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ROBERTO BARBUTI, STEFANO CHESSA, ROBERTO FRESCO, PAOLO MILAZZO

PREFACE

The technological innovation in biology and agriculture often leveraging on innovation in computer science and engineering, pushed forward the process of integration among these disciplines. In particular, information technology (IT) provides common methodologies and tools for the automatic acquisition and analysis of the data that concern the management and optimization of the natural and territorial resources.

In agriculture, applications of IT enable the integration of interventions concerning its sustainability and productivity, by offering methods and tools to monitor, control, analyse and optimize the production while keeping it respectful of the environment. Similarly, the best practices for bio sustainability, for the management of bio-diversity and for the bioremediation of the environment (including soil, water etc…) are also progressively adopting IT, which enable more focused (and thus more effective) applications.

In this context, the conference "Technologies and innovation for sustainable management of Agriculture, Environment and Biodiversity" (TI4AAB), was held in July 2016 at the Natural History Museum of the University of Pisa located in the Calci Charterhouse (Calci, province of Pisa) in order to encourage the sharing of emerging knowledge about the above topics.

In fact, the conference was dedicated to fostering innovative cross-disciplinary research and applications and to stimulating the exchange of strategies and experiences, among academic and company experts from different disciplines (agriculture, biology, computer science and engineering and environmental decision making), in order to encourage a common, interdisciplinary discussion about the adoption and perspectives of IT in modern agriculture, environmental management, biodiversity and bio-sustainability in general.

The conference was held under the auspices of the municipality of Calci, the University of Pisa and of the "Ordine dei Dottori Agronomi e Dottori Forestali". It was also attended and supported by some leading national and worlwide industries, like CAEN RFID, OSRAM, STMicroelectronics, EBV Elektronik, Qprel Srl, AEDIT Srl, EMipiace Srl, and Zefiro Ricerca & Innovazione Srl, and by the Italian National Forestry Authority.

This volume constitutes a selection of the contributions presented at the conference and cover the aspects of innovation in agriculture, biology, and applied information technology. In particular, concerning innovation in agriculture, the paper by Nin et al. studies new soilless cultivation systems for wild strawberry growing in the Tuscan Appennine mountains. The paper by Prisa describes experimental research concerning the use of zeolites in combination with effective microorganisms, in order to improve the quality of olive trees. Finally, the paper by Lombardo et al. describes collaborative approaches to innovation in agriculture (co-generation of technology).

Concerning innovation in biology, the paper by Baldacci et al. describes the results of the preliminary phases of the AIS-LIFE project, which aims at developing aerobiological information systems in order to improve pollen-related allergic respiratory disease management. Still concerning the AIS-LIFE project, the paper by Natali et al. aims to describe the strategy used in AIS-LIFE project, to evaluate daily pollen concentration in the atmosphere produced by many allergic plant species. The use of data and GIS system are shown as an approach to assess allergy risk maps.

Concerning innovation in computer science applied to agriculture and biology, two contributions focus on modeling approaches, and two contributions provide a survey of information technology applied to agriculture and biology. Specifically, the paper by Bodei et al. describes the application of the IOT-LYSA formal modelling framework to a possible scenario of grape cultivation, in order to assess water consumption, and the paper by Barbuti et al. proposes a mathematical model of artificial reefs, in order to study the dynamics of algal coverage and of populations of fish in some Italian artificial reefs. Finally, the paper by Fresco et. al. explores the current challenges and IT solutions in order to realize a digital agriculture framework, intended as an evolution from Precision Farming to connected knowledge-based farm production systems, and the paper by Pucci et al. provides a survey on biologging methodologies for the collection of knowledge about animals' behaviour, making a review of some related common data analysis techniques.

All papers have been carefully reviewed by experts in the specific fields. Here is the list of the reviewers, that we thank for the collaboration.

