Ontological and Sensor-Based Supporting System on Damage Prevention for Tamarind Farming: a Case Study of Phetchabun Tamarind Farms

Phimphan Thipphayasaeng[1]
and Sant Phanichsiti[2]
Phetchabun Rajabhat University, Phetchabun, Thailand
[1]phimphan.thi@gmail.com
[2]maxzmust@gmail.com

Received: 18/10/2019
Accepted: 27/11/2019

Abstract **- To achieve products in quantity and quality, farmers need both knowledge on how to handle problems and precise relevant farm data. Tamarind fruits are the major economic product of Phetchabun, Thailand, and they require a countermeasure against insects and diseases to damage them. This work presents a combination of knowledge-based and sensor-based framework to support tamarind farmers in handling invading diseases and insects. An ontology is designed to create a network of relevant farming concepts for smart decision-making while sensors are exploited to obtain precise and real-time data of the farm climate. Together, they provide a service to alert once farm circumstances are likely to be invaded by pests and diseases. Furthermore, recommendation on how to handle the problem and information about tamarind in which are established in the ontology are accessible for farm caretakers. In evaluations, the framework shows promising results from achieving 0.85, 0.97 and 0.91 in average for precision, recall and f-measure, respectively.**

Keywords **- Ontology, Sensor-Based Supporting System, Tamarind Farming**

I. INTRODUCTION

A tamarind is an economic fruit famous for its antioxidant and anti-inflammatory properties [1-4]. There are several health benefits from consuming tamarind fruits including improving digestion [2-3] and strengthening liver and heart [5-6]. Moreover, they can be used in pharmacological usage as herbal ingredients for producing medicines for treating cough, cold and asthma [7]. In Thailand, agriculture of tamarinds is mostly located in Northern and North-eastern region, especially in Phetchabun, Loei and Uttaradit for most productivity rate respectively [8]. For Phetchabun, tamarind is the most important export fruit which values about 1,200 million baht annually [8].

Same to a cultivation of other fruits, productivity and growth rate of tamarind is affected by diseases and pests, especially in a pre-harvesting phase [9-14]. The damaged fruits are devalued and can rarely be sold. Commonly, prevention of the damage is preferable, but applying too much pesticides or chemical compounds should be avoided. In fact, the invasion of disease and pests is however able to be specifically prevented if realized sooner, but most of the cases are recovery from the invasion.

In this work, we propose a combination of knowledge-based system using ontology representation [15-17] and sensor detection for supporting tamarind agriculture. The main objectives include to alert farmers for possible pest and disease invasion, to provide information for detecting of tamarind-related harmful organisms, and to suggest a method to prevent and cure such threats. Moreover, the knowledge providing in a developed ontology is not only about commonly used agricultural method, but also organic method regarding 'Sufficiency Economy Farming'. This work thus is expected to expedite tamarind farming dynamically from difference in individual farm settings and location with data from employed sensors. The rest of this paper is organized as follows. Section 2 provides details of background knowledge and related works in smart farming and agriculture-supporting applications in Thailand. Section 3 proposes our methodology for developing the ontological and sensor-based supporting system on damage prevention for tamarind farming. In Section 4, assessment of the developed ontology and the application is experimented and reported. Section 5 gives a conclusion and discussion of the paper as well as the plan for future work.

II. LITERATURE REVIEWS

A. Tamarind Farming and an Invasive Insects and Diseases

Tamarind (Tamarindus indica) is a leguminous tree in Fabaceae family. The trees bear a fruit in a pod-like shape containing a brown pulp which is edible and has several culinary uses around the world. The pulp is also used in traditional medicine and as a metal polish. A wood from the trees can be used for woodworking and tamarind seed oil can be extracted from the seeds. Tamarind is cultivated around the world in tropical and subtropical zones.

The tamarind has been naturalized in South-east Asia including Indonesia, Malaysia, Sri Lanka, Philippines, and Thailand while Thailand has the largest plantations among these nations, followed by Indonesia and Myanmar. Similar to other fruits, diseases and pests are the main issues in tamarind cultivation.

For invasive insects and diseases, there are researches about timing and factors of their invasion as exemplified in Table I.

