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Framework for Intelligent Early Warning Systems of Crop Diseases

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ABSTRACT

The Early Warning System (EWS) is a critical tool for efficiently preventing hazards in agricultural productivity, as well as pests and illnesses. Early detection of plant diseases helps in increasing crop yields and decreasing losses. EWS can acquire relevant and timely information in areas where this information or data is unavailable. This paper presents a framework aimed to warning farmers of the expected crop diseases that might affect their crops. It will support a timely recommendation for the appropriate agriculture practices directed towards correct farm management. The proposed framework objective is to design a model for utilizing weather forecasting and domain knowledge that is related to the effect of weather on plant diseases. The framework output depends on the integration of weather data, which might affect crop diseases and farmers' databases that include farmers' locations and cultivated crops. Furthermore, it will enable agriculture extension agents to communicate with farmers and provide them with advices about weather data and how to deal with it to preserve crops and increase yields.

Key words: Early warning system, knowledge base, Crop diseases.

1. INTRODUCTION

Climate change would have a significant impact on food supply that is required to mitigate population increase [1-4], it also has an effect on pests and diseases [5- 8]. Controlling and directing the effects of pests and diseases in farming is a major challenge. A notion known as "smart farming" has emerged in modern agriculture [9, 10], which involves the large incorporation of advanced technologies of information and communications into farming practices, has been developed and applied as a new method for crop management and decision making [9, 11]. Climate monitoring and EWS are necessary for crop disease management since there is a strong relationship between climate variables and the nature of spread, incidence and severity of diseases on plants.

Farmers should adopt EWS in their strategies for monitoring and managing their farms, this system helps them make the right decision to protect their crops from climate change variables that affects crop production. Early Warning is "the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response" [12]. According to the United Nations' International Strategy for Disaster Reduction (ISDR) [13], it integrates four main elements for the Early Warning Systems:

a) Risk Knowledge: specifies all sources of hazards and provide proactive procedures to mitigate the potential effects of hazards.
b) Monitoring and predicting: To generate precise warnings in a timely manner, continuous monitoring of hazard factors and precursors is required. Wherever practical, warning services for various dangers should be coordinated to take advantage of shared institutional, procedural, and communication networks.
c) Dissemination and communication: Warnings must offer clear, helpful information that facilitates suitable reactions in order for people to understand them. To ensure that everyone gets reached and to prevent any one route from failing, many communication routes must be employed, in addition to enhance the warning message.
d) Response capability: The general population must also be informed of the warning system and how to respond to notifications. Disaster management authorities must lead organized education and preparation programs in order to achieve this.

In the majority of developing countries, weather stations are very expensive for the prevalent use of small farmers and their systems are closed, and cannot be connected to the internet to visualize in real-time under a web page or mobile application.

There are various definitions of EWS however; most of them contain components related to detecting potential risks, notifying persons concerned about the risks, and assisting them in needed actions to decrease harm [14, 15]. EWS is typically administered as a national service, with distribution occurring in a chain from regional to local managerial units, and finally to end-users. Effective EWS according to Glantz [16] is a system that consists of monitoring and forecasting that are linked to communication systems and reaction plans.

Zhu *et al*. [17] used WebGIS technology to construct a monitoring and EWS system for porcine pasteurellosis, resulting in a new technique for the prevention and control of porcine pasteurellosis. Ramírez-Gila *et al*. [18] designed a cheap electronic device for gathering and wireless transmission of climatic data, they developed a mobile application with EWS for avocado wilt complex disease to advise farmers of the appropriate land practices in farm avocado wilt complex disease management. Liu *et al*. [19] introduced a new approach that predict the greenhouse indoor climate 72 hours ahead and used it as input to the disease prediction model for detecting the presence of disease as early as likely.

Global information and EWS (GIEWS) was founded in the early 1970s. It is regarded as one of the first significant global sources of information on food production and food security within the Food and Agriculture Organization (FAO). The system supplies usual bulletins of food crop production and markets on an all-encompassing scale, in addition to more specific regional reports based on intelligence from FAO's regional and country offices. In 2011 GIEWS utilized the Agricultural Stress Index (ASI) as a mark for early labeling of agricultural areas that may be affected by droughts or dry spells [20]. The ASI system generates a map every ten days that depicts regions where water stress affects crops throughout the growing season, which are then evaluated by data from public organizations or using agrometeorological models based on data received from national meteorological networks, resulting in indicator convergence [21].

