Location-aware expert system design for olive fruit fly spray control

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Abstract— **Location-awareness significantly enhances the functionality of ubiquitous computing services and applications, and enriches the way they interact with the users and resources in the environment. Many location-aware systems adapt the way they behave according to the context of the current location without explicit user intervention. The aim is to increase usage and effectiveness by taking environmental context of a specified location into account.**

In this work we present the design and functional simulation of a Location-aware Expert System suitable for the ground control of the olive fruit fly. The proposed system enables rapid prototyping of location-aware services in an intelligent precision farming environment and combines location sensing technologies with wireless Internet, Geographical Information Systems, Expert Systems (ES), and Decision Support Systems. We focused on the design of an ES, mainly by designing the Knowledge Base (KB) and by outlining the factors and infrastructure that must be considered during the olive fruit fly spraying process. Based on this framework we can develop specific Location-aware services such as finding if the current area is to be sprayed, estimating the amount of the spraying solution that must be sprayed, abort for a reason the spraying process etc. These services aim in a more efficient and environmental friendly control of the olive fruit fly.

***Index Terms*— Location-aware, middleware architecture, Expert System, precision farming, olive fruit fly.**

I. INTRODUCTION

OLIVE fruit fly (olive fly) (scientific name; *Bactrocera oleae* or *Dacus oleae* (Gmelin), Diptera, Tephritidae) is the most serious insect pest of olive fruit in the world. Olives are the only breeding host plants. This insect affects the olive tree cultivation causing serious qualitative and quantitative consequences with economic impacts and monetary losses [1]. Control of olive fruit flies depends on either killing the hatching eggs and larvae in the olive fruit or stopping the female from mating or laying eggs. This can be accomplished with broadcast foliar sprays, or bait applications using different attractants in combination with insecticides, or with massive numbers of sterile males release. However, spray applications from the ground seem the most appropriate for several reasons, such as economical, climatic, environmental etc.

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During the spray applications there are several problems concerning geospatial, meteorological, biological, environmental and other agro-environmental data. These data are user, location and time adaptive. This has motivated the introduction of ubiquitous computing technology in an intelligent precision farming environment, namely an environment that it is saturated with heterogeneous computational and wireless communication devices naturally integrated to farmer activity. The environment should be aware of the specialized context in order to provide information and services whenever farmers need them.

Location-aware computing has been created by the evolution of wireless networking and mobile ubiquitous computing in combination with the advances in location sensing technologies [2]. In this context, ubiquitous computing is a new paradigm, relying on the use of tiny devices embedded in everyday objects and environments, collecting and delivering information and communicating wirelessly, and intelligently, between themselves. Location-aware applications are able to integrate information related to geographical position, mapping, routing, searching, multimedia content and address location functionalities with user-specific profile and content. There are a wide variety of location-aware applications [3] which are used in emergency situations, navigation, environmental monitoring (habitat, pollution, etc.), precision agriculture, industrial automation, security, advertising, etc..

Precision farming utilizes new information and communication technology techniques to get localized environmental conditions of farm through the use of satellite or aerial imagery, GPS and other means. The information gained is utilized to make decision regarding appropriate use of water, nutrients, pest management, etc., to make environmental safe and optimal use of resources and improve productivity and quality. We may envisage a completely smart field system where automatically water, fertilizer and pesticide will be applied based on the sensor measurements. Some of the processes like fertilization and especially crop protection require frequent updates in information.

Sensor systems that are continuously present can deliver such information. Sensor networks have been used in precision agriculture to assist in spatial data collection, precision irrigation, variable-rate technology and supplying data to farmers. One of the examples of this has been to prevent frost damage to vineyard [4]. Another example has focused on measuring the microclimate of a potato crop to deliver detailed information for decision support systems for phytophthora (destructive parasitic fungi causing brown rot in plants) control [5]. This involves measuring temperature and relative humidity in the crop canopy. An overview of available wireless sensor technologies that are applicable to agriculture and food industry has been given in [6]. To the best of our knowledge, none of the above applications considered the introduction of agents and Web-services as part of their solution. Wireless sensor networks typically publish the data to the World Wide Web and allow real-time access to the data. Different types of data are collected by the sensor nodes to measure specific environmental parameters, as well as generic data, such as GPS (Global Positioning System), temperature, relative humidity, wind speed and wind direction, light, motion, etc.. At the server the data can be visualized and analyzed within a Geographic Information System (GIS), and published via the Web to give researchers seamless access to information.