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SUSTAINABLE PRECISION AGRICULTURE FROM A PROCESS ALGEBRAIC PERSPECTIVE: A SMART VINEYARD

Abstract: C. Bodei, P. Degano, G.-L. Ferrari, L. Galletta. *Sustainable precision agriculture from a process algebraic perspective: a smart vineyard.*

The adoption of precision agriculture has been enabled by the arrival of the new ICT technologies included in the wider context of the Internet of Things. We advocate that formal software engineering models and methodologies can provide support to the design of networks for precision agriculture. We propose here the process algebraic framework as a formal support for understanding the possible data-flows for decision-making, once identified from where data are to be gathered. In particular, we exploit IoT-LySa, a recently introduced process calculus, through which we model a possible agriculture scenario. We consider grape cultivation, with particular attention to a careful usage of water. The static analysis developed for IoT-LySa can be used for predicting the interactions among nodes, how data spread from sensors to the network, and how they are manipulated, so helping in water preservation.

Keywords: Precision Agriculture, Internet of Things, Formal Methods, Process Algebras.

Riassunto: C. Bodei, P. Degano, G.-L. Ferrari, L. Galletta. *Modelli basati su algebre di processi per l'agricoltura di precisione sostenibile: il caso di una vigna.*

La diffusione dell'agricoltura di precision è stata resa possibile dallo sviluppo di nuove tecnologie ICT incluse nel contesto più ampio del Internet of Things. Noi sosteniamo che i modelli e le metodologie formali dell'ingegneria del software possano supportare la progettazione di reti per l'agricoltura di precisione. In questo articolo proponiamo le algebre di processi come un'infrastruttura per il supporto formale alla comprensione dei flussi di dati per la gestione di tali reti. In particolare, noi utilizziamo IoT-LySa, un calcolo di processi recentemente proposto, tramite il quale modelliamo un possibile scenario agricolo. Consideriamo l'ambito della viticoltura, concentrandoci in particolare sull'utilizzo consapevole dell'acqua. L'analisi statica sviluppata per IoT-LySa può essere usata per predire le interazioni tra i nodi della rete, il modo in cui i dati si diffondono dai sensori alla rete, e come tali dati vengono elaborati, al fine di favorire il risparmio idrico.

Parole Chiave: Agricoltura di Precisione, Internet of Things, Metodi Formali, Algebre di Processi.

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INTRODUCTION

Precision agriculture is a management concept that is based on observing, measuring and responding to variations of micro-climatic parameters, as well as parameters of plants and soil, in order to optimise resources, such as water, fertilisers and plant protection products, so to drive agricultural actions.

As a result, productivity can be improved and the environmental impact minimised, thus supporting sustainable agricultural practices.

One of the enabling ICT technologies in this area is that of Wireless Sensor Networks, included in the wider context of the Internet of Things (IoT). These networks consist of devices (i.e. the "things") that observe the physical environment, and of processing nodes that cooperatively make decisions and issue operations on the environment, depending on these observations.

We argue that formal software engineering models and tools can provide support to the design of networks for precision agriculture. A formal description of these networks can be indeed useful for allowing designers to focus on the needed requirements in terms of information flow. Once focussed on *what* is needed, designers can focus on *how* to obtain it in terms of implementation.

We propose to exploit process algebras as the enabling formal methodology in this framework. A process algebra is an abstract, yet expressive programming language that provides a set of primitives for modelling the behaviour of a system composed by many independent and interacting components. They come endowed with well-founded and established techniques for reasoning on the design of the system and its optimisation. In particular, modelling can help us in understanding the possible data-flows for decision-making, by identifying from where data are to be gathered and which kinds of aggregation functions are really necessary. Furthermore, models offer a way to evaluate how effective is the precision of the network under