Andersson *et al*. [22] investigated the ability of a local participatory EWS to improve smallholder farmers' drought preparedness. In order to suit farmers' needs, the EWS concentrated on forecasting hydrological variables such as rainfall to represent meteorological drought, soil moisture to represent agricultural drought, and streamflow to represent hydrological drought. Fall and Carisse [23] built a model that can anticipate strawberry powdery mildew intensity, alarms, and action thresholds to fine-tune the strategies of fungicide application considering some weather parameters. Furthermore, the model can be utilized as a research tool to verify agricultural practices.

The objective of the proposed framework is to design a model for utilizing weather forecasting and domain knowledge that is related to the effect of weather on plant diseases. Hence, it will support a timely recommendation for the appropriate agriculture practices directed towards correct farm management.

2. THE EARLY WARNING SYSTEM FRAMEWORK

The proposed framework integrates between knowledge base of the effect of weather data on the appearance of crop diseases and a farmer database that includes farmer locations and cultivated crops. Further, it has a communication module for sending recommendations for farmers as short messages. The knowledge engineer will collect knowledge from the domain experts in agriculture. For each crop included in the system, the knowledge about the effects of weather data on the vulnerability of diseases will be collected. The knowledge will be represented using rule-based approaches. Figure 1 shows a sample of rules that are part of the knowledge.

Rule 1
If (27< Max-temperature < 35) and humidity >65 and month (5 or 6) then
(crop=potato and predicted disease="Stem Rust")
Rule 2
If (27< Max-temperature < 30) and humidity >50 and month (3 or 4) then
(crop=potato and predicted disease="Stem Rust ")
Rule 3
If (27< Max-temperature < 35) and humidity >65 and month (5 or 6) then
(crop=potato and predicted disease="Stem Rust" if plantation-date (15-20/1))

Figure 1: Sample of the rules that represent knowledge.

The proposed framework will support different scenarios:

1- If the agricultural extension agent or farmer inputs predicted weather data manually, the expert system will match the weather data and the knowledge base then it will display the predicted diseases and their correlated crops.

2- In another scenario, the system will get the predicted weather data automatically through web service from weather forecasting providers Application Programming Interface (API) as shown in Figure 2. Based on the recommendation of the domain expert the system will fetch the new weather data every period of time. The system will search for existing knowledge and predict possible diseases. It will alert the registered farmers with the predicted diseases. In addition, it will send the extension advices for farmers to take proactive procedures to mitigate the effect of the potential diseases.

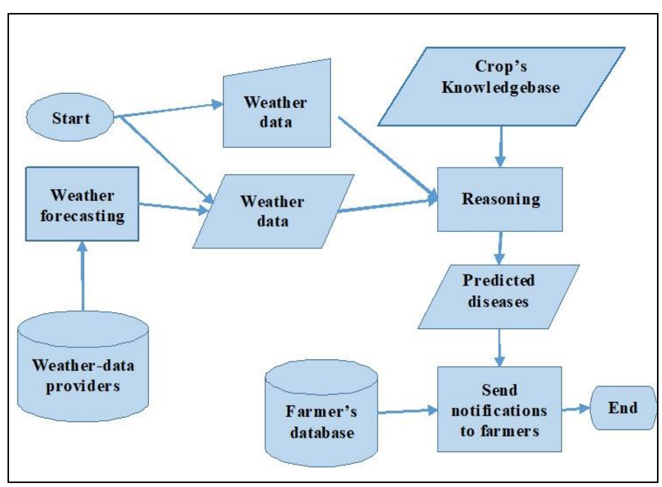

Figure 2: Flow chart of the proposed early warning system.

3. METHODOLOGIES

The inputs of the proposed framework will be the knowledge of crop diseases, farmer's database, and weather data, while the outputs will be the predicted diseases, and extension advice. The main processes are:

- Building a database for farmers.
- Building a knowledge base for crops.
- Building inference to take weather data and the knowledge base of the predicted diseases.
- Using web service API to send messages to the farmers.

