A full integrated system for agroclimatic and pest monitoring at farm and landscape scales in Campania Region

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Abstract. The current agrometeorological monitoring of the Campania Region is both inadequate for its users and insufficient to support the simulation of pest risk models. This work describes a cyber-physical system which has been designed to overcome these limitations, with the objective of (i) automate all the tasks involved in climatic data management, including also the intervention of the human expert when appropriate, (ii) develop dependable pest risk models and provide the input data they need, and (iii) provide real-time agrometeorological data presentation. The system is built around an automatic climatic data management engine called WeatherProg, which manages data collection, quality control, data reconstruction, and digital maps production. A proper climatic database has been developed to support the operations of WeatherProg, as well as a Web application for real-time publication of data handled by the software. Pest risk models, fed by point measurements and the digital maps produced by WeatherProg, are going to be prototyped. Furthermore, a new small measurement station has been prototyped, with the aim of being low-cost and easy to relocate, in order to support the characterisation and models parameterisation for different areas. This paper illustrates the current status of the system and discusses future directions.

1. Introduction

The agrometeorological monitoring system of the Campania Region currently comprises about 35 agrometerolgical stations covering the whole territory. The technical staff in charge of the network manages by hand collected data, and publishes daily aggregations on weekly basis, although the measurements are performed at a 10-minutes time scale.

This solution is clearly unsuitable for the needs of the operators in the Campania Region, which range from agronomy professionals who support the farmers, to phytopatological experts in charge of producing pest risk bulletins for the agricultural farms in the Region. The limited number of the available stations cannot properly capture and monitor the complexity of the regional environment. Moreover, the manual management prevents the possibility of real-time delivery of agrometeorological data.

To face all these problems, a collaboration was established including an agrometeorological and pest monitoring work package within the URCoFi Executive Plan (Unit of coordination and strengthening of the activities of surveillance, research, experimentation, monitoring and
education in the phytosanitary field), which involves the Department of Agriculture of the University of Naples Federico II and the Phytosanitary Central Office of the Campania Region, amongst other partners. This work package includes also the development and execution of pest risk models for the different agroecosystems.

This work presents a cyber-physical infrastructure which has been developed to accomplish all these tasks. The core of the whole system is the WeatherProg software [1, 2], a computer program capable of performing all steps of data management, from their collection to the production of digital maps of the climatic variables of interest, which in turn are used to feed the pest risk models. Data is currently collected from the existing institutional network, but in order to monitor and characterize the microclimatic environments of the fields in which pests will be studied and monitored, a new small, low-cost, and low power consumption measurement station has been prototyped. This station has been designed to be easy to relocate, in order to enable the characterisation of pests and risk models on different areas, where different crops are produced. Finally, the data processed by the system are made available to the public by means of a web application, specifically designed to allow users to easily retrieve data of their interest.

It is worth mentioning that the human expertise is not cut off by this cyber-physical infrastructure. In fact, WeatherProg is intended to be a semi-automatic software: for instance, the ultimate decision about anomalous data is left to the intervention of the regional officers. In order to allow them to easily interact with the backend software, and to tune its parameters, a web dashboard has been designed and is going to be implemented.

2. Materials and Methods

2.1. The study area

Located in southern Italy between 13°45′E, 15°49′E, 39°59′N and 41°31′N, Campania is the third most populated region of the country, but due to its extension of about 13 600 m², it is the most densely populated region of Italy. Its inland is occupied by the Apenine Mountains, oriented roughly NW-SE, whereas the Sele and Campana plains border the coast. The Sele plain is named after the river which traverse it, while the Campana plan is traversed by the Volturno river. Nevertheless, the majority of the regional territory is hilly, for the 50% of the territory, against the 35% mountainous and the 15% flat. Consequently, the elevation ranges from 0 m to 1904 m above mean sea level.

The agrometeorological monitoring is in charge of the Agrometeorological Regional Centre (CAR) under the Department for Agriculture of the Campania Region. The station network run by the CAR includes, at the time of this writing, 34 stations spanning an elevation range from 11 m to 794 m a.m.s.l.

