Talking Vine: A Novel Smart Farming Application based on Wireless Distributed Sensing and Communication

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***Abstract*— This paper introduces "Talking Vine", a novel service that aims to tighten and "humanize" the relationship between users and *IoT*-enabled plants by means of distributed wireless sensing and communication technologies. The proposed system is under experimental validation within a farm vineyard in Trentino, Italy.**

Keywords—distributed wireless sensing, internet of things (IoT), emotional intelligence, human-machine interface, smart farming.

I. Introduction

Recently, distributed wireless sensing technologies such as Wireless Sensor Network (*WSN*) and Internet of Things (*IoT*) devices have proven their potentialities for the continuous monitoring of environmental parameters in many indoor and outdoor application scenarios [1]-[4], also thanks to the spread of low-cost and plug-and-play technological solutions. In particular, precision farming is one of the most challenging and interesting fields both for the technological challenges that must be addressed as well as for the innovation that such technology and related services can bring, even for small and medium farms.

II. Motivations and Objectives

The human society is facing fast changes related to social relationships and the usage of information and communication technologies (*ICT*). The COVID-19 pandemic set a watershed on social relationships: human contacts and interactions have been minimized to aseptic surrogates; the digital acceleration went into overdrive, pushing us faster, and further, into computer-mediated communication and human-machine interactions. Accordingly, the *ICT* should provide answers not only by the pragmatic and functional viewpoints, but it should also avoid the transformation of human relationships to standalone agents exchanging messages rather than feelings and moods. In fact, physical and emotional contacts are fundamental to well-being and to the development of intelligence and social behavior [5]. While Affective Computing [6] and novel paradigms such as the Social Internet of Things (*SIoT*) [7] and the Internet of Behaviour (*IoB*) have been investigated, the actual human-machine interfaces are still designed to be impersonal and far from human behavior. As the technology improves, our perception of dealing with human-like entities will be more and more effective (e.g., thanks to natural conversation, gamification, virtual and augmented reality) leading to behave with machines as they were humans [8]. Nevertheless, such entities still lack of fundamental features of the human kind communication and interactions: the ability to exhibit emotions, moods, personality, and even consciousness. In this context, the interdisciplinary research field on Emotional Intelligence investigates the capability to (*i*) recognize both own and others emotions, (*ii*) identify and classify feelings, (*iii*) exploit such information for thinking and behavior, and finally (*iv*) adapt the mood to the surrounding environment. These concepts were introduced since 1976 [9], but they gained more popularity with Goleman's best-seller twenty years later [10]. More recently, the ability of computers to feel and simulate emotions is still an open and emerging research topic, which has direct applications in robotics and conversational agents [11]. Nowadays, wireless sensing technologies and artificial intelligence (*AI*) offer new opportunities for introducing the Emotional Intelligence paradigm as applied to *IoT* [12]-[14] to enrich the quality of experience and humanize the interaction between mankind and machines.

In this framework, the context of smart farming is not only facing an increasing innovation by the technological viewpoint, but it is opening new opportunities also in terms of marketing and relationships with customers [15]. As confirmed by the recent diffusion and the success of crowdfunding initiatives and plants/animals long distance adoption, there is an increasing desire of passionate consumers to discover and better understand the ecosystem and production chain that leads to the final product, as well as to have a closer relationship with the farmer, plants, and animals. Moreover, the diffusion of social networks is key

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enabling technology for seamless communication. Accordingly, the idea behind the “Talking Vine” research project is to attract interest and tighten the relationship of the final customer who "adopts" a plant (i.e., grapevine) by providing human-friendly updates about its growth and condition. Since customers are not typically expert in the technical aspects of the agriculture domain, the acquired information must be translated into simple states characterized by a high level of abstraction and possibly towards an emotional oriented perspective. In this sense, the plant is “humanized” and plays as a social actor claiming its state in terms of emotions and feelings that can range from welfare or illness to fear, or excitement. For example, while good environmental conditions (e.g., a sunny day) might be translated into happiness, the drought stress of the plant together with hostile weather forecast might be synthesized as rage and fear.

