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Concept of Horticulture Ambient Intelligence System

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Anotace

V souvislosti se změnami klimatu se setkáváme s prognózami o nedostatku srážek a vody k uspokojení potřeb obyvatel a zemědělců. O udržitelnosti těchto zdrojů rozhoduje hospodárnost při zemědělských a zahradních činnostech. Mezi tyto činnosti patří zavlažování a zalévání. Zde je prostor pro aplikaci inteligentních systémů pro udržitelné hospodaření s vodními zdroji.

Klíčová slova

Voda, srážky, závlaha, hospodaření s vodními zdroji, udržitelnost, zahradnictví.

Abstract

In the context of climate changes, there are predictions about the lack of rainfall and water to satisfy the needs of population and farmers. The sustainability of these resources determines watering efficiency in agricultural and horticultural activities. These activities include irrigation and watering. There is scope for the application of intelligent systems for the sustainable management of water resources.

Keywords:

Water, rainfall, irrigation, water resource management, sustainable, horticulture.

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Introduction

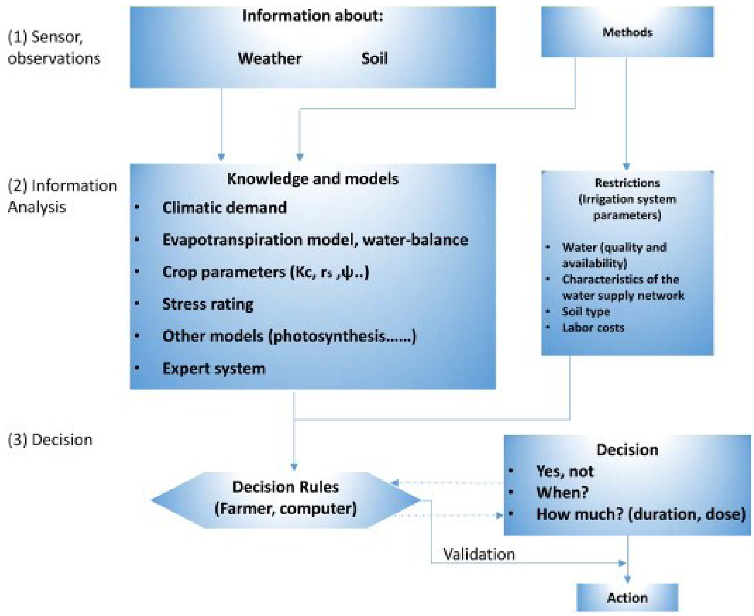
There is a big pressure on water consumption (Hayashi, et al., 2012) and there is a need to ensure similar level of production with decrease of water spending (Pereira, 1999). Three questions about irrigation are such as following:

- The first question (when?) implies the determination of the irrigation period, i.e. time between two irrigations.
- The second question (how much?) requires to define the dose (volume, height, or type of application) of water.
- Will be there some rain in a close time? For how long? If the rain comes in few hours, it is wasteful to start irrigation.

To perform a successful irrigation scheduling, some basic data and knowledge (sometimes formalized in "models") must be taken into account (see Figure 1). Either the farmer or the automatic irrigation system (computer or embedded controller with watering algorithms) will determine the dose and irrigation and frequency using a set of decision rules (Vera-Repullo, et al., 2015).

Another question is about methods of watering – where should be watering points placed. There are two possible options – both are opposite to each other. First is above the soil and second is under the soil. Upper watering has advantage in easy construction and in soil watered in whole profile – from the surface to below. When watering pipe is located under surface, then it must be in proper depth (Cancela, et al., 2015).

In this context, there is a need for smart but simple tool for optimising water consumption on horticulture. Almost all horticultures use only eyes and experience to make decision - how much water is needed for watering the flower bed. If there is a possibility to optimize this process to lower water consumption without any negative effect on plants. This can be considered as „sustainable horticulture".



Source: (Vera-Repullo, et al., 2015)

Figure 1: Stages and agents involved in the irrigation decision process.

There are plenty of automatic watering systems. The simplest systems are based on pure time management. Water valves are open every certain time and preset amount of water is released. Smarter systems can measure or calculate level of soil humidity and turn on watering when soil humidity is below defined level. Those systems can be bought in stores and hobby markets.

More advanced systems can be intelligent by using for example Penman method to calculate amount of evaporation water (Yu, et al., 2010). Those systems are based on prediction – there is known amount of water in soil and current meteorological data. So system can predict when humidity in soil is getting below critical value.