Not only the number of available stations is too limited to properly capture the aforementioned complexity of the regional environment, but also the equipment of these stations is highly variable. All the stations measure air temperature, rainfall and air humidity, but for 10 stations these are the only climatic parameters measured. Air pressure is measured by only 9 stations. All the 11 fundamental climatic variables are measured by at least one station in the network, but no one station is equipped to measure all the climatic variables.

2.2. The cyber-physical infrastructure

The architecture of the proposed cyber-physical infrastructure is illustrated in figure 1. The sensor networks on the territory provide input data to the system. Raw data are collected by the CAR, which sends them to the WeatherProg engine on hourly basis with a lag of one hour from the real time measurement. However, the format of the received data is not suitable for subsequent climatic operations, hence the first task of the WeatherProg software is to decode the received data, and store it in a WMO-compliant climatic data base, developed using the PostgreSQL relational DBMS [3].
Figure 1. High level architecture of the proposed cyber-physical system

WeatherProg then performs a range of quality controls to spot and flag anomalous measurements, and reconstructs both wrong and missing data. This step purposely involves some manual intervention from an human expert, in order to finally decide from the wrongness of anomalous data. In fact, apart from clear-cut correct and clear-cut wrong measurements, there is a range of suspicious cases which may or may not be correct. In such cases, rather than trying to make a guess, the measurement is flagged as suspicious and left to the human expertise for the ultimate decision. For the case study described in this paper, the human experts are the regional officers of the CAR. A Web-based dashboard allows the expert to review the output of the quality control and make the ultimate decisions. Moreover, the dashboard allows also to configure some of the parameters of the models embedded in WeatherProg.

The following step of the climate data management chain performed by WeatherProg is the production of digital climatic maps of relevant variables. According to the needs of the pest risk models which will consume them, digital maps of both fundamental variables like temperature or rainfall, and derived variables like evapotranspiration, can be produced by WeatherProg. Digital maps are stored in a raster database called rasdaman (Raster Data Manager) [4], which makes available the datacube representation. A datacube is a representation of a digital map with more than two dimensions, where the additional dimensions can encode additional information. The simplest case is a three-dimensional map where the x and y dimensions represent easting and northing as usual, while the z dimension represents the time of the digital map. This datacube can actually be regarded as an "array of digital maps", where each element of the array is a digital map at a specific point in time. Example of datacubes are shown in figure 2a.

Once datacubes have been created by WeatherProg and inserted into rasdaman, pest risk models can be run, representing the last link of the chain. Thanks to the datacubes, a mechanistic pest model can be run on whatever point within the study area. Moreover, a pest risk map may also be produced by running the model over an area of interest. Figure 2b graphically explains how operations on datacubes work.
3. Results

3.1. Main Engine

The WeatherProg software was originally developed within the SOILCONS-WEB project (LIFE08 ENV/IT/000408). It requires some modifications in order to be inserted within the cyber-physical infrastructure proposed in this work, and to become capable of working with data at the time scale of 10 minutes.

The decoding module of WeatherProg has been completed. This module interacts with the CAR data servers on one hand, which send the data of the regional network, and the climatic database on the other hand. Since the format of incoming data is subject to change, and has actually changed during the period of this study, the interface between WeatherProg and the incoming CAR data has been made flexible, so as to be capable of handling future format modifications effortlessly.

The same flexibility has been implemented for the interface between WeatherProg and the climatic data base. To this end, instead of directly making SQL queries wherever needed by the various WeatherProg modules, the software makes appropriate function calls to a dedicated module, which in turn takes in charge to appropriately querying the database.

3.2. Low-cost Stations

The design of the low-cost measurement station has been driven by a twofold objective. Firstly, the coverage of the various regional environments by the CAR network (only 34 stations) is numerically insufficient and geospatially too coarse in order to build adequate digital maps that can support the prediction of accurate agrometeorological time series at ungauged geospatial locations. Lastly, these stations must be cheaply maintained and easily relocable over the years, in order to monitor different areas and/or agroecosystems. It is crucial also considering the possibility by a farmer to invest few moneys to get the standard equipment (hardware and software directly connected to our servers) we developed. This way the farmer can run pest risk models using in-situ measurements instead of those coming from predicted climatic cubes.