Location-aware systems need intelligent capabilities to be adaptive to farmers, reactive to context, and learn from their behavior in support of decision-making and to provide high quality services based on their preferences. These services have to be accessible to diverse and non-specialist farmers through simple and effortless interactions. Expert systems combine the experimental and experiential knowledge of specialists to aid farmers in making the best decisions for their cultivations. Several attempts have been made to develop decision support systems and expert systems for optimizing agriculture operations. Support systems have been developed for weed control [7], irrigation [8-10], fertilization [11, 12] and pest management [13-15]. However, an important issue that has not been given the proper attention so far is the development of a middleware that processes and delivers contextual information to the farmer and simplifies any decision process concerning the agricultural practice. Agents and Web services have been considered as an alternative to cope with some of the challenges of intelligent agro-environmental monitoring and control systems, including precision farming environment, such as problems related with the pest management, the fertilization, the water management, etc..

The main contribution of this paper is to present the design and functional simulation of a Location-aware Expert System suitable for the control from the ground of the olive fruit fly. The functionalities of the proposed design are evaluated in the problem of monitoring the olive fruit fly population and control the olive fruit fly by ground spraying operations. The proposed system enables rapid prototyping of location-aware services in an intelligent precision farming environment and combines location sensing technologies with wireless Internet, GIS, Expert Systems (ES), Decision Support Systems (DSS), multimedia, and artificial intelligence techniques. These technologies are expected to produce supporting tasks like the countering measures selection and the alarm spraying levels. The motivation for developing such an application is because olive fruit fly is the most serious insect pest in the world that affects olive trees cultivation leading to significant quantitative and qualitative consequences.

In the remaining the paper is organized as follows. The problem description is provided in section II. The infrastructure, by means of the data acquisition process, and data and knowledge structure are discussed in section III. In the sequel, in section IV, the design of the modular middleware design is explored. Section V discusses functional evaluation issues of the application and presents the basic results aiming at to show the capabilities of the proposed system. Finally, in section VI the main conclusions are drawn.

II. PROBLEM DESCRIPTION

A. *The olive fruit fly*

Olive fruit flies survive best in cooler coastal climate, but are also found in hot, dry regions. The optimum temperature for development is between 20^0C to 30^0C. High temperatures (35^0C or more) are detrimental to adult flies and to maggots in the fruit. However, since the flies are very mobile they have the ability to seek out cooler areas of the orchard and urban trees. The olive fruit fly has three to five, generations per year depending upon local conditions.

B. *Monitoring olive fruit fly*

In order to monitor insect populations adequately, it is important to have systems, which record both biological and climatic data. These data need to be collected in real time and give information about both adult and larval stages. The use of such information is only valid if it is incorporated into pest management models. In the case of olive fruit fly, monitoring of adults in traps (i.e. McPhail traps) and observations of larval stages in fruit samples are coupled with climatic data (temperature, relative humidity etc) to make predictions of damage and take preventive measures. Such climatic data is collected from automatic agro-climatic weather stations, which are capable of recording and storing great quantities of climatic data and sending it automatically to a central collection point.

C. *Ground spray process*

Spray applications from the ground seem the most appropriate for several reasons, such as economical, climatic, environmental etc. The spray process takes place during a day using tractors. Each tractor covers one section of the spraying area. The insecticide applies in a course spray or stream to a small portion of the tree. There is no need to cover the whole tree, because the adult flies are attracted to the bait, feed on it and die. During the spray applications several problems may arise:

- The air temperature and wind speed values are unknown to the spraying attendant. In this case, the spraying could continue even when the meteorological conditions have been violated.

- The spraying areas cannot be memorized by the attendant and therefore over or under spraying may occur.

- The spray volume is dependent on the coverage of olive trees and therefore the spraying attendant cannot easily determine if the number of the olive trees per area unit is low, medium, or high. The attendant is not aware of the existing areas inside the spraying area which must not be sprayed for some reason (i.e. domestic or environmentally protected areas, biological cultivations, etc.).

- The olive fruit fly population of the spraying area is not known to the attendant and therefore the spray volume per area cannot be determined at all.

- The lack of communication between the supervisor of the spraying application and the attendants. The exact location of the attendant and the spraying coverage are not always known to the supervisor and therefore the whole spraying process can be altered.

- The problem is spatially distributed. Insects are usually dispersed in a wide geographical area and the solution, by means of predicting the insect population level, should maintain this spatial dimension.