TABLE I
SHOW AN INVASIVE INSECTS AND DISEASES IN TAMARIND

Type	Name	Seasoning/Timing	Damage	Phase
Insect	Cockchafer (Microlrichai Sp.) [11, 18-20]	April-June / night	Bud and leaf	Budding phase
	Lavae of Castor semi-looper (Achaea janat) [11, 18-19]	Rainy Season / entire day	Leaf and fruit	Fruiting phase
	Citrus fruit borer (Citripestis sagittiferella) [11, 18-19]	December and January	Fruit pod	Fruiting phase
	Scale insect (Diaspididae) [11, 18-19]	All time	Branch, bud, fruit pod	Growing, Budding, Fruiting phase
	Bean weevil (Caryedon gonagra) [11, 18-19]	All time	Fruit pod	Budding and Fruiting phase
Disease	Rotten pod disease (Phomopsis sp.) [9-10, 18-19, 21]	Rainy Season	Fruit pod	Budding and Fruiting phase
	Powdery mildew (Pseudoidium tamarindi) [9-10, 18-19, 22-23]	Rainy and cold season	Fruit pod	Budding and Fruiting phase

TABLE II
SHOW RESEARCH AND APPLICATION FOR SUPPORTING AGRICULTURE IN THAILAND

Title	Main Task / Purpose	User /	Application type	Technology / Technique	Type
[15]	Developing an ontology from analysis of 40 web pages of a durian domain	Product	Knowledge Representation, Information Search	Ontology representation	Research / Method
[24]	The framework to provide a suggestion on how to be self-reliant and sustainable farm	Durian farmers	Individual-based recommender system	Ontology representation and inference	Research / Method
[25]	A sensor-based environment providing real-time warnings of risks in farm operations, such as disease alarms and warning on approaching rain showers	Thai farmers	Applications and Services	Sensors and models for weather and disease forecast	Research / Method
[26]	A geographic information system application about Thai geography for Agriculture management	Farmer	Ecosystem and Delivery	Geographic information system	Mobile application
[27]	A recommendation system on rice cultivation planning by considering of geographic and climate information	Thai farmers	Information Provider	Geographic information system and rule inference	Mobile application
[28]	A recommendation system for Thai farmer on fertilization and soil quality regarding farm location	Thai rice farmers	Individual-based recommender system	Information system and rule inference	Mobile / Web application
[29]	Web-based information provider in various aspects on rice cultivation	Thai farmers	Individual-based recommender system	Knowledge organization	Web Portal
[30]	A personalized recommendation system for Thai rice farmer on how to care for rice paddy	Thai rice Farmers	Information provider	Ontology representation and inference	Research / Method
[31]	Application with the Internet of Things Technology Control in Smart Farms Mushroom	Thai rice Farmers	Individual-based recommender system	Sensors for environment monitoring	Mobile application
[32]	IoT and agriculture data analysis for smart farm	Thai mushroom farmers	Individual-based recommender system	Sensors for environment monitoring	Mobile application
[33]	Using IoT to sense the change of environment in the farm for precision farming	Thai farmer	Individual-based recommender system	Sensors for environment monitoring	Mobile application
[34]	A recommendation framework for managing swine breeding farm	Thai farmer	Individual-based recommender system	data-driven model management	Web-based Information System

These organisms are an invasive being that is harmful to the tamarind in common. Normally, the professional farmers know about them and are prepared in handling them based on incident history of their farm. However, if the outbreak occurs out of their prepared time (from climate changes), the damage will be heavy and required urgent treatment. For treating the diseases, chemical medicines are commonly used. Specified chemical insecticides are applied to annihilate the invasive pests. Though, these chemical substances can save the day, it is commendable to use them as less as possible; thus, prevention of the outbreak is more preferable.

B. Smart Farming and Agriculture-Supporting Applications in Thailand

There are several works aiming to use information technology for supporting agriculture in Thailand. They can be classified into two types as research and application. For research, method and model are proposed in publications with the latest technology and idea. On the other hand, applications are those services accessible and usable from website, personal computer or mobile applicant. We summarize them with brief details in Table II.

From the review, the core technology in these works can be categorized into two main groups which are information-based system and sensor-based system. The information-based systems focus on assisting to users in terms of decision-making, providing clear detail on handling problems and optimizing their productivity. The most used information representation from these works is an ontology since it is claimed for its ability in sharing knowledge for both machine and human [35-36]. For sensor-based systems, detection of climate and environment is their aim in which can help farmers in realizing precise factors in farming. In this work, we combine the use of both sensor and knowledge representation to cope with tamarind farming issues. We expect that the real time detection of sensors and decision-making of an ontology with inference can effectively help farmers to rationally solve their issues in time.