III. Wireless Sensing Technologies

The recent improvements and diffusion of wireless radio interfaces embedded on System-on-Chip (*SoC*) and the exploitation of different wireless bands and protocols, such as Sub-GHz communications, have improved the radio communication range and the spectrum efficiency that wireless sensor devices can achieve, together with the reduction of power consumption, cost, and size. Accordingly, the number of sensors that can be deployed in real world applications is increasing and the network topologies and protocols complexity can be relaxed as the need of multi-hop connections is reduced. In the context of outdoor applications, such as precision farming, *LoRaWAN* technology and related Cloud-based software infrastructures are boosting the diffusion of *IoT* devices thanks to the increasing of usability and interoperability of acquired data. From the hardware perspective, during the last years a lot of effort has being put on the design and the implementation of innovative, efficient, reliable and low-cost sensors for acquiring the information required to estimate key indicators of the environment, the soil and the crop, in order to model and forecast the physical processes occurring on the field. For example, many infection and diseases models require to measure the leaf wetness, temperature, and humidity, and/or to monitor the number of a particular kind of insects.

IV. System Architecture

The proposed system architecture is defined by three layers devoted to sensing, processing, and communication (Fig. 1). The sensing layer is in charge of acquiring the environmental parameters measured by wireless sensors in the crop (e.g., on the air, on the plant, in the soil), the weather conditions are measured by local weather stations (e.g., wind, rain), and the weather forecast are downloaded from online services. The processing layer is responsible of evaluating the plant state associated to input data. In particular, multiple aspects that are relevant to plant state and health are considered (e.g., need of water, risk of infections, positive/negative environment, and weather forecast). Their outputs are latter mapped to a human emotion by a rule-based engine. Finally, the communication layer renders the state/emotion to a rich textual message according to the user’s preferences (i.e., media channel, language).

V. Evaluation of Plant State and Emotion

The core component of the Talking Vine system aims to synthesize a virtual emotion of the plant according to its

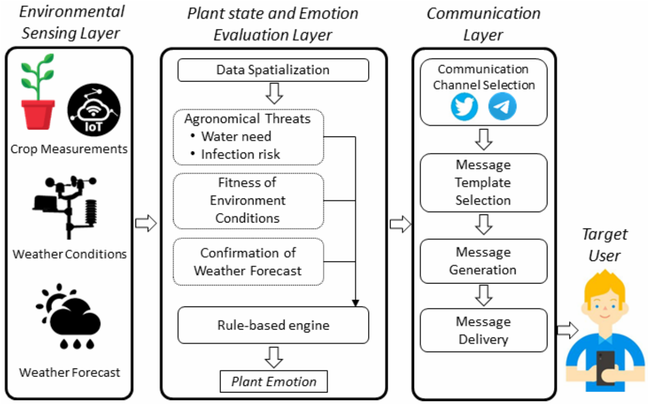

Fig. 1. The Talking Vine system architecture. The environmental sensing layers acquire crop and weather measurements, which are processed to synthesize the plant emotion. Finally, the emotion is translated to a textual message delivered to the target user by means of instant messaging channel.

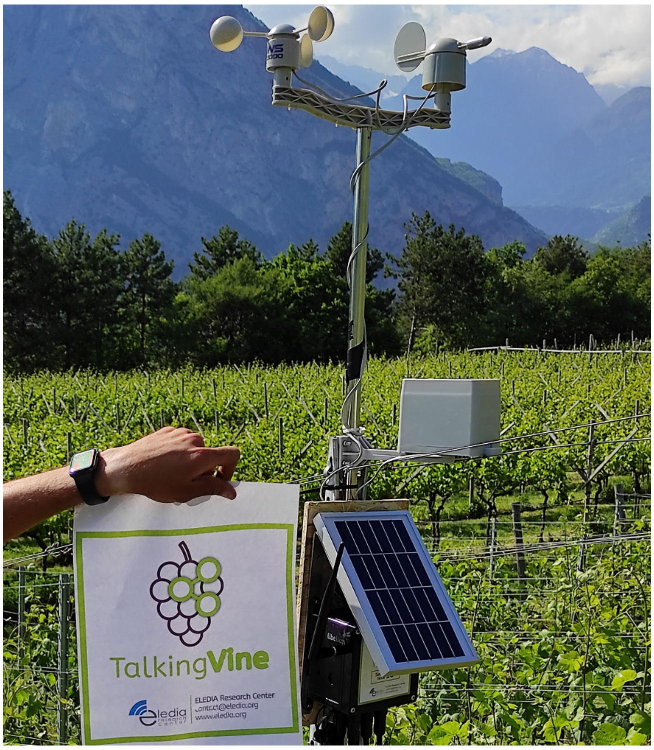

Fig. 2. A wireless sensor node installed in the experimental validation site. The sensor is also equipped with a weather station and a solar panel.

