CHEMICAL ENGINEERING TRANSACTIONS

VOL. 58, 2017

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216

DOI: 10.3303/CET1758104

Planthology: an Application System for Plant Diseases Management

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The goals of modern agriculture are obtaining high yields that meet the increasing nutritional requirements of the World population. This is extremely difficult for three kind of reasons: i) the lands dedicated to agricultural use are strongly reduced in industrialized Countries; ii) farmers prefer an homogeneous product, because it is easier to manage, with consequent reduction of biodiversity, iii) globalization and climate change have led to the introduction of new pathogens and pest in environments other than original ones, resulting in serious production losses. The consequences of these problems, followed by not timely intervention leads to conditions that make not possible to obtain any kind of profit. In this work, we present an application system for remote plant diseases management. The system is based on the availability of a panel of expert plant pathologists that will be able to remotely diagnose diseases in plants, allowing the possibility of monitoring distinct areas or farms at the same time. Three modules mainly compose this system: (i) the *planthology server* (ii) the *planthology mobile application* (ii) the *planthology web application*. The planthology server represents the back-end core of all the Planthology system. The mobile application is designed for the agronomists involved in farm management. Each one of them will be able to provide a generic case study with the observed symptoms, including from 1 to 5 geo-referenced photos of the case, adding also treatments carried out in the crops grown in the farmer. The web application is for the expert pathologists, and allows them to make diagnosis observing images and data provided to the system by the farms. The collected and validated case studies will feed a *dynamic* atlas of plant diseases that could contribute to the global dissemination of knowledge of the symptoms inducted by plant diseases. The mobile and web applications exchange information in a bidirectional way: the user provides the case and the expert pathologists provide a therapy, and eventually requesting other kind of information.

1. Introduction

In the last decade, emerging plant diseases have been reported worldwide and caused considerable economical losses. For example, in Italy, several virus diseases such as Citrus tristeza virus (Davino et al. 2013), Tomato yellow leaf culr virus (Davino et al., 2012), Pepino mosaic virus (Davino et al., 2017), the emergence of Fabaviruses (Panno et al., 2014) and the recrudescence of Tomato mosaic virus and Tomato spotted wilt virus (Panno et al., 2012) have a considerable impact on productions, bringing farmers to change crop or to renounce farming activity. When conditions are optimal for pathongens, losses in yield can be computed from 60 to 70% and up. Symptoms of diseases may range from spotting on leaves, necrosis, to the complete withering of the plant, with corresponding impacts on photosynthesis and production. In other cases, fruit lesions and necrosis disfigure or reduce the marketability of the products. Various aspects of epidemiology of the disease caused by pathogen are relatively well understood, but, many time, not efficient method is available to control the diseases (Whitehead et al. 2002).
The international trade could hide in the future increasing risks due to the introduction of new emergent pest and diseases with a consequent great negative impact in the agriculture and environmental sustainability, as

Please cite this article as: Davino S., Panno S., Arrigo M., La Rocca M., Caruso A.G., Lo Bosco G., 2017, Planthology: an application system for plant diseases management, Chemical Engineering Transactions, 58, 619-624 DOI: 10.3303/CET1758104

has happened in the past with the worldwide spread of Citrus tristeza virus (Davino et al., 2013) or viral diseases of tomato (Hassen et al., 2010). For these reasons, is fundamental to develop new strategies for plant diseases control. In this context, the development of an application system for remote plant diseases management can be useful in order to early intervene for the containment of the diseases. In this work we propose a system that could help in this issue. In the following sections we will describe how our system works, describing its main functionalities and implementations.

2. Materials and Methods

The *Planthology application system* can be considered as composed by three main software modules: The *Planthology Server*, the *Planthology WebApp* and the *Planthology MobileApp*. A diagram showing the organization of these three main software system components is shown in Figure 1. Note that our system is actually in a prototype phase and the WebApp is already publicly available in http://www.planthology.org.