III. RESEARCH METHODOLOGY

A. Design of Tamarind Management Ontology

An ontology [37-39] is chosen to create a network of related information regarding tamarind farm management. In this ontology, information such as disease, pest, tamarind tree morphology and environmental factors along with individual farm information is theoretically connected into a network of concepts. As ontological components [40-41], concepts are designed as classes, and the concepts are related to other by assigning relations including is a (hierarchical relationship) and property (part-to-whole relationship). For property relation, there are two subtypes as object properties (part-of relation; class to class) and data properties (attribute-of relation; value to class).

For covering all aspects needed for tamarind farming services, the ontology (translated to English) as shown in Figure 1 is designed using HOZO ontology editor [42], and details of some major classes are given in Table III.

The ontology is designed to represent network of information as knowledge representation for tamarind farm management. The relations have a coverage to cultivation in the farm and how to handle possible issues. The classes are scoped to only information related to tamarind farming; hence, other information such as scientific name, color of the leaf and shape of the tree is omitted in this ontology.

The ontology as knowledge representation though is unable to work in an application without instances [40]. In this work, OAM [43] is chosen to assist in instantiation by mapping a database schema to a schema of the developed ontology. The instances in this work include the environment factors gaining from the sensors and the individual farm information in which is obtained from the user input.

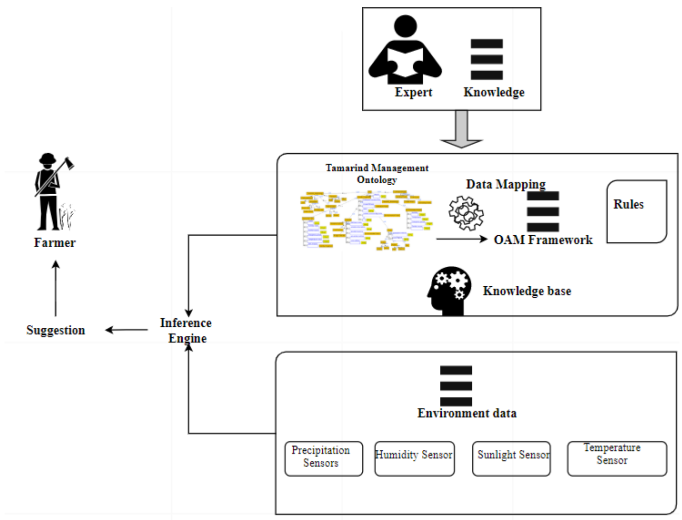

Figure 1. Developing the Ontological and Sensor-Based Supporting System on Damage Prevention for Tamarind Farming