- Information collected is usually noisy and imprecise. This is due to instruments faults, communication errors and other local disturbances at the measurement point.

- There is usually a great degree of redundancy involved. For example the temperature is very unlikely that will change dramatically over a short period of time.

- Many monitoring agro-meteorological stations need to be installed, with the purpose of measuring the monitored indices in the vicinity of the station. These stations are distributed over a wide area.

D. Requirements from the agro-environmental context

To avoid failures in the spray treatment a number of factors should be taken into account, namely; the area of olive trees should be large enough, the population of olive fruit flies should increase significantly, the olives must be in an advanced stage, the female to male insect ratio should be greater than one, the female insects must be mature, and finally the temperature, wind speed and humidity levels should exceed a threshold.

The requirements from the agro-environmental context may include the efficiency in preserving measures taken against the spatial dispersion of the olive fruit fly, the efficiency in ground spraying treatment, the environmental protection, the quality assurance, the reduction of cost, etc.. An analysis of the most important requirements follows:

- *Preserve spatial dispersion*: A pest free area is an area in which a specific pest does not occur as demonstrated by scientific evidence and this condition is being maintained. In cases where the olive fruit fly free area is situated near or within an infested area, preventive measures and specific procedures are required for its establishment and maintenance. Efficiency in preserving measures taken against the spatial dispersion of the olive fruit fly requires the determination, establishment, verification, declaration and maintenance of the olive fruit fly free areas, as well as the consideration of the possible need for buffer zones.

- *Efficacy in ground spraying treatment*: The ground spraying treatment is called to fulfil dissimilar needs. First, off-line data gathering and making them available for in-depth analysis should be fulfilled. Next, real-time reporting requirements for identifying and reporting the current environmental conditions should be considered. Finally, guidance requirements need to be examined, not simply to give answers to certain problems, but also to foresee and forewarn about potential environmental problems. For a real-time ground spraying treatment system the main objective is to provide to the farmers improved service reliability and adaptability to changing environmental conditions.

- *Environmental protection*: The guidelines on standards for agricultural pesticide applications and related procedures consist of detailed specifications and requirements. Application timing will be influenced by meteorological conditions, which may result in physical, and volatility spray losses. Temperature, relative humidity, wind speed and the possibility of rain can all affect the efficiency of spray dispersion.

- *Quality assurance*: The quality assurance guidelines, by means of compliance with approved procedures, should include the surveillance procedures (both trapping and fruit sampling when used), regulatory controls and corrective action planning.

III. INFRASTRUCTURE

A. Data acquisition environment

In order to provide information about insect population biological and climatic data must be collected. Note that monitoring of adults in traps and observations of larval stages in fruit samples are coupled with climatic data to make predictions of damage and take preventive measures. Climatic data is usually collected through automatic agro-climatic weather stations, which are capable of recording and storing great quantities of such data, and then sending the data wirelessly to a central collection point. The sensor network should combine the functions of sensing, data gathering and storage, computation, processing and communication through a wireless medium. It should also provide reliable, time critical and constant environment sensing, event detection and reporting. Some proposals have already been made to deploy sensors networks to precision agriculture [4-6, 16], aiming at to enhance the efficiency and growth of cultivations. In [17] was proposed a four-tiered Wireless Sensor Network (WSN) architecture to transmit the data from an array of sensors to the server, through their clusterheads and field-zone gateways, using a two-way data stream over a wireless link.

Testing and evaluating the olive fruit fly control operation in its target environment with a suitable infrastructure and a volunteer user community is costly and usually does not scale well to large number of users. Furthermore, the sensor network may comprise of an appropriate number of motes that could be distributed in a vast experimental region of olive trees;

preliminary investigation suggest an area of at least 150000 olive trees, so that the ground spraying will have significant results. For these reasons such applications in agriculture are still rare [6] and the problem of designing scalable sensor network architecture is open and of primary importance. To proceed with a different approach we created a simulation environment that supports the evaluation of key aspects of the treatment operations, without extensive resource investments necessary for a full application implementation and deployment.

Thus, although a complete evaluation requires many different aspects to be examined, such as user interface issues, system and network related issues, as well as physical device considerations, our concern here is merely how to improve the test environment and how we can use it as part of the evaluation process for this application.