2.1 The Planthology Server

The modern trend in the software development is to create *cloud-native* applications. *Cloud Computing* is a relative new technology model that allows the development of an application without worries about the underlying physical infrastructure. Actually, it is possible to rent by a public *Internet Cloud Service Provider*, a physical and/or virtual computing system with a certain amount of computing power, memory, network bandwidth and data storage space at a reasonably cost, in order to install the basic software ecosystem that will host the developed application. This kind of available service is named *Infrastructure as A Service* (IAAS for short). IAAS leads to a lot of benefits, whose the most relevant is the possibility to implement a generic application without the need to purchase any physical computing system, avoiding worries about its possible failures and breakdowns. Furthermore IAAS allows the use of *on-demand* resources and *easy scalability* as the application grows (Cloud Standards Customer Council , 2016). For the development of our system, we decided to rent the minimal resources needed for our application from a *Cloud service provider*. Afterwards, we have installed a free operating system (Centos 7, a Linux free and community distribution derivate from the Red Hat Enterprise Linux commercial distribution) and all the basic software required by the Planthology application system. The back-end core of all the Planthology system is the Planthology Server, implemented using the *Java* programming language. It's main purpose is to provide accessible services and functionality across standard interfaces and protocols (*Http Secure*, *Web Socket*, *Web Services* and *REST*) to the front-end counterparts, i.e. the Planthology WebApp and the Planthology MobileApp*.* The whole back-end part of Planthology is developed using the *Java Enterprise Edition*(*Java EE* for short) technologies to build all the main functionalities of the system, such as persistence of data on the database, images storage in the *file repository* and communication with WebApp and MobileApp. Figure 1 resumes all the subset of Java EE technologies used to build the system. The hearth of the back-end is represented by *Wildfly*, an application server full compliant with Java EE specification. It provides a framework that allows to easily manage many aspects of the application. In details, it supports long time persistence of data and information using a database and a file repository. Moreover, it makes possible the delivery over http or http-secure protocols of web pages containing static and dynamic contents such as images and information based on user request. Finally, it allows communications with mobile devices using Web Socket, REST and *JSON* Web Services to provide full-duplex communication between backend infrastructure and mobile devices. Note that we have not underestimated the security aspects of the application. The communication between the server and the different client applications (web and mobile) are encrypted using the HTTP-Secure protocol which ensures data confidentiality during the connections. In addition, we use an authentication module that permits identity and access management of the user in the system. We provide this functionality using *Keycloak Server*, a module embeddable into Wildfly that facilitates the development of all the aspects related to user authentication and authorization. Moreover, Keycloak allows to assign a role to each user in order to protect the access on the resources of the application. Orchestrating all this technologies, the Planthology Server allows the collection of inhomogeneous type of information, like images or textual data provided by common user and expert pathologists across the Web App and Mobile App. Such kind of data are organized into a general catalogue, organized in three main categories: *diseases*, *plants* and *pathogens* (figure 2 left). This may help expert pathologists to better visualize the information in order to formulate insights and diagnosis. Additionally, for the same purpose, common user can easily access the responses provided by pathologists.

2.2 The Planthology Web Application

The Web App (hosted on a public cloud server provider and reachable at the address http://www.planthology.org) represents the front-end of the Planthology System. It is designed for two kind of different user categories: *expert pathologists* and *common web users*.

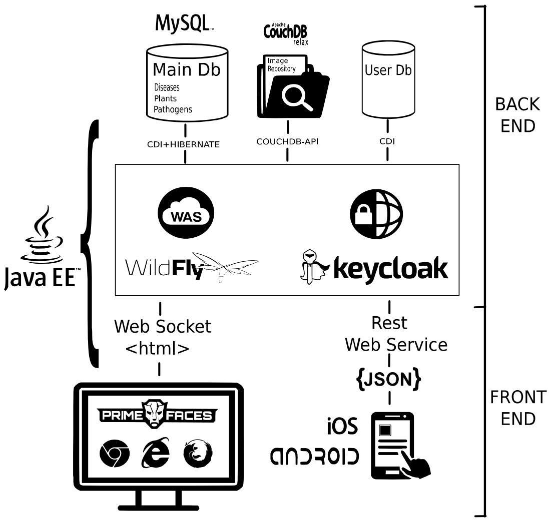

Figure 1: The Overall System

The user interface is implemented by using the *Primefaces Framework*, one of the most popular *User Interface components library* in Java ecosystem. The Web App supports the expert pathologists in the creation of atlas of pathogens, plants and diseases in which they can put all the data and information resulting from previous researches or laboratory experiments.

Figure 2: Three screenshots of the Web application: (Left) Main page, (Middle) A case submitted by the Mobile App, (Right) An example of search using a set of plants as key.