This system shows significant parts of Ambient Intelligence. AmI is growing fast as multidisciplinary area which can allow many areas of research and applications to have a real beneficial influence and a performance added value. The basic idea behind is that by enriching an environment with technology (sensors and devices interconnected through networks), a supporting system embedded in the environment can be built such that based on the real-time information gathered and the historical data accumulated, important and proactive decisions can be done by the system in order to support the horticulturist activities in that environment (Augusto, J. C., 2010), (Augusto, J. C., et al., 2010), (Cook, D. J., et al., 2009), (Cook, D. J., et al., 2007).

Sustainable horticulture need more information from different data sources. So there can be applied parts of business intelligence processes that enables intelligent systems to know more than ever before. This system can be named Horticulture Ambient Intelligence (HAmI).

Horticulture is small part of agriculture. In comparison with agriculture, the most of decisions in horticulture is based only on horticulturist experience or estimation. There is a possibility to apply some procedures from agriculture to horticulture. The research is about integration of open data and local sensors data to improve watering and make horticulture more sustainable. The paper is a part of research at Department of Information technology at Czech University of Life Sciences in Prague. If principles of Horticulture Ambient Intelligence will be confirmed, than HAmI can be used in larger fields in agriculture business.

Materials and methods

Most systems are focused on only one part of water treatment, which is an issue. They use one of the following options:

- Time management for periodical watering
- Sensor for measuring humidity level
- Method to calculate evaporation from soil and plants
- Near IR imaging to check plants health

But only a few systems can combine those data as a synthesized data source. The explanation can be done on a common situation. There are few hot days and no rainfall. So, due to evaporation from plants and soil the water level is getting down. All our systems decide that there is a need for water, which is a proper decision – all marks are in the conformity. System is starting to irrigate, but in a short time after watering, heavy rain comes.

Therefore, a massive watering is a waste of water. So system can use weather forecast to make real proper decisions in short-term lookout. Even in a situation when plants are in water shortage for few hours. Even advanced systems calculate only with current situation based on local measurement predictions (Giusti & Marsili-Libelli, 2015).

All decisions have to be made in a fully informed state. This is key advantage of proposed concept „HAmI“ that offers a complex data synthesis where farmer can optimize water consumption. HAmI can help all because in a rainless time. HAmI can make our plant production sustainable and friendly to water resources.

Data requirements

Every plant has specific water supply needs – different amount in different time and in different soil depth (O`Shaughnessy, et al., 2012), (Yavuz, et al., 2015). Next variable in the decision process is soil – there is a need to consider all soil characteristics (Romero, et al., 2012) because of different water leakage and evaporation levels. The third part is information about meteorological data – forecast data to provide at least 24 hours prediction.

To design such a tool, there is necessary to specify data requirements. One part of those data is everywhere worldwide. It is the nature itself. Intelligent system must only have proper devices to measure it and analyse it. This allows decision support system to make imminent view of situation, and also provide look into past – system can pick up data to rate our decisions and interventions on the garden. Perhaps Penman Method can be used to water evaporation calculation (Yu, et al., 2010).

The second part of data is also important because it depends on weather forecast. Our system should be capable to offer some predictions. Minimal information needed is about weather for at least next 24 hours. One day is minimal time to prepare garden work plan. The second important function is prediction likelihood of diseases and pests. If there is current information and system can compare the information with weather forecast then it can enable to make our gardening smarter, friendly to water resources and also predict plants diseases.

Low or near zero cost is required in small business. There is a chance to design the system by using free data, free software and low cost computer components (but with reasonable value for money ratio). Very good price to performance ratio is crucial.

To provide necessary information, specific set of sensors is needed:

- Temperature
- Humidity
- Light intensity
- Rainfall

First two sensors will be located in different level. Correct level of measurement is needed to obtain proper data for all plants. Each crop has special demand. For basic measurement, there can be only one sensor set for each patch. If the patch is big or has different conditions – for example due to partial tree shade, it is recommended to use multiple sensor set.

Meteorological data

External forecast data and current weather information is crucial for a proper data analysis. Currently, it is very difficult to obtain the data in the Czech Republic. The Czech Hydrometeorological Institute (CHI) provides data on the Internet under the Creative Common licence – mark author, non-commercional use and no changes. The licence is quite suitable and sufficient enough to conduct proposed tests.

However, like other European National Meteorological and Hydrological Services, CHI operates on cost recovery model and sells some raw data (Pettifer, Primet, 2009). Moreover, data provided by CHI are represented as image or HTML code, which definitely makes data hard for machine reading – especially images. There are tools that can extract required information even from an image, but a less difficult option is needed to realize the proposed system. The system will be hosted at a small computer board with no CPU power to spare.

Fortunately an alternative open data resource is available in Norway at the web address http://yr.no. Norwegian meteorological service is very popular in the Czech Republic due to highly accurate forecasts. Provided data are available under an open licence for free use, even for commercial purposes. Second data source will be http://openweathermap.

org/ – an open meteorological data service with API. Data are easy to access due to machine-readable formats. Supported data formats are such as XML, JSON or HTML format. The data set contains current data and prediction for next five days. The university meteorological station – http://meteostanice.agrobiologie.cz - can be used as a reference point. There are current and past data available for analysis.