TABLE I
FACTORS THAT AFFECTING THE SPRAYING CONTROL PROCESS

Data	Structure	Nature
Geographic		
Location models and coordinates	Points	Spatial
Road network	Lines	Spatial
Spraying area	Polygons	Spatial
Slope	Contour Map	Spatial
Tracking paths	Points	Spatiotemporal
Biological		
Insect population	Contour Map	Spatiotemporal
Pest management models	Model	Spatiotemporal
Soil		
soil type	Polygons	Spatial
soil temperature	Contour Map	Spatiotemporal
soil compaction	Polygons	Spatial
soil moisture	Contour Map	Spatiotemporal
Meteorological		
Air temperature	Contour Map	Spatiotemporal
Air humidity	Contour Map	Spatiotemporal
Wind speed	Contour Map	Spatiotemporal
Cultivation		
Olive trees	Points	Spatial
Olive cultivars	Categories	Spatial
Coverage with olive trees	Polygons	Spatial
Olive size	Categories	Spatial
Olive hardness	Categories	Spatiotemporal
Olive coloration	Categories	Spatiotemporal
Environmental		
Water cources	Polygons	Spatial
Environmentally protected areas	Polygons	Spatial
Domestic areas	Polygons	Spatial
Biological crops	Polygons	Spatial
Operational		
User profile	List	-
Equipment characteristics	List	
Spray solution specifications	List	-

B. Data and knowledge structure

Comprehensive knowledge of the factors and the data that affecting the control process against olive fruit fly and the biological cycle of the insect is important for controlling efficiently and environmental friendly the olive fruit fly by ground spaying applications. These factors which have spatial, temporal or spatiotemporal nature, they are shown in Table I and outlined below:

1) Geographic features

Geographic features are collections of themed information layers that can be used together. Each geographic feature has attributes that identify and describe the feature. These attribute are classified to types such as counts, amounts, ratios, categories, ranks etc.. Below are given the most important geographic features that must be taken in to account.

a) Location models and coordinates

The proposed architecture supports symbolic and geometric location models and provides the functionalities needed by both the location awareness [18] designer (super user), who deploys services, and the end user, who uses them. In geometric location models there are three coordinates; latitude, longitude and altitude. Several issues are involved in choosing a map coordinate system, including where the spaying area is located, how large the area is, and which is the optimum precision.

b) Road network

Even though, the spraying process is done in the fields where there is a little or no road network, the movement of the tractors and the attendants from one field to another is becoming usually by a rural road network. In the fields we may assume that there is a virtual road network that it allows tractors to move in the spraying area and attendants to spray the olive trees. These networks can be used to optimize the navigation during the spraying process and reduce the duration of this process.

c) Spraying area

The area that is covered by olive trees and need to be sprayed is another important feature. This feature gives the location and the extent of the area that each tractor or attendant covers, so as to not occur over or under spraying.

d) Slope

Slope is a measurement of how steep the ground surface is. If the ground surface of the spraying area is too steep then it is more possible the spraying in this area to be done by an individual attendant rather than a tractor.

e) Tracking paths

Tracking paths determine the speed and location for each tractor or attendant. With these paths we can calculate in real time the area and the number of trees that have been sprayed for each tractor or attendant.

2) Biological data

a) Insect population

Knowledge of insect population and population dynamics is essential for taking decisions such as when to spray, which areas to be sprayed and what spraying density is going to be used. Olive fruit fly population is determined by monitoring of adults in traps (i.e. McPhail traps) and observations of larval stages in fruit samples. The data need to be collected in real time include the number of females adults, the number of males adults, the degree of infestation and the distribution in the fields of the above data.

b) Pest management models

Pest management models for olive fruit fly are descriptions of models of the insect and olive cultivation, which include phenologies and management strategies.

3) Soil data

Olive fruit fly may complete its pupal stage in the soil. Therefore, knowledge of pupation depth of the olive fruit fly in nature is an important factor to determine the degree of infestation in an area. There is influence of four abiotic factors on the pupation depth of olive fruit fly. These factors are: soil type, soil temperature, compaction and soil moisture.

TABLE II
DEVELOPMENTAL THRESHOLDS FOR OLIVE FRUIT FLY AT CONSTANT TEMPERATURES

Stage	**Lower (^{0}C)**	**Upper (^{0}C)**
Egg	6.1 - 7.8	35.0 – 37.8
Larva	3.9 – 8.0	35.0
Pupa	5.0 – 8.9	30.0
Adult	4.5	38.9

4) Meteorological data

a) Air temperature

The air temperature relationships and developmental thresholds for olive fruit fly are shown in Table II. The adult activity is approximately 15.5^{0}C. High temperatures in 38-41^{0}C range are detrimental to adult flies and to immature stages in fruit. The air temperature during the spraying process must be between 12^{0}C to 28^{0}C.

b) Air humidity

Olive fruit flies survive best in more humid climates but also infest olives that are grown in dry regions.

c) Wind speed

High air wind speed inhibits the flight of olive fruit flies and therefore these insects are not fed by the sprayed solution and survive. The air speed during the spraying process must be less than 8m/sec.