3.1 Building a database for farmers

The first step is building a database for farmers, it will include farmers' names and contact data (mobile number, email, address including governorate, district, and village). Also, the database will include information about cultivated crops (crop name, plantation date). We built a prototype web-based and mobile application that enables the farmers to register and avail their data such as full name, phone number, governorate, district, village, and crops.

3.2 Building a knowledge base for crops

The knowledge will be represented as a rule base. The knowledge engineer will acquire knowledge from the domain expert and enter it into the knowledge base. The knowledge engineer will collect climatic data that causes diseases specific to a crop, as well as instructions on how to deal with the diseases. In the proposed system the rules will be stored in a database. We will use database queries to search the knowledge base and predict the diseases. The design of the database that stores the knowledge is displayed in Figure 3.

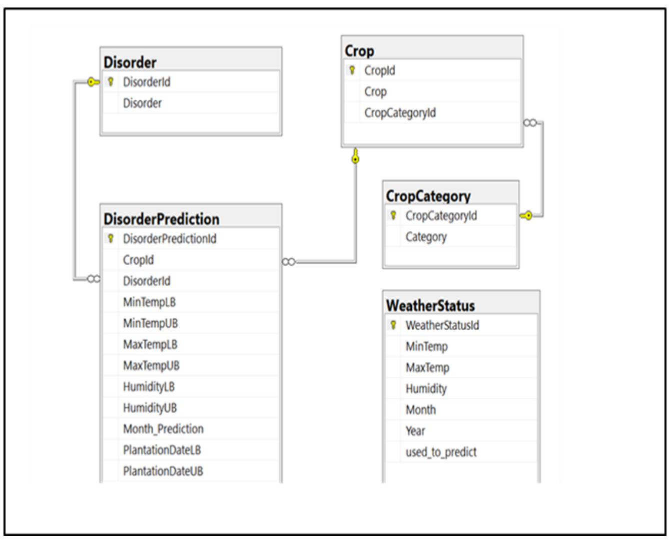

Figure 3: Database design for the knowledge representation.

The DisorderPrediction table is the main table to store the knowledge rules. Each rule will be stored as a record in the table. The DisorderPrediction table has the following fields:

1. DisorderPredictionId is the primary key of the table and it is an identity field.
2. CropId is a foreign key for the table crop; it refers to the crop that is related to the rule.
3. DisorderId is a foreign key for the table disorder; it refers to the disease that is related to the rule.
4. Month_Prediction to store the prediction month that fits the rule.
5. MinTempLB to store the lower value of the minimum temperature that fits the rule.
6. MinTempUB to store the upper value of the minimum temperature that fits the rule. For example, when rule condition has part (If (10< Min-temperature < 15)), we will store 10 in MinTempLB and 15 in MinTempUB.
7. MaxTempLB to store the lower value of the maximum temperature that fits the rule.
8. MaxTempUB to store the upper value of the maximum temperature that fits the rule.
9. HumidityLB to store the lower value of the humidity that fits the rule.
10. HumidityUB to store the upper value of the humidity that fits the rule.
11. PlantationDateLB to store the lower value of the plantation date that fits the rule.
12. PlantationDateUB to store the upper value of the plantation date that fits the rule.

In case there are other weather parameters like wind speed we shall add two fields to store lower and upper bound.

The WeatherStatus table is used to store the predicted weather data. The main fields are:

1. MinTemp to store the predicted minimum temperature.
2. MaxTemp to store the predicted minimum temperature.
3. Humidity to store the predicted Humidity.
4. Month to store the month of data.
5. Year to store the year of data.

3.3 Building inference

The main idea of the inference is to use SQL query to select the knowledge which are related to the given month and weather data. In order to fire a specific rule, the rule condition is checked. For example, if the rule conditions include minimum temperature like (If (10<= Min-temperature <= 15)), the part of the query that will fire it will be:
'and ((MinTempLB <= minTemp) or (MinTempLB IS NULL))
and ((MinTempUB >= minTemp) or (MinTempUB IS NULL))', MinTemp is the given minimum temperature. The value on MinTempLB is 10, and the value of MinTempUB is 15.