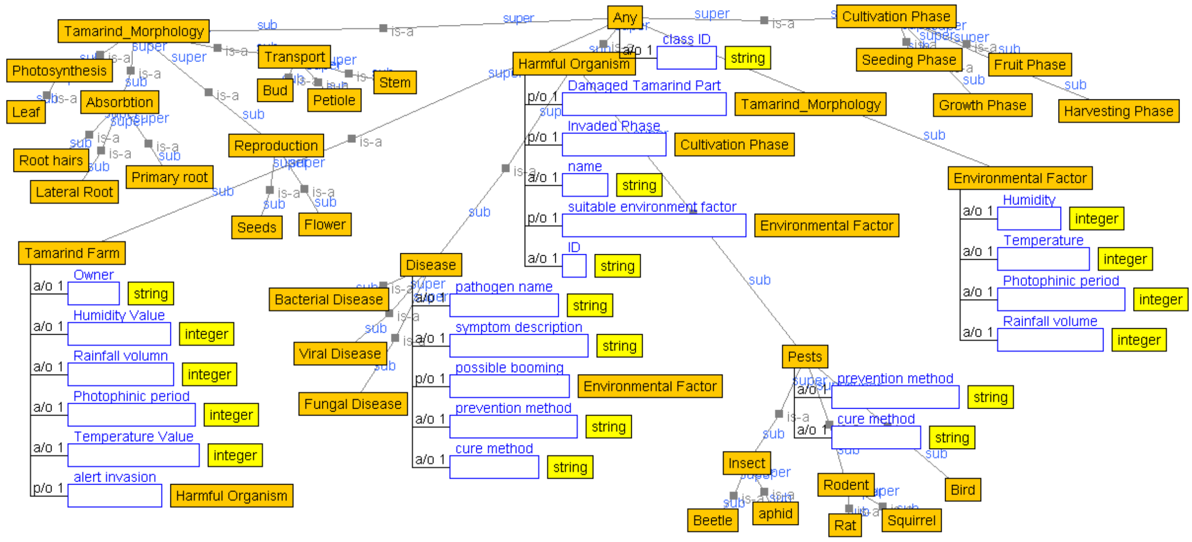

Figure 2. The Core Concepts of Tamarind Management Ontology

TABLE III
DETAILS OF MAJOR CLASSES IN THE TAMARIND MANAGEMENT ONTOLOGY

Ontology Class	Definition	Hierarchical Relation	Property Relation
Harmful Organism		• Having 2 subclasses ○ Disease ○ Pest	• Having 3 part-of property ○ damaging part [*Tamarind Morphology*] ○ invading phase [*Cultivation phase*] ○ suitable environment factor [*Environmental Factor*] • Having 2 attribute-of property ○ name [string] ○ ID [string]
Disease	harmful diseases specifically to tamarind trees	• Subclass of *Harmful Organism* • Having 3 subclasses ○ *Fungal Disease* ○ *Viral Disease* ○ *Bacterial Disease*	• Having 1 part-of property ○ possible booming [*Environmental Factor*] • Having 4 attribute-of property ○ pathogen name [string] ○ symptom description [string] ○ prevention method ID [string] ○ cure method ID [string] • Having 5 Inherited properties from *Harmful Organism*
Pest	harmful animals specifically to tamarind trees	• Subclass of *Harmful Organism* • Having 3 subclasses ○ *Insect* ○ *Bird* ○ *Rodent*	• Having 2 attribute-of property ○ prevention method ID [string] ○ cure method ID [string] • Having 5 Inherited properties from *Harmful Organism*
Tamarind Morphology	a part of tamarind tree based on functional systems	• Having 4 subclasses ○ Transportation System ○ Absorption System ○ Photosynthesis System ○ Reproduction System	none
Environmental Factor	Factors about climatic environment	none	• Having 2 attribute-of property ○ Humidity [integer] ○ Temperature [integer] ○ Daytime period [integer] ○ Rainfall volume [integer]

B. Services of the Proposed Framework

1) Alert Service

The alert service is designed to give a warning to farm caretakers about the possible invasion of disease and pest regarding environmental factors. Since these harmful organisms have a specific set of factors to become booming, we decide to apply sensors to detect environmental factors of the tamarind fields for the more precise alert. Thus, the alert will be activated and informed to users when the environmental factors are matched to the pre-defined rule set based on farming knowledge.

A detail on the chosen sensor types to detect environmental factors is related to the knowledge of tamarind farm management about a chance for suitable environments of disease and pest booming. In this work, four types of sensor as shown in Table IV are selected for obtaining the different factors in a tamarind farm.

The outputs of the sensors are then stored in a database which is mapped to the ontology. These values are then sent to the ontological rule matching modules, and if matched, the alert is triggered and informed to the farm caretakers. The ontological rules in this work are the production rule in which contents of the 'condition part' are the classes and values of a property in the designed ontology while the 'result part' is the instances linked to the class in the Harmful Organism tree. In representation, the ontological production rule is defined as follow.

IF {condition_1 and condition_2 and … condition_n } THEN {result}

The result part is triggered only if all the conditions are matched. In the condition part, the assigned operation depends on the type of ontological relation. For part-of relation and string data type of an attribute-of relation, exact and partial string-matching is allowed. The integer-based attribute-of relation however allows basic mathematic operations including greater than, less then, equal to, in between to match up property value. The rules to activate alerts are exemplified in Table V.

The rules are obtained by extracting knowledge from publications and guidelines from Department of Agricultural Extension, Thailand. For example, details of the 'powdery mildew disease' are extracted from [9-10, 18-19, 22-23], and information of 'cockchafer' (Holotrichia sp.) is from [11, 18-20]. The rules then are reviewed and approved by tamarind experts.