5) Cultivation data

TABLE III
INFESTED OLIVES (%) FOR DIFFERENT CULTIVARS

Cultivar	Infested olives (%)
Sevillano	80-90
Manzanillo	18-30
Mission	69-81
Frantoio	13-15
Leccino	15-44
Arbequina	3-7
Koroneiki	4-10

a) Olive cultivars

There is a range of susceptibility among different olive cultivars. The size of olives is considered one of the most important factors. There is a positive correlation between infestation levels and olive sizes. As a result, infestation is higher in large olive sided cultivars than one bearing small olives. The percent of olives infested for different cultivars is shown in Table III.

Olive hardness is another important factor determining the infestation levels. There is a negative correlation between infestation and hardness. When olives reach their final sizes are become softer.

The olive coloration seems to play a role in infestation. Green olives are more susceptible than brown ones.

b) Coverage with olive trees

The coverage density of the olive trees in the spraying area is important for the determination of the density and the distribution of the sprayed solution.

6) Environmental data

The location of water courses, domestic or environmentally protected areas and biological crops areas is very important in order to determine appropriate buffer zones between the sprayed and these areas.

7) Operational data

Operational data includes user profile, specific equipment characteristics (size and power of the tractor, sprayer's specifications etc) and the spray solution specifications (dosage, method of usage, precautions etc.).

IV. LOCATION-AWARE MIDDLEWARE ARCHITECTURE

The proposed Location-aware middleware architecture utilizes software agent technology and Web-services, in order to allow the design and development of modular, stand-alone software components. The middleware should be able to gather data in a systematic way and making them available for in-depth analysis, as well as to identifying and reporting the current environmental conditions, and to foresee and warn about potential problems. Agents [19] and XML Web services [20] can assist users in a range of different ways; they hide the complexity of difficult tasks, they perform tasks on the users' behalf, they can train or teach the user, they help different users to collaborate, and they monitor events and procedures. In order to acquire a robust understanding of the agro-environmental work practices and to make the ideas more concrete we will conduct an appropriate simulation scenario.

The developed middleware offers the characteristics such as: temporal continuity, reactivity, cognition, presence of agents, collaborative behaviour, mobility, location and authentication, dynamic architecture, infrastructure for developing autonomous agents, integration of agents and Web services, support for interoperability and spatiotemporal optimization. The proposed location-aware middleware architecture is presented in Fig. 1 and comprises of four modules; The Communication module, the Location-Aware

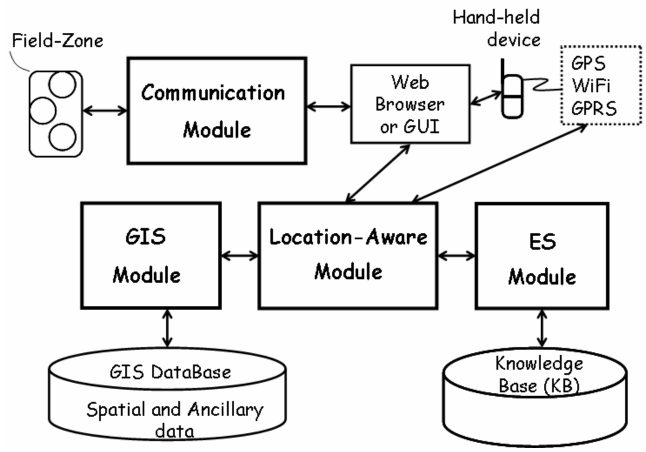

Fig. 1. A global view of the system architecture.

module, the GIS module, and finally, the ES module. Since these modules are independent of each other new modules may be added or existing ones may be modified in order to expand and/or improve the usage of the proposed architecture. The architecture supports symbolic and geometric location models and location awareness commands, which are responsible for the management of the functionalities of the system. The middleware provides an agent interface that facilitates the composition, sending and receiving of messages between agents.