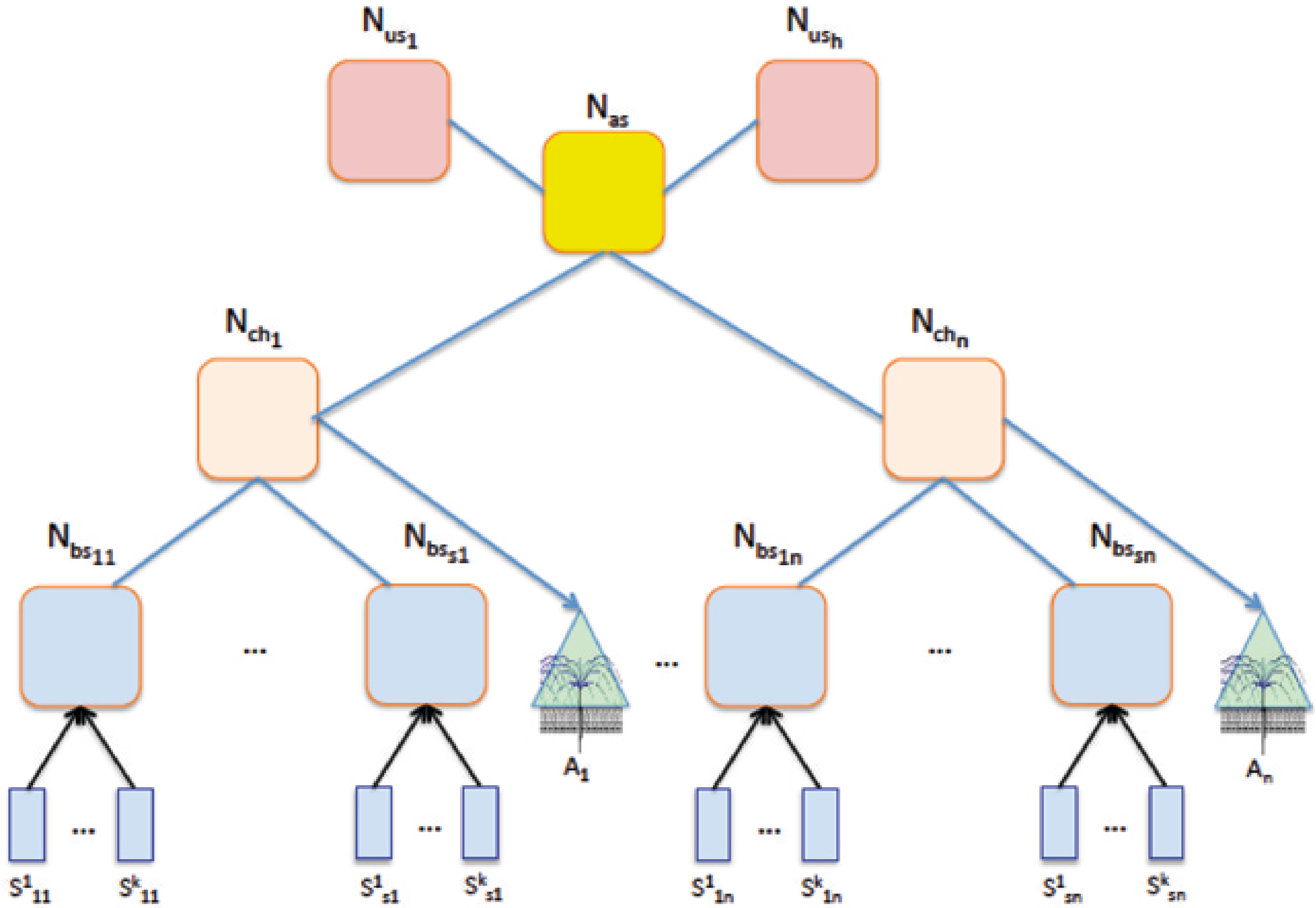

Fig. 1 - Organisation of the irrigation control system.

development, allowing designers to understand how to tune data collection in terms of granularity of the observed areas, of frequency of sampling, and so on.

We resort to the process algebra IoT-LySa (Bodei *et al.*, 2017, 2016b) to model and reason about Wireless Sensor Networks for precision agriculture. We illustrate below our proposal, with the help of an example of a possible agriculture scenario of grape cultivation, in which water must be preserved.