TABLE IV
EMPLOYED SENSORS AND THEIR DETAILS

Sensor Type	Measuring unit	Environmental Factor	Duration / Frequency of detection	Employing Area
Non-contact temperature sensor	Celsius (°c)	Air temperature	Hourly	Located in a field
Non-contact humidity sensor	Percentage (%)	Air relative humidity	Hourly	Located in a field
Sunlight sensor	Minute	Daytime period	Continuously	Located near the field
Rain gauges and precipitation Sensors	Millimetre	Frequency and amount of rainfall	Daily	Located near the field

TABLE V
THE ONTOLOGICAL PRODUCTION RULE

Rule	Condition part	Result part
1	Humidity ≥80% & Rainfall ≥ 100 mm.	pod rot disease (Phomopsis sp.)
2	Humidity greater than or equal to 70% & Daytime ≥ 13 hours	powdery mildew disease
3	Rainfall <30 mm. & average temperature at night <20 °c	Butterfly larvae
4	average temperature at day time ≥ 33 °c & Daytime > 12 hours	cockchafer (Holotrichia sp.)

2) Information Providing Service

This service provides information related to harmful organisms. The information is a text-based content for users to read as a guideline in tamarind farming. This service is expected to be an additional knowledge provision to users to be aware of harmful organisms that may possibly occur extraordinarily outside of their prevalent season. There are two functions in this service: general information for browsing and specific information regarding alert.

For the former, users can browse descriptive information based on ontology concepts by navigating through the network of the developed ontology. The content in which is stored in attribute-of relation explains the details of the class. For instance, the symptom relation (attribute-of relation of the class 'Disease') of the ontology gives a detail of how the symptom of the disease is and which part of a tree to be noticed.

For the specific information regarding the Alert service, the information of the alerted objected is retrieved from the ontology and given to the farm caretakers. This includes the method or solution to handle the alerted issue such as how to cure a disease or to prevent spreading of a disease. This part of the service is designed to help farm caretakers to swiftly handle the situation before the tamarind fruits are damaged.

IV. EVALUATION

To evaluate the proposed framework, we set up two experiments. The first experiment is to evaluate the designed Tamarind Management Ontology and its accompanied production rules. This evaluation is to ascertain the quality of our knowledge base regarding knowledge engineering and domain knowledge. The second experiment is to evaluate the results of the framework. By comparing the Alert service with a decision of farm caretakers, we can see that the knowledge provided in the ontology is resemble to tacit knowledge of farm experts or not.

A. Ontology Evaluation

In this evaluation, 5 ontology experts were asked to assess the designed ontology and its rule set. They were asked to answer the questionnaire regarding quality of the ontology. The questionnaire is in Likert scale [44] in which 5 is 'totally agree' to 1 refers to totally disagree. There are 6 quality aspects as given in Table 6. The evaluation result in average from 5 experts is shown in Figure 3.

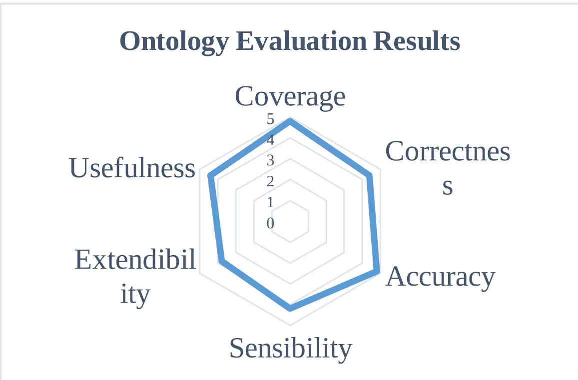

Figure 3. Average Evaluation Results on Quality of the Ontology in 6 Aspects

The results show that ontology experts agreed that the ontology is in high quality, especially for both coverage and accuracy of ontological relations for the average of 4.8 score. It is noticeable that the experts gave the lowest score as 3.8 to extendibility quality. From interviewing, they mentioned that the concepts in the ontology are too specific for the application and should need some editions for extending to other knowledge; for instance, there are other types of pests for other plants, and the cultivation phases for other plants may be different. Some of the experts also added that we should consider the different type of farmland (uphill and forest area) in the future to make the ontology more flexible to users' various farm setting.

TABLE VI
ASPECTS FOR EVALUATING THE DESIGNED ONTOLOGY

Ontology quality aspects to be evaluated	Description
Coverage regarding the scope of the work	To evaluate the given classes and scope of this work
Correctness of contents	To evaluate the ontology classes and relation among classes regarding the domain knowledge
Accuracy of ontological relations	To evaluate the ontological structure in terms of ontology design and semantic representation
Sensibility of chosen terms	To evaluate the terms (in Thai) chosen to represent class and relation name
Extendibility of the ontology	To evaluate the overall design in case of extendibility for other usages including extension to other fruits and extension for handling another issue of tamarind farming
Usefulness of the ontology	To evaluate the usability of the ontology in the designed application

B. Application Result Evaluation

In this section, we tried to evaluate the practical use of the proposed framework. The focused service in this experiment was the Alert service in which took the real-time data from deployed sensors and made decision regarding ontological rules.