A. Communication Module

The Communication (Com) module is classified into different types of mobile agents and in accordance with their functionalities. It is closed related with the developed WSN, the network-based operations, the sensors' hardware, as well as the data acquisition mechanisms. The network operations of the Com module are distributed into four layers each one of which is controlled by specific task oriented mobile agents. Agents in each layer achieve their assigned task by collaborating with each other and with other agents in other layers and transmit the processed data to their destination layer. It receives the required sensing data captured by the sensor acquisition devices, performs query dissemination and network processing.

B. Location Aware Module

The Location-Aware module coordinates all modules of the proposed application. It is responsible for the input of the location of an object into the system, the transformation of the position coordinates of the moving objects, the management of the information and the tracking layers of the GIS module. It combines the data provided with the location data of the objects, as well as with the data provided by others components and communicates of the server, the moving clients and the graphical user interface. It is also responsible for the management of the tasks and events that must be executed during the spraying process and the management of the multimedia content (images, sound, video, text to speech and hypermedia). Finally, it presents the created services to the end user in a graphical user friendly form.

C. Geographical Information System Module

The Geographical Information System module (GIS Module) implements processes such as navigation, routing, geo-coding, map representation, searching and etc.. It is responsible for the management of the spatial and ancillary data. The spatial data are stored locally and can be updated using the appropriate commands. The spatial data is presented in the information layers the number of which depends on the features of the created services and the type of the application. A special type of an information layer is the tracking layer, which stores the position of the moving objects in real-time. Ancillary data are the attributes of the spatial objects (points, polygons etc.), the users' profile and actions, the system parameters, the sensing data, etc.

The interactivity of the GIS functionality is achieved by invoking some appropriate commands (e.g. data updating, system management, browsing, multimedia management etc), which also use one or more information layers.

D. Expert System Module

The Expert System module has two components, the Knowledge Base (KB) and the inference engine (InfEng). The KB consists of rules encoding the domain expertise. Each rule is an expression of the form:

if <*conditions*> then <*actions*>

where if the *conditions* are true then the *actions* are executed.

The KB is contained in an XML file having a special structure. The actual representation of a rule in XML notation has the following form:

<Rule name="Rule53">
<Condition id="01" frame="AIR" slot="T" attribute=">=" value="17.5 "/>
<Condition id="02" frame="AIR" slot="Speed" attribute=">=" value="3.4"/>
<Conclusion id="001" frame="SPRAY" slot="Density" attribute=":=" value="0"/>
</Rule>

The sequence of Condition tags form the *if* part of the rule and the sequence of Conclusion tags form the *actions* part. Each condition of a rule is connected with the previous and the consequent ones by a conjunction. If there is a sequence of values corresponding to the same frame, slot, attribute triplet the values are written to the value field separated by comma.

Adopted XML notation [21] uses frames, slots, attributes and values to represent conditions and conclusions. A frame, usually, corresponds to an object having a set of characteristics represented by slots. Each slot has several attributes and to each attribute can be assigned one or more values. The XML files are converted into an internal knowledge representation structure before they used by the system. The internal representation of the knowledge base contains a list of rules, a list of possible decisions, a list of conditions and a list of slot,

TABLE IV
DECISIONS OF THE ES AND THE USED DATA

Decision	Data
- Infestation levels are high - Infestation levels are low - High infestation risk - Low infestation risk	Geographic, Soil, Meteorological Cultivation
- Temperature is too low - Temperature is too high - Humidity is low - Wind is too high	Soil, Meteorological
- Spray with density "X" - Stop spraying process - Abort spraying process - The area has been already sprayed - This area is not your spraying area	Geographic, Soil, Meteorological, Cultivation, Environmental, Operational
- Olive cultivar susceptibility is high - Olive cultivar susceptibility is low	Cultivation
- Distance from a previous position is too small - Turn left/right	Geographic, Soil, Meteorological, Cultivation, Environmental, Operational

attribute pairs. Inference engine supports forward chaining (or data-driven inference) mechanisms. A list of the main decisions of the proposed system is shown in Table IV and a general view of the decision process is shown in Fig. 2. The forward chaining works forward, starting from available knowledge. It assumes mentally, that the head of a rule is an

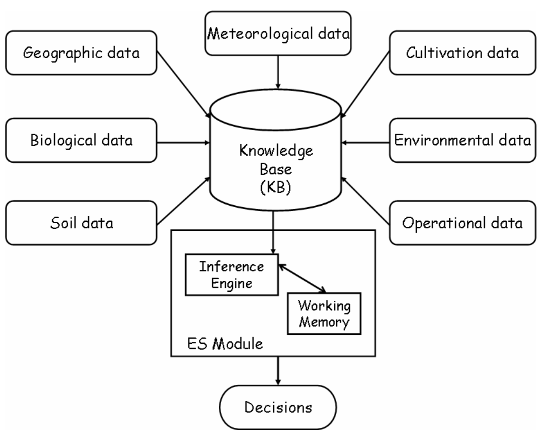

Fig. 2. General view of the decision process.

action (or conclusion), and the body is the condition for performing this action. The inference engine does not have a goal. Instead, it looks at all the facts stored in the database. If these facts satisfy the condition of some rule, the inference engine fires that rule by performing the action the rule specifies. So it starts from the facts and works towards consequences.