It is possible, for instance, to categorize a pathogen (*viroid*, *virus*, *phytoplasma*, *bacteria*, *fungi*) in the atlas, adding also a textual description and some images. Furthermore, it is possible to add well know diseases, supplying them with a lots of information about plants affected by the disease, related pathogens, as well as information about symptoms and therapy. The Web App give also support in the visualization of the cases provided and submitted by the users by the mobile application (figure 2 middle). This allows the pathologists to watch for the cases submitted by the users, for the final purpose of annotation. To this issue, pathologists make use of their personal knowledge and experience, and take advantage of continuously fed atlas of diseases, plants and pathogens that can be efficiently explored by special search and filtering facilities (figure 2 right). In the eventuality that a case similar to the one that is going to be submitted is present, suggestions about the possible countermeasures, therapies and treatments are immediately available. The new information provided by the user, after the validation by the pathologists, potentially enrich the atlas. We provide the previous functionality distinguishing the following three application roles for the users, using the authentication module Keycloak. This allows to control and restrict the data and resource access by assigning them different roles: *administrator* , that can manage all the resources, contents and users of the application, *pathologist* that can validate the user case studies and insert, update and delete the content of the atlas and finally *basic user* that can submit case studies from the MobileApp, view the status of their case and only read the content of the atlas. This role must be assigned manually by the administrator after the user registers and her email address is verified. Also the administrator can change or revoke the a role previously assigned and delete a user from the application. All this functionality are provided across the keycloak module.

2.3 The Planthology Mobile Application

The widespread use of mobile technology is changing the way people interact with content and their surroundings. In fact, sensors that are always on and mobile devices have been used more often to monitor activities in everyday life, collecting data about user behavior, suggest services and supporting people on the job. On the other hand, as reported by StatCounter (2016), in their Global stats, in 2016 mobile and tablet internet usage exceeds desktop for first time worldwide. Innovative and ever more powerful mobile information communication technologies continue to emerge and become widely available. In addition to these studies, according to the NMC Horizon report (Adams Becker *et al*., 2017), analyzing recent research on emerging education technologies emphasized that mobile technologies will have a significant impact on learning and instruction in the near future (one year or less). Likewise, the pervasiveness of mobile devices, along with the availability of efficient mobile broadband connections, offers a unique opportunity to develop innovative methods of learning, collaborating, supporting workers on the job, as well as to develop policies aimed at participation, given that the use of mobile devices transcends age, social status, economic level, gender and ethnic origins (Arrigo et al., 2013). This trend offer new opportunities for specialist distant consulting, new application scenarios are opening up. In this paper we focus on learning on the job, as well as supporting agronomists involved in farm management, by a mobile platform that involve a set of plant pathologists for the remote diagnosis of plant diseases and providing a therapy. In particular,the mobile app (developed for iOS and Android devices) works in conjunction with the planthology server as well as the Web App. Specifically, the planthology system has been developed using a client server architecture. As described in the Figure 1, the planthology mobile app communicates with the server module using some JSON webservices. As mentioned in the previous paragraph, the planthology server implements a set of json webservices to allow the interaction of the mobile client module with the server and the web app. The planthology mobile app gives users the possibility, by their mobile device, to submit a study case to the expert pathologists in order to have a therapy; access the on-line case study list; browse an atlas of plant diseases directly. In this way, users have a valuable tool to receive remote diagnosis of diseases in their plants anytime, anywhere and, above all, also contribute to the global dissemination of knowledge of the symptoms inducted by plant disease. All communications between server and mobile clients are secured with username/password and, for privacy reasons using Secure Socket Layer (SSL). Moreover, the system use standard protocol to exchange information like JSON, REST and HTTPs. When the application starts, there is a login view, to identify the user on the planthology server; once logged in, the user can access the atlas of plant diseases, the list of own case studies and a geo-localization of submitted case studies. Specifically, in the ***Atlas of plant diseases*****,** a list of plants is shown with a photo (see first three figures from the left in figure 3), name and number of validate case studies for that plant. Then, if the user select one of them (a plant) s/he will have a list of all analysed cases; thus, for each case, all the information about *plants affected*, *pathogens* , *symptoms, diagnosis, therapy, location* and a set of *photos* is shown.

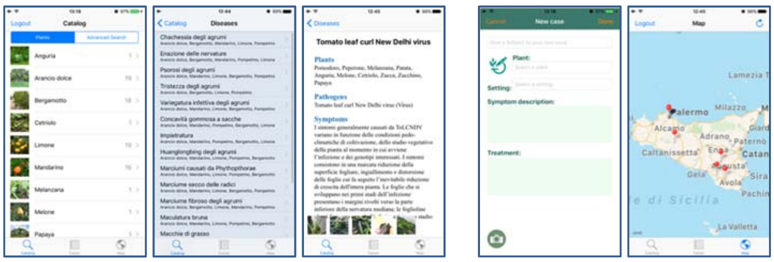

Figure 3: (First three figures from the left) Atlas of plant diseases in the mobile app, (Last two figures from the left) Case studies in the mobile app.