Due to decision-making based on weather forecast for a certain precise location, complex data processing combining data from multiple sources with different time attributes must be designed to achieve the best possible results.

A key part of proposed data processing is the evaluation. Every forecast service uses its own algorithm. Data sources provide distinct weather forecast data. This must be kept in mind due to analytic process design. The second problem is in the area size. Small field requires information about very specific area but not about entire city or region. The best estimation will be obtained for few hundreds of square meters.

Suggested data sources are such as:

- Local current weather – sensors array and nearest weather station as a reference point
- Local past weather – sensor data from the past
- Larger area current weather – weather situation in the entire city
- Larger area past weather – data from weather forecast service for entire city
- Larger area future forecast – weather forecast for entire city or region

Every data from other source has to be compared with our measuring. For exact estimation, system have to calculate variance. More values can be obtained by analysing variance changes in time. Forecast data providers rarely change their algorithm – variance can differ during time.

Weights of every single data source can be assigned by variance analysis, which makes the analysis more accurate after certain time. As an example, used sensors can measure temperature with ±0,5°C every single second. For our purpose, it is ideal to save every minute average data. The first data source provides an exact look at temperature curve at the monitored field. The second data source comes from local weather station. As an example, the weather station at CULS provides different data amount every 10, 15 and 60 minutes. For the purpose of temperature variances determination in the location, comparison of temperatures from professional tools and also verification of correct sensor data provision are done. The third part is made of data from countrywide measurements. A precise weather forecast based on multiple meteorological data sources is needed, enabling simultaneous data analysis. A forecast evaluation is made possible by comparison of external data and system local data and, consequently, it enables to prepare a scaled irrigation decision system. Synthesis of multiple forecasts helps to specify forecast for decision-making at certain location.

Forecasts evaluation

Due to a limited size of the article, following example of yr.no data can be shown:

<time from="2015-08-14T14:00:00" to="2015-08-14T15:00:00">

<!-- Valid from 2015-08-14T14:00:00 to 2015-08-14T15:00:00-->

<symbol number="1" numberEx="1" name="Clear sky" var="01d"/>

<precipitation value="0"/>

<!-- Valid at 2015-08-14T14:00:00 -->

<windDirection deg="144.0" code="SE" name="Southeast"/>

<windSpeed mps="3.7" name="Gentle breeze"/>

<temperature unit="celsius" value="23"/>

<pressure unit="hPa" value="1018.2"/>

</time>

There is a forecast for every next hour and every record has a valid time. So, if it can store every record from every hour forecast, those data can be compared and decision can be made about evaluation value. Once having enough evaluations available, the system can decide how accurate the record was. Then it is possible not even to rate entire meteorological service but also to rate certain months or weeks.

Accordingly to (Verzijlbergh, et al., 2015) those methods can be used:

- Forecast error – $\epsilon_{t+k|t} = y_{t+k} - \hat{y}_{t+k|t}$

In this notation, $\hat{y}_{t+k|t}$ denotes a forecast of variable y issued at time t valid for time $t+k$ and y_{t+k} is the observed value of the variable. In this context, k (not to be confused with the previously introduced clear sky index kt) is often referred to as the forecast lead time.

- Bias – bias(k) = $\frac{1}{T}\sum_{t=1}^{T} \epsilon_{t+k|t}$

where T denotes the length of the evaluation period (i. e. the number of forecasts evaluated). The bias thus represents the mean of the forecast error.

- Root mean square error

$$-\ RMSE(k) = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(\epsilon_{t+k|t})^2}$$

- Relative root mean square error

$$-\ rRMSE(k) = \frac{\sqrt{\frac{1}{T}\sum_{t=1}^{T}(\epsilon_{t+k|t})^2}}{\frac{1}{T}\sum_{t=1}^{T} y_t} = \frac{RMSE(k)}{\bar{y}}$$

where $\bar{y}$ denotes the average of all observations. To compute the average irradiance, observations can be discarded during the night when the irradiance is zero.

Results and discussion

Case study

A simple case study is focused on strawberry bed irrigation. In general, similar methods can be used on any crops in horticulture or agriculture. The first basic information is the crop water, temperature and sunlight demands. Secondly, sensor set is proposed as a hollow rod. In the rod, all sensors and necessary cabling are placed. Thirdly, pivot table for data analysis is designed.