A PRECISE IRRIGATION CONTROL SYSTEM FOR A SMART VINEYARD

Smart irrigation

Smart irrigation control systems are an efficient and sustainable way to manage water, i.e. one of the essential and critical resources in agriculture.

A precise irrigation control system must be able to:

- identify the variability conditions of soil and crop with respect to space and time, and introduce and measure the corresponding quantitative parameters;
- collect and analyse these measurements using an appropriate scale and frequency;
- make the appropriate decisions and plan the consequent operations with the aim of irrigating with the appropriate amount of water each sub-area.

We consider the irrigation system AgriSens, based on a Wireless Sensor Network and developed at IIT Mumbai for monitoring and irrigating grape crops at Sula Vineyard, Nashik (India) (Shah and Da, 2012).

Given the shortage of water in this region, the main task of the system is to regulate irrigation according to *evapo-transpiration*, a variable parameter that measures water demand of the crop.

This parameter depends on several factors, among which weather, soil moisture, kind of plant and stage of development. Irrigation is needed when evapo-transpiration exceeds the supply of water coming from the soil or from precipitations. AgriSens consists of a combination of wired and wireless sensors that collect soil data like pH, moisture, temperature and so on.

These battery-powered sensors are deployed at a grid of *30 m* by *30 m*, and can transmit in a range of [*30 m*, *1000 m*]. The collected data are sent in a multi-hop manner to a base station node. The base station node performs a first elaboration of data and then transmits the results via a mobile phone technology to the remote Agri-information server in Mumbai.

Tab. 1 - Model of the irrigation control system.

$$
\begin{array}{l}
\textbf{Base Station Node i of Cluster Head j} \text{ with } i \in [1,s], l \in [1,k], j \in [1,n] \\
N\!bs_{ij} = \ell_{bs_{ij}} : [P_{bs_{ij}} \parallel S^1_{bs_{ij}} \cdots \parallel S^k_{bs_{ij}}] \\
P_{bs_{ij}} = *[(z^1 := 1).\cdots.(z^k := k).\langle\langle i, f_1(z^1\cdots z^k), \cdots, f_m(z^1\cdots z^k)\rangle\rangle\{\ell_{ch_j}\}]* \\
S^l_{bs_{ij}} = *[(\tau.l_j := v_{lj}).\tau]* \\
\textbf{Cluster Head j} \text{ with } j \in [1,n] \\
N\!ch_j = \ell_{ch_j} : [P_{ch_j} \parallel P'_{ch_j} \parallel A_j] \\
P_{ch_j} = *[(1; x^1_1 \cdots x^m_1).\cdots.(s, x^1_s \cdots x^m_s)\langle\langle j, aggr_1(\vec{x_1}, \cdots, \vec{x_s}), \cdots, aggr_r(\vec{x_1}, \cdots, \vec{x_s})\rangle\rangle \triangleright \{\ell_{as}\}]* \\
P'_{ch_j} = *[(j; x).\langle j, x\rangle]* \\
A_j = *[(\!| j, \{\mathsf{StartIrrigation}, \mathsf{StopIrrigation}\} |\!)]* \\
\textbf{Agri-Information Server} \\
N\!as = \ell_{as} : [\Sigma_{as} \parallel P_{as,1} \parallel \cdots \parallel P_{as,n} \parallel P_{as,us_t}] \\
\quad P_{as,1} = *[\quad (1; w_{11}, \cdots, w_{1r}) \parallel \\
\qquad\qquad (w_{11} \geq th_{11}) \; ? \\
\qquad\qquad\qquad \langle 1, \mathsf{StartIrrigation}\rangle : \\
\qquad\qquad\qquad (w_{11} < th'_{11}) \; ? \\
\qquad\qquad\qquad\qquad \langle 1, \mathsf{StopIrrigation}\rangle]* \\
\quad \vdots \\
\quad P_{as,n} = *[\quad (n; w_{n1}, \cdots, w_{nr}) \parallel \\
\qquad\qquad (w_{n1} \geq th_{n1}) \; ? \\
\qquad\qquad\qquad \langle n, \mathsf{StartIrrigation}\rangle : \\
\qquad\qquad\qquad (w_{n1} < th'_{n1}) \; ? \\
\qquad\qquad\qquad\qquad \langle 1, \mathsf{StopIrrigation}\rangle]* \\
\textbf{User t} \text{ with } t \in [1,h] \; N\_us_t = \ell_{us_t} : [P_{us_t}]
\end{array}
$$