Pest risk models, in fact, requires a very precise characterisation of the environments at the farm scale in order to tune model parameters; but it is infeasible to have the required number of...
of stations all across the regional territory. Alternatively, a reduced number of stations can be deployed in a limited area, sufficiently for a proper characterisation of the pest risk models, and being moved after the model parameters have been tuned.

The measurement station prototype is based on an Arduino-like platform, embedding an Espressif microcontroller [5] and a Sigfox transmission chip [6]. It has been developed to be energy-independent, in order to work with little or no manutention effort. Moreover, it has a good computational performance, and is capable of retrieving, hold when needed, and, transmit information from a wide range of sensors.

Each component of the measurement device has been chosen according to its cheapness, but also its dependability, durability and, for the sensors, accuracy. This choice has led to the best trade-off between affordability and quality for the device as a whole.

The fact that the resulting equipment is very low cost makes this solution appealing for a multi-point farm monitoring. The device is currently equipped and programmed to work with sensors measuring air temperature, precipitation, leaf wetness, relative humidity and wind direction, speed and gusts, but other sensors can be easily added and monitored so as to expand the set of measured climatic parameters.

3.3. Web Applications

An easy-to-use, GIS-like web application has been developed to allow end users to retrieve data of their interest. It is shown in figure 3.

The interface guides the user towards the selection of the available data. Upon loading, the user is asked for the selection of one or more stations of the network. The selection of the climatic variable is enabled only when at least one among the selected stations is capable of measuring that climatic variable. Moreover, the appropriate aggregation for each climatic variable is displayed when a time scale higher than 10 minutes is selected.

The Web application then produces a chart for each requested climatic variable, showing
Figure 4. Example of a search result

the evolution of the climatic parameter during the time interval of interest. An example of the produced charts is shown in figure 4. Both charts and data in a spreadsheet can be downloaded, in a variety of formats including also open formats for spreadsheets.

4. Discussion
The work discussed hitherto proves the feasibility and the advantages of a semi-automatic management and real-time publication of the climatic data collected by the institutional agrometeorological network of the Campania Region. However, this is only a starting point.

The work outlined here has, in fact, laid the foundations for the complete end-to-end cyber-physical infrastructure.

4.1. Main Engine
The quality control logic has already been updated to work at the 10 minutes time scale. However, while some checks can be performed on the data point in isolation, like the logical
checks, there are also more complex checks like the spatial and climatological ones, which require a quality-controlled time series to be used as reference. Therefore, the quality control will be enabled by firstly perform the simpler checks on all the available data, and then the more complex modules will be enabled.

4.2. Low-Cost Stations
The development of the low-cost station requires the evaluation of the accuracy of the measurements. This analysis will be performed shortly after the first deployment of the devices. The evaluation will take into account the presence of the quality control performed by WeatherProg, in order to assess the dependability if the whole cyber-physical system.

Moreover, the low-cost stations will be relocated on a yearly basis, in order to study and optimize the parameterization of the models for different combinations of crops and pests.

4.3. Web Application
The Web application will be expanded to present also data from the low-cost devices. The user will be able to choose whether to visualize the data of the institutional network, the low-cost station network or both.

Data presentation will be further expanded with OGC-compliant data delivery mechanisms, especially for raster data, which will be added when available from the rest of the chain.

5. Conclusions
The proposed integrated approach has proven capable to overcome the limitations of the current agrometeorological monitoring system, allowing for real-time quality control and data presentation which would not be possible with the current manual-only data management.

However, the importance of the human expertise is recognised, as the system is not built as a closed, unmodifiable package which produces ultimate decisions. Instead, WeatherProg is intended to be a semi-automatic system, aiming to ease the work of the human experts by focusing their attention only on the critical pieces of data which require to be reviewed.

Apart from already providing value for the end-users and the regional officers, the results obtained by the implemented infrastructure strongly encourage the development of other functionalities of the system, which will result in a full integrated system for agroclimatic and pest monitoring.

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