In order to inference using the method of forward chaining we merely need to fire (or execute) actions whenever they appear on the action list of a rule whose conditions are true. This involves assigning values to attributes, evaluating conditions, and checking to see if all of the conditions in a rule are satisfied. A general algorithm for this might be:

while values for attributes remain to be input
read value and assign to attribute
evaluate conditions
fire rules whose conditions are satisfied.

V. Demonstration of the System's Functionalities

The proposed system is used in the design of a sensor application that monitors air temperature, humidity, wind speed, light, and mobility. Any real case scenario may comprise of few hundreds of scalar sensors that could be distributed in a vast experimental region of olive trees.

A. System Implementation

The system was implemented, using Microsoft Visual Studio.NET. The olive fruit fly treatment application was executed on a laptop with Microsoft Windows XP and on pocket PC with Windows Mobile 6. For the development of the GIS module ESRI MapObjects 2.4 and ArcPad 7.0 were used for the laptop and the Pocket PC, respectively. Simple and advanced GIS functionalities were used which are related to mapping, tracking, routing, searching etc. The vector-based geographical data was stored as shape-files (.shp). The hypermedia content can be browsed by an internal Web browser or by the default Web browser of the Windows OS. The developed software has voice capabilities thanks to Microsoft Agent 4.0.

B. Functional Simulation

In this section we report some preliminary simulation results of the olive fruit fly application. As it is expected there are two cases to be considered; monitoring and control with ground spraying.

1) Monitoring the olive fruit fly population

The monitoring in the olive fly application was performed using either a Web-based or a simple GUI prototype. Users input queries at the server in an SQL-like language describing the data they wish to collect, to combine, to transform, and to summarize. The system can choose from several plans and operator orderings for any given logical query. For example, to find the average temperature of a field-zone the system collects readings only from sensors of this field-zone, instead of collecting readings from every sensor in the network and compute the average. The above suggests a query optimization problem, by means of choosing the lowest-cost plan. The queries can be adjusted according to the request. For example, the users may retrieve the most recent, average, maximum, or minimum value, received from any or all the sensors or periodic sensor readings. In fact queries may consist of *select - from - where - group by* - having blocks to support selection, join, projection, aggregation and grouping. We support tree queries types: *Search by attribute, Search by Query and Search by Distance*. In the Fig. 3 we provide an example query to clarify some of the possibilities. The *Search by attribute* query requests to show all the traps from the *TRAP* layer with olive fly population (*TRAP.dacus* attribute) greater than 10 insects per trap.

2) Control in ground spraying treatment

Ground spraying treatment in olive trees is performed by taking into account the wireless sensor network configuration.

For each field-zone the system provides the olive fly population per trap and the volume of the required spray. Note that a trap only partially covers the spraying field-zone. In each field-zone a tractor is assigned for ground spray application, which carries a computer (laptop or pocket PC) with wireless Internet access (Wi-Fi and/or GPRS). The temperature is assumed to be in the range of 14^0C to 28^0C, whereas the air speed does not exceed 8m/s. The information layers of the GIS module that were utilized in the simulation are shown in Fig. 3 and described in TABLE V.

TABLE V
THE GIS INFORMATION LAYERS OF THE OLIVE FRUIT FLY CONTROL

GIS Layer	Description
OPTIONS	The layer is a GIS interactive menu. The user may invoke commands to update the GIS data, to browse though the Web pages, etc..
TEMPERATURE	Provides the temperature values from each cluster.
RH	Provides the relative humidity values from each cluster.
AIR	Provides the airspeed values from each cluster.
ROADS	Provides the road network of the spaying area.
TRAP	Provides information of the location of each trap and the insect population level per trap.
SPRAYAREA	Shows the areas that are covered by olive trees and need to be sprayed. It also shows the density of the olive trees in the spraying area.
TRACTOR	Shows the areas designated in each tractor.
AREA	Shows the boundaries of the area which is to be sprayed.
TRAPAREA	Provides information about the trap area and the extreme levels that the spray applications must commence.