The aggregated data are further processed and stored in the remote server. The irrigation control system decides the suitable irrigating actions for each sub-area in the crop: e.g. if in one of them the level of soil moisture goes down a given threshold, then sprinkler actuators are activated. Users, i.e. farmers and researchers, can directly access the server agri-data at any location and help in decision-making.

Our process algebraic model of the smart vineyard

To give an overall picture of our methodology, we model the AgriSens system in IoT-LySA.

The whole system network, illustrated in Figure 1 and described in Table 1, is a pool of nodes running in parallel that can communicate with each other.

Each node, uniquely identified by a label l, (e.g. l_{as} is the label for the Agri-Information Server), consists of control processes and, possibly of sensors and actuators. Communication is multi-party: each node can send information to a set of nodes, provided that they are in the same transmission range. Outputs and inputs must match in order to communicate. In more detail, output is modelled as

$$\langle\langle E_1, \cdots, E_k\rangle\rangle \triangleright \{L\}.\, P$$

meaning that the tuple of messages $E_1, \ldots, E_k$ is sent to the nodes with labels in L. Intuitively, a message E_i contains a value, either a piece of raw data gathered by a sensor or the result of an aggregation of other data, e.g. the average of moistures collected by several, contiguous devices.

Input is instead modelled as

$$(E_1, \cdots, E_j; x_{j+1}, \cdots, x_k).P$$

and embeds pattern matching. In receiving an output tuple of the same number of elements, the communication succeeds, provided that the first j elements of the output match the corresponding first elements of the input, and then the variables occurring in the input are bound to the corresponding terms in the output, i.e. the values of the output expression are assigned to the input variables.

Each base station node N_bs_{ij} is connected to a bunch of sensors $S\_bs_{ij}^{\,1}, \ldots, S\_bs_{ij}^{\,k}$ that sense the environment in the crop sub-area controlled by the base station control process P_bs_{ij} and write the sensed values on its store. The node also includes other components that we omit here because irrelevant. Similarly, the action τ denotes internal actions of the sensor we are not interested in.

The node base station N_bs_{ij} collects data $z^{1\ldots}$ z^k from its sensors, processes them with the help of the filter and aggregation functions $f_1, \ldots, f_m$ and transmits their results to the Cluster Head node N_ch_j. The communication is performed as explained above: e.g. the output performed by the process P_bs_{12} matches the input performed by P_ch_2, and therefore the variable x_1^m is bound to $f_1(z^1 \ldots z^k)$, the variable x_2^m is bound to $f_2(z^1 \ldots z^k)$, and so on. The construct **[...]** implements the iterative behaviour of processes and of sensors.

Each Cluster Head node N_ch_j controls a subset of the base station nodes N_bs_{ij} that send it their data ($\boldsymbol{x_i}$ stands for the array $(x_i^1 \ldots x_i^m)$). This control is done upon receiving the relevant data, that are then aggregated with the functions $aggr_1(), \ldots, aggr_r()$.

The Cluster Head node then sends the obtained results to the Agri-Information server *N_as*.