Sensor rod

Basic sensor rod can have three levels of sensors. Each sensor level monitors specific values provided for a qualified irrigation decision-making. The three levels are such as:

- + 20cm – for light intensity sensor, air humidity and temperature
- + 5cm – for air temperature
- - 10cm – for soil humidity and soil temperature

Data stated above provide enough information for basic decision-making. There is a lack of information about amount of local rainwater. This can be fixed by adding rainfall measurement device. With rainwater information can be used Penman method to calculate evaporation and predict the length of time period before the water level drops below a comfort level.

Prototype of sensor set is prepared. Core of sensor set is micro computation board Arduino Nano, with communication unit nRF24L01. Main computation part is based on Raspberry Pi computer. Sensor set is composed from:

- BH1750 – light sensor – output in lux
- DHT22 or DHT11 – for air temperature and air humidity
- 18B20 – for soil temperature
- SHT10 – for soil humidity
- BMP180 – as barometric measurement

Sensor set is powered by small solar panel and energy is stored in rechargeable batteries. Energy consumption optimization has become the main part of testing. In the same manner, all chosen sensors are tested for measurement precision.

Source: own processing

Figure 2: RaspberryPi board.

Wireless communication is available for larger areas (Nesa Sudha, et al., 2011). RaspberryPi conducts all data processing and downloads open data on site. RaspberryPi can be powered by AA batteries or by car accumulator, which leads to significant energy savings. A power transformation module BattBorg is able to handle electric current between 7 V and 36 V. If there is power connection RaspberryPi can be powered by regular micro USB power source including mobile power banks. The same power sources can be used to power portable modem. When no power network is there combination of solar panels with a battery pack can be used (Deveci et al., 2015).

To provide correct data processing exact weather forecast is needed. This is probably the most difficult part of the system. Weather forecasts are very fuzzy with hourly updates and changes. Current forecast systems are able to predict exact situation for next 24 hours. When more hours are predicted, there is more uncertainty in the forecast. The level of uncertainty can be reduced by using more data sources. Data sources can be evaluated and selected with better prediction results by data source combinations and by time evaluation.

There are no historical data at the beginning of measurement. So, the system has to learn in time. The system provides summarized information about soil environment to the horticulturist, which is an added value. There are two ways of information provision:

- Periodical updates to the server – can be used also as data backup;
- Direct information sharing via secured Wi-Fi connection to a mobile application.

Sensors enhancement

Sensors rod can be enhanced when they are placed as a part of array with multiple sensors. The first optional sensor is near infrared camera to watch one segment of plants. The camera will record image in visual light or near infra-red spectrum. A proper colour model and mathematical model are needed for image evaluation to set precise soil to plants ratio. According to (García-Mateos, et al., 2015) a* in L*a*b* is the best channel with an optimal election and an accuracy of 99.2% by itself.

Next possibility is to add another sensor for extra information. It can be a laser sensor for checking plants health status. Through laser detection HAmI system can make estimation about plant condition (Li., et al., 2015).

System architecture

HAmI system is planned as three layer architecture. The first layer is described in the article. It is a sensor part providing data feed for decision subsystem of Horticulture Ambient Intelligence. In the first layer, there is also data mining subsystem that obtains information from open data sources, especially, meteorological data.

The second layer is composed from business intelligence processes. Those processes will be optimized for horticulture specific needs and for low computing power of low consumption computer board. This layer will provide data for correct decisions in accordance between local data, weather open data and specific needs of a crop.

The third layer is designed as decision support subsystem of HAmI. The layer accepts basic principles of ambient intelligence systems. Those system are designed to make decision as a reaction to external data in accordance with quick changing conditions.

Conclusion

The proposed project is ambitious. But, there are some facts that must be taken into account. Climate changes are continuous due Earth history. Weather has been changing since the time when first gases were released and created atmosphere around the Earth. Therefore horticulture as part of agriculture business has to be ready for next changes and must accept idea of sustainable and economical farming. Horticulture follows the above mentioned concept. The proposed concept is a part of the research plan of the Department of Information Technologies at the Faculty of Economics and Management, CULS Prague.

What is the status of HAmI? There is an early prototype of measuring system where some sensors are tested for accuracy and durability. On the other hand, there is also the first version of weather skill measuring system based on Data Cube principles. At the moment, Data Cube is implemented in Microsoft Excel with Power Pivot add-on. There is a continuous evaluation of forecasts from two sources for the first stage of implementation.

Making a cloud application for collection of those skill measurements and synthesizing data into one simple user’s outcome is found as very difficult and challenging. In 2016, first measuring device will be launched on a real garden to test its operating characteristics.

The proposed system is capable to save large amounts of water without significant affection to the plant production. Every gallon of water that is saved at gardens or at larger fields is ready to be used for another purpose. HAmI system can be extended as a cloud solution with shared measurements that will lead to higher accuracy of weather forecasts for an end point application. Currently, there are three parallel developments in process. First prototype test should be ready in one year.

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