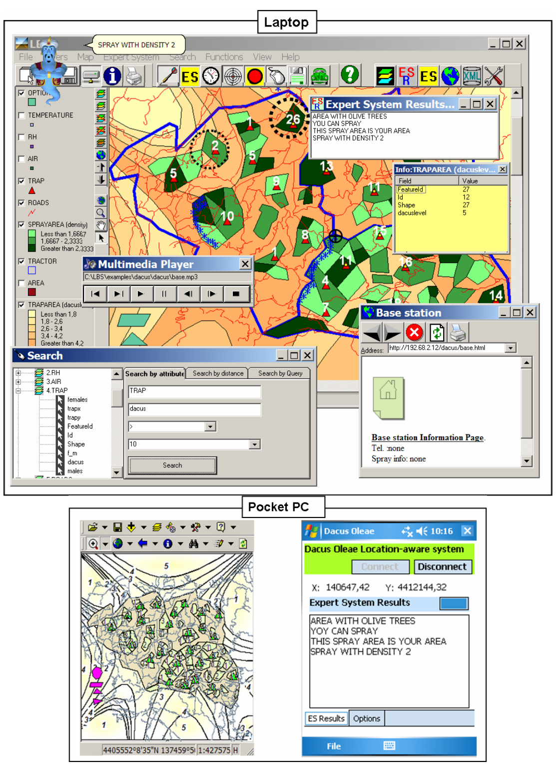

Fig. 3. Location-aware ES application using Laptop or Pocket PC

During the spray application the KB becomes aware about the location of the tractors in respect to the designated olive trees area. Then, a decision about the volume and the actual spray area is made and the tractor attendant proceeds with the operation. If it is not allowed to spray the area, the ES reports to the attendant with the reason, i.e. temperature is too high/too low, wind speed is too high, etc.. Note that when a tractor is in the area that is designated to be sprayed by another tractor, a location-based notification is sent to the attendant with the correct number of the tractor. Notifications are also sent by the system informing both the attendant and the spraying supervisor when a tractor is within an area that has been already sprayed or nearby a protected area that must not be sprayed. In such cases, the spraying supervisor may send a notification to both or to all the spraying attendants. Further, when a trap is within the range of a tractor the system notifies the attendant with an estimation of the number of insects that have been captured by this trap. An additional capability is that the attendant may use multimedia data, such as photos of the spraying areas, sound files with advises, or orders on the spraying operation, textual information, network data concerning the spraying operation etc.. Finally, the attendant has the capability of personalizing the system, namely, to update the database, or utilize help on the system's operation.

VI. CONCLUSIONS

Olive fruit fly is the most serious insect pest of olive fruit in the world. Spray applications from the ground seem the most appropriate treatment. However, during the spray operations there are several problems that are location and time adaptive. This has motivated the introduction of ubiquitous computing technology in an intelligent precision farming environment. These environments which are heterogeneous should be aware of the specialized context in order to provide information and services whenever farmers need them. The ubiquitous nature of Internet enables precision farming professionals to easily access agro-environmental information at any time. In precision farming environments the information and farmers are distributed, thus demanding considerable coordination and communication among the professionals that work in such settings.

In this work we proposed a location-aware expert system design suitable for agro-environmental applications. This system constitutes an effort toward the design of an intelligent, flexible, and integrated, large-scale, precision farming system. The system was designed with the characteristics of a cooperative agent group, where agents share a common goal and each one adopts a request to do its share toward achieving the goal of the group. There are a wide variety of location aware applications utilizing specific location sensing capabilities; however, the realized one has the property to combine enabling technological advances in Internet, wireless communication with GIS, ES, DSS and multimedia systems. It also integrates many interesting architectural characteristics, such as, the independence of the positioning system and the location model support, the location-based decision support, the user friendly environment with multimedia capabilities of the GUI, the flexibility in the development of new location aware application and services, etc.. The proposed system enables the creation of large-scale, outdoor, widely distributed, heterogeneous networked embedded systems that inter-operate and adapt to their environments. The developed architecture may adapt future technologies, encapsulating and integrating various modules as agents.

Future challenges include network protocols, system support for small devices, communication methods, data processing and energy efficiency. Images as well as video streams, along with signal processing techniques can be tested to identify the olive fruit flies.

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