminders.

7.2.1.Immediate spray recommendation module

The functionality of this module is to provide an immediate spray recommendation to the grower (with options). The module would need to register the current needs or recommendations for all pests so that options would be presented with a rationale for choice. It communicates with the databases for pest control, trap catch, pest monitoring, pests-pesticides, witholding periods, harvest records (from previous season), and IFP Manual ruleset. Four situations may trigger the use of the module:

1. After the user enters monitoring or trap data.
2. Whenever the system infers that the data indicates spray need for a particular block. This would be without entry of current data but due to past data entry(ies).
3. Whenever the system infers that spraying is not required on a block and the reason why. This would be without entry of current data but due to past data entry(ies).
4. Time of year (e.g. highly recommended first spray for CM and LR, green tip oil for scale).

7.2.2.Monitoring recommendation module

The functionality of this module is to provide monitoring recommendations to the grower. The module would need to be aware of current needs or recommendations for all pests so that options would be presented with a rationale for choice. It communicates with the databases of harvest records (from the previous season), pests-pesticides, pest control records, trap catch, pest monitoring, withholding periods, and IFP Manual ruleset. Two situations can occur to invoke trapping and pest monitoring recommendations:

1. Whenever entering the system depending on time of year and region.
2. After a specific action has been taken which requires a followup monitoring.

7.2.3.Recent spray applications module

The functionality of this module is to provide detailed information of the previous spray applications to a particular orchard. The module would need to be aware of current needs /recommendations for all pests so that options would be presented with a rationale for choice. It communicates with the databases for pest-pesticides and pest controls records. One situation can occur to invoke the Recent spray applications module:

1. Whenever entering the system. An option will be available to check the date and product of last spray applied for any pest on any specified block.

7.2.4.Reminder module

The functionality of these modules is to remind the user that certain data must be entered in order for some of the other modules to function , especially those relating to the Grower Advice package. It communicates with the databases for pest control records, trap catches, pest monitoring, and withholding periods which in turn influences the decisions made by the spray application modules. Two situations can occur that invoke the Reminder module:

1. When the harvest dates for each variety are missing from the withholding period database.

2. A general reminder to enter data or message advising when data was last entered.

7.3.Improving the Thresholds Module

This module is intended to provide detailed information about what thresholds to change in the IFP manual. It will be initially based on at least the last three year's datasets nationally or regionally as the improvement of the thresholds requires at least that much data before a confident recommendation could be made. The module is intended to identify trends in the operation of the orchards nationally or regionally, that differ from that recommended by the current IFP ruleset. It communicates with the IFP ruleset, trap catch, pest monitoring,pest control record, harvest assessment, and packhouses databases in order to make the modifications. These modifications would normally be applied nationally (this is the primary aim) or restricted to a particular growing region (this is the primary aim) or specific orchard (this is the secondary aim). After operating the expert system for further year, it may be possible to suggest changes on individual orchards. Recommendations for threshold modification would normally happen at the end of the season when the harvest assessment is completed and can be selected for a particular district, orchard, cultivar block, or apple variety depending on the criteria for analysis.

8.Preliminary design and Implementation Issues

To develop such an agent based distributed expert system requires many technologies to be combined to form the system. At present Java [9] is going to be used to implement the system with the Voyager distributed based architecture [7] used as the means for controlling the various agents that would be created to perform the tasks within the IMPES. At the heart of the inference engine for the IPMES, a combination of the FuNN [1], EFuNN [3], and the Java Expert System Shell (Jess) will be used.

The development of the IPMES will be along a modular design whereby modules will be created and added over time to satisfy all the functionality of the system described. This means that a system with minimal functionality can be deployed whilst the other modules are being developed in parallel.

9.Plans for testing the system

Once the initial prototype has been developed, it will be deployed initially for use by HortResearch for testing then used on a subset of the orchards that have adopted the IFP programme for refinement of the system itself.

10.Conclusion

This paper has described the initial architecture for an adaptive agent-based distributed expert system for pest management known as IPMES. The objective of IPMES is to support the orchardists decisions on managing their orchard and in turn improve fruit production in New Zealand orchards. The IPMES will use a combination of connectionist and rule-based techniques that are controlled using a distributed agent-based architecture.

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