The or part 'or ((MinTempLB IS NULL))' is used for handling the case when the rule condition does not include minimum temperature. All other weather data such as maximum temperature and humidity will be handled in the same way.

The "ViewDisorderPrediction" is a database view that retrieves data from tables that are related to the knowledge base. The query engine of the Microsoft SQL server was adopted to parse the knowledge base. Figure 4 shows the query structure. When the query will be executed the rules that match the query will be fired and retrieve the predicted diseases.

```
SELECT DISTINCT Crop, Disorder, PlantationDateLB,PlantationDateUB FROM
dbo.ViewDisorderPrediction WHERE (
        Month_Prediction= Month
        and ((MinTempLB <= minTemp) or (MinTempLB IS NULL))
        and ((MinTempUB >= minTemp )) or (MinTempUB IS NULL))

        and ((MaxTempLB <= maxTemp) or (MaxTempLB IS NULL))
        and ((MaxTempUB >= maxTemp)) or (MaxTempUB IS NULL))

        and ((HumidityLB <= Humidity) or (HumidityLB IS NULL))
        and ((HumidityUB >= Humidity)) or (HumidityUB IS NULL))
)
```

Figure 4: Inference selection query.

3.4 Using web service API to send messages to the farmers

The expert system will give the administrator more power by displaying the diseases that are expected and the best practices for controlling them based on meteorological data. Currently, the administrator manually feeds weather data to the expert systems, and he can issue notifications and contact farmers who have enrolled. In the next phase, all things could be executed automatically. The system will be run on the server and it will check periodically for any received weather data, the prediction period will be specified based on the domain experts. The system will receive the weather data from the weather forecasting API, after that the system will predict diseases and send messages to the farmers who planted crops that are related to the predicted diseases using the short message service API.

4. CASE STUDY FOR APPLYING THE PROPOSED FRAMEWORK

As part of applying the proposed framework, a climatic Early Warning System (CEWS) has been developed. CEWS is a web-based information system that aims to help farmers to mitigate the effects of climate change, in addition, to providing farmers with immediate extension recommendations.

The main components of CEWS:

- Farmers' database that contains contact data of farmers who belong to the selected regions of the Sustainable Agriculture Investments and Livelihoods Project (SAIL). Further, the database will include other information such as farmland area, summer crop, and winter crop.
- Early warning system messages component to send recommendations to the farmers. Also, it displays more details and messages on the website.
- The expert system component aims to transfer expert knowledge to farmers and newly graduated agriculture engineers. In the preliminary version, it acquired the knowledge related to the effect of weather conditions on the vulnerability of appearing plant diseases. In the future, we plan to associate with each disease the proactive procedures that prevent it and mitigate its effects.

Figure 5 shows the expert system screen, the end-user has to specify the month and he can specify weather data such as minimum temperature, maximum temperature, and humidity. According to the end-user inputs, the system will display the expected plant diseases.

Figure 5: Expert system screen for disease prediction.

Also, EWS enables farmers to ask questions and get more details about the effect of weather data on different diseases. Currently, partial knowledge of potatoes and garlic has been acquired. In the future, we can add more crops' knowledge to cover most of the important crops cultivated in Egypt to help farmers control, manage and prepare the right treatment for crops' diseases in an effective way that could save the yields and increase them. It is worth mentioning that such a monitoring system is not limited to disease control but can also be used in the other agriculture applications like determining the best cultivation date, pest control, and precise irrigation.

6. CONCLUSION

This paper introduced a framework for plant diseases early warning system. It aims to help farmers to protect their crops against diseases. It tries to mitigate the effect of diseases that are caused due to weather conditions and climate change. The framework has a knowledge base component to hold knowledge of weather data such as humidity, minimum and maximum temperatures, and vulnerability to plant diseases. The developed expert system helps farmers and any agriculture specialist to enter weather data then predict the effect of it on the appearance of the diseases at the selected month. Also, the framework enables administrator to collect data about the farmers and the cultivated crops and facilitate delivering of best agriculture practices to them. For future work, a study of the possibilities of sending early warning messages automatically based on weather data needs to be conducted and evaluated by farmers.

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