The Agri-Information server *N_as* processes the data sent by all the Cluster Head nodes $N\_ch_1, \ldots, N\_ch_n$ and makes its decision on irrigation. If the server detects that some water is needed in the area controlled by the Cluster Head node N_ch_j (i.e. if the water demand w_{j1} is *over* a given threshold th_{j1}), it sends a "start irrigation" order, and conversely, when it detects that there is sufficient water (i.e. if the water demand w_{j1} is *below* a given threshold th'_{j1}), it transmits a "stop irrigation" order. The relevant Cluster Head node N_ch_j transmits the received orders to the corresponding actuators A_j triggering the irrigation sprinklers. Furthermore, users N_us_t can access the data processed and stored by the Agri-Information Server *N_as*, e.g. for checking whether there are the conditions for particular manual processes, like pruning. For the sake of simplicity, we omit the specification of the components of the users' nodes N_us_t.

Note that wireless communication depends on the transmission range. For instance, base station nodes and sensors cannot directly communicate with the Agri-Information Server and therefore they have to rely on multi-hop communication via Cluster Head nodes, which instead can communicate, via a mobile phone technology, with the Server in Mumbai.

DISCUSSION

In (Bodei *et al.*, 2016a, 2016b, 2017) we equipped IoT-LySa with a static analysis that describes the interactions among nodes, how data spread from sensors to the network, and how data are manipulated. A static analysis is able to safely approximate and predict system behaviour, by only inspecting its specification and without running it, as done in the model checking techniques, which require to consider each reachable state of a system.

The loss in precision is compensated by the gain in efficiency: computing the prediction is far less expensive than computing all the possible dynamic evolutions of the system. The result of the analysis can be exploited as the basis for checking and certifying various properties of precision agriculture design, e.g. reliability of devices and nodes. Applications succeed if the communications among nodes and sensors are reliable. Problems can arise from energy consumption, to which sensors are quite sensitive, and from accidental damages to devices. We can use our analysis in a ''what if'' fashion, by wondering what happens if a certain node is compromised or damaged: are the required overall functionalities still guaranteed in case of adverse and unstable operating conditions? If the answer is no, the designer should rethink the system. For instance, the designer can add further communications in order to make up for the possibly compromised communications, and consequently improving the accuracy and the reliability of the collected data.

The IoT paradigm introduces large sets of data that need to be processed to make decisions on actuators. Such systems should be resistant against "bad" data that may come from possibly damaged sources (sensors and memory locations), because of accidental failures or security attacks. Making critical decisions, in dependence of data coming from unreliable sensors can have severe consequences in security. To this aim, we exploit the fact that IoT-LySa is an extension of LySa (Bodei *et al.*, 2005, Gao *et al.*, 2008), a calculus designed for studying security, in particular of cryptographuch protocols. In the present scenario, we could resort to taint analysis. Taint analysis predicts how information flows from specific data sources to the computations that use these data (Schoepe *et al.*, 2016, Schwartz *et al.*, 2010). The basic idea is to classify unreliable data sources as *tainted* and the others as *untainted*, and then mark the derived data as well, through suitable propagation rules. In (Bodei and Galletta, 2017), some of the authors proposed a Control Flow Analysis for statically predicting how tainted data spread across an IoT system. The analysis can be further enriched with causal information, as in (Bodei *et al.*, 2013, 2015), in order to capture the possible causal relations among communications: this could help in reconstructing how data are derived. By exploiting analysis in our agricultural framework, we can determine possible unreliable sensing data, e.g. those coming from sensors that are not reliable because of physical damages or failures. Hence we can address fault-tolerance aspects, by tracing unreliable data and by investigating their impact on the aggregation functions from which depend the most critical decisions.

Furthermore, the proposal in (Bodei and Galletta, 2016) is a preliminary step, still based on IoT-LySa, to infer quantitative measures on systems evolution. The derived quantitative evaluation is exploited to establish the cost of communications, in particular those that can be prone to security attacks, and the possible security countermeasures. Costs can be computed in terms of time overhead, energy consumption, bandwidth, and so on. All these factors must be carefully evaluated for achieving an acceptable balance among usability of the system and the cost required to ensure the desired level of performance and security.

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