In this experiment, we set up the system as explained in Section 3 in three voluntary tamarind farms. All farms had cultivated for tamarind fruits at least 5 years, and the farm caretakers were an experienced farmer. The period of the experiment was 120 days for each farm around April to July, 2019. The automatically generated alerts of disease and insect invasion occurred in the farms were counted and compared with farm caretakers' expectation or happening of the invasion of disease and insect. The measurements in this evaluation are precision (P), recall (R) and f-measure (F1) [45] with the count criterion as follows.

- True Positive (TP): alert is given and there is actual invasion within 2 days or caretakers expect the invasion.

- False Positive (FP): alert is given but there is no actual invasion within 2 days or caretakers do not expect the invasion.

- False Negative (FN): alert is not given but there is actual invasion within 2 days or caretakers expect the invasion.

In calculation of P, R and F1, we use (1), (2), and (3), respectively. The results are then separated into cases of disease and insect invasion, and they are given in Table VII.

$$P = \frac{TP}{TP+FP} \quad (1)$$

$$R = \frac{TP}{TP+FN} \quad (2)$$

$$F1 = 2\,\frac{P \cdot R}{P+R} \quad (3)$$

The ratio of all incidents of all experimented farms was 13:40 while the alerts were triggered for 14:47 for disease cases and insect cases respectively. From the results, we notice that the alerts on diseases obtained the high score in both precision and recall. In the other hand, the alerts of insects suffered from lower precision score as 0.79 in average since there were many false positive cases. However, the framework received a satisfying high recall in overall average for 0.97 score. This indicates that the alerts could cover most of the invasion cases in practical.

In an attempt to analyze the false alerts, especially the insect cases, we interviewed farm caretakers about it. We learned that these farms had applied on organic pesticide made by natural products beforehand. This effectively prevented the invasion of certain insects and thus made the system to false alarm on insect invasion. They also mentioned that unless they applied such pesticide, the alerted insects may occur in their farm.

By asking the participants about other services aside of the experimented Alert service, they mentioned on lacking of the service to help them in fertilization and soil management. Additionally, they mentioned that there were other invaded insects and animals in which are local pest differently based on their area and yet included in the system.

TABLE VII
EVALUATION RESULTS IN PRECISION, RECALL AND F-MEASURE OF THE PROPOSED FRAMEWORK

Farm ID	Disease			Insect			All		
	P	R	F1	P	R	F1	P	R	F1
A	1.00	1.00	1.00	0.76	1.00	0.87	0.80	1.00	0.89
B	1.00	1.00	1.00	0.73	0.92	0.81	0.79	0.94	0.86
C	0.86	1.00	0.92	0.87	0.93	0.90	0.86	0.95	0.90
Average	0.95	1.00	0.98	0.79	0.95	0.86	0.85	0.97	0.91

V. CONCLUSION AND FUTURE WORK

Smart farming has been in need to support Thai agriculture to improve their productivity, especially the products of locals. This work presents a method to combine the intelligence of farm caring and the detection of real-time data for supporting tamarind farming which is the major products of Phetchabun, Thailand. The use of ontology representation for collecting related information in handling invasion of pest and disease along with its inference rule makes the framework able to make rational decision similar to human thinking. Sensors are deployed to obtain real-time data of climate factors for precise information in individual farms. By combining both, intelligence and precision could be yielded for smart farming towards tamarind cultivation. From the evaluation, the designed ontology received an approve for coverage regarding the scope of the work, accuracy of ontological relations and correctness of contents. In the experiment in practical use, the framework obtained an impressive recall and f-measure score in overall average for 0.97 and 0.91, respectively. The result also shows that the framework performed the best in alerting for disease invasion.

In the future, we plan to extend the framework to cover farming of other plants including macadamia and rice by extending the developed ontology. Moreover, we will apply knowledge of fertilizing and soil management into the framework for coverage of cultivation process. In addition, we plan to deploy the systems to other tamarind farms in the area to facilitate their productivity.

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(Arranged in the order of citation in the same fashion as the case of Footnotes.)

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