This information is validated and provided by expert pathologists .Furthermore, in the ***Case studies***, the user can see all case studies s/he has sent for consulting, cases ready for send (case studies elaborated but not yet sent) or elaborate a new case study. As you can see in the last ttwo figures of figure 3, in order to submit a new case study, the user has to provide a *title*, *plant name*, *setting* (*Indoor*, *Landscape*, *Garden*, *Greenhose*, *Farm*, *Forest*) *symptom description*, *treatment description*, *case photos* (taking photos from 1 to 5). Finally, s/he can decide to send the new case immediately to the expert pathologists or save it for further editing. However, automatically, all the created case studies, are associated with a geographical location (using data from the *GPS* of mobile devices). In this way it is possible to track plant diseases throughout users' contribute, following the traces they leave during the daily activities. The location info are finally shown in the map section where the user can see a map distribution of all provided case studies.

Figure 4: Cintrage troyer rootstock with severe symptoms of flaking (panel A) and redness (panel B) probably due to Citrus exocortis viroid (CEVd)and dwarfism in orange old trees (Panel C and D).

3.Case study

A case study for the early identification of one disease was carried out. In a citrus grove, located in Catania Province (Figure 4), an operator with a smartphone on which the Planthology Mobile Application was installed, opened a new case: the first operation carried out to create a new case of study was *REQUEST A DIAGNOSIS*". Subsequently was created a *SUBJECT* category and was compiled the following data: *PLANTS: Citrus; SYMPTOMS DESCRIPTION: "The symptoms observed are: peeling bark, accompanied by dwarfism. Plants shown cracks in the bark, epinasty of leaves, necrosis of cortical veins and very long cracks – the rootstock is Citrange"; SETTING: open field*. Thereafter was compiled the dataset TREATMENT: "NPK fertilizer-based, aphicides products, anti-fruit drop products, herbicides". Using the button SUBMIT the case was submitted to the attention of expert plant pathologists.

Once terminated the submission the application sends the following message: WAITING FOR REPLY. This means that the case has going to be examined. By the information provided by the operator regarding symptoms, dispersion in field and the rootstock conditions, the expert pathologist has examined the case by logging into the system, by using the Web App hosted in https://www.planthology.org. The pathologist had hypothesized that the most probable cause of disease was the Citrus Exocortis Viroid – CEVd, requesting as response to the case 5 samples, consisting of 10 shoots taken from symptomatic plants, previously photographed and georeferenced. Such samples has been sent to Plant Virology Laboratory of SAF Department, University of Palermo. The samples were analysed by real time RT-PCR, using a commercial kit (PlantPrint, Valencia, Spain), following the manufacturer's instructions. Results showed that all the samples were positive to CEVd with a Ct value that ranged from 28 to 33. These results confirmed the diagnosis efficiency realized by phypathologists group involved in Planthology application.

4. Conclusions

In this work we have proposed an application system for plant disease management, that allows to remotely submit a plant disease case to a panel of plant pathologists. The case is submitted by a Mobile App, starting from taking a photo of the sick plant. The case is then submitted to the attention of the expert pathologists that will give details to the submitter about the disease, eventually requesting samples, or finally suggesting a cure. We believe that the proposed system could be of great impact from several point of view. First because it gives the possibility to diagnose and eventually take place minimizing the physical intervention of the plant pathologists, with the main consequence of cost saving. Moreover, there is also a consequence from the computational point of view. It is important to point out that all the images related to the cases that will be diagnosed by the experts, could be potentially used to feed a data set of images of plants with a related plant pathology. Nowadays, the progress in the so called research field of *machine learning* have developed very effective classification algorithm that starting from annotation example, are able to learn the automatic classification of unknown case. In particular, we plan to use the so called Deep Learning neural networks to build a system that can help in the automatic discovery of plant diseases. We really believe that the annotated dataset could be used for such purpose, and we have already planned to work in this direction in the near future.

Acknowledgments

We thanks Doctor Mauro Zambito and all the staff of MZeta Web & Software (http://www.mzetaweb.it/) for the development of the Android Version of the Mobile Application Module.

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