Fig. 3. An example of the messages (in Italian language) sent by a grapevine to its final user by means of the Telegram instant messaging platform.

agronomical state and threats, which are estimated by analyzing wireless measurements. The output emotion is eventually evaluated by the communication component for message generation and delivery to the target user. Towards this end, each plant should be ideally monitored by a dedicated sensing device. Although, the deployment of such a large amount of device is not feasible in practice due to the high cost. Nevertheless, machine learning (*ML*) and prediction techniques such as Kriging can be effectively exploited to obtain a sufficient resolution with a reduced number of measurement points [16]. The monitored environmental parameters, historical profile, and weather forecast can be exploited to estimate high-level information about the plant state and threats, such as the need of water and the risk of infections.

A. Evaluation of Agronomical Threats

Due to the lack of a digital twin of the plant able to fully model its agronomical state and characteristics, a simplified modelling approach has been considered. In particular, we consider two main plant threats: the need of water and the risk of pest/diseases infection, that have been studied as related to the increasing interest in decision support systems (*DSS*s) for precision farming. In particular, methodologies for estimating the water need and its availability in the soil based on distributed and pervasive measurements (e.g., air and soil temperature and humidity, weather history and forecast) have been proposed and exploited for providing to the farmer an optimized irrigation schedule, reducing the waste of resources [17][18]. Therefore, by analyzing the output of such models, it is possible to estimate if the plant lacks of water. Another application of interest in precision farming *DSS* is related to the efficient usage of agrochemicals for healing and especially for preventing plant diseases [19]-[21]. According to the phenological state of the plant (e.g., using the *BBCH*-scale) and to the infection model of a given disease, that can be estimated by analyzing real-time and historical measurements, it is possible to evaluate the infection risk at a given time. In particular, Talking Vine system integrates the outcomes of previous works [18][21] for estimating the level of such plant threats. Their exploitation is particularly convenient because both works are based on fuzzy logic and their output is defined in terms of linguistic variables (i.e., *low*, *medium*, *high*), therefore there is no need of defining thresholds and calibration parameters for obtaining a coarse risk indicator.

B. Synthesis of Plant Emotions

The design of a computer-based *AI* with emotional skills mimicking the human way of thinking is of course still science fiction, therefore the proposed Talking Vine experiment relies on technological simplifications to make it feasible. The first objective of the project is to understand if such a system can be of practical interest for service providers (i.e., farmers) and final users. Accordingly, plant emotions are synthesized by a rule-based engine. The rules are arbitrarily defined by the farmer and the communication staff. In fact, the final output should be coherent with marketing and dissemination strategy (e.g., farmers might like to force a balance between positive and negative emotions). In particular, the considered emotion set is *happiness, joy, wonder, neutral, sadness, fear,* and *anger*. A rule generates an emotion accordingly to the evaluation of one or a combination of the following information:

- agronomical threats risk (i.e., a *low* risk leads to *happiness*, *medium* risk leads to *fear*, and *high* risk leads to *anger*);
- environmental measurements (e.g., according to the difference of average temperature and humidity with respect to ideal and historical conditions within the same period of the year, *wonder* or *sadness* can be triggered);
- confirmation of weather forecast estimated on the previous day (i.e., when a positive forecast come true, such as a sunny day after raining, then it leads to *happiness*, else it leads to *sadness*).

The default plant emotion, such as in the case no rule is verified at a given time, is *neutral*.

VI. Communication and Interactions with the Users

The final output of the Talking Vine system is the spontaneous notification of messages from plants to the end users. In order to have simple, transparent, and effective communications, the system is designed to support multiple media channels. Toward this end, the system can exploit the most diffused third party messaging applications and social networking platforms, such as Twitter and Telegram. This approach allows the plug-and-play activation of the service on users' device without the need of installing and configuring any software. The system actually supports only the sending of messages to the users and it is not capable of replying. Nevertheless, their feedback messages are already acquired and stored, as they are valuable for analytics and future advancements. The end users are pre-registered by the system administrator in order to define user's association with the plant(s). In fact, each plant interacts only with the owner/reference user. Primary user's information include the name, email, age, and the language, that are exploited during the message synthesis. According to the anti-spam restrictions implemented by instant messaging platforms, a one-time activation procedure is required. In particular, the user must first send a message to the Talking Vine service (i.e., a virtual user – bot registered to the messaging platform) and provide an identifier (e.g., the email or a secret code) that allows the system to recognize the user and to associate the preferred messaging account/channel. Afterwards, it is possible for the system to send spontaneous messages directly to the user's device. While the system evaluates plants state periodically (i.e., daily), the sending of messages occurs with a lower frequency based on user's preferences, it can vary from a few messages per month to more than one message per week. According to the Talking Vine objectives in terms of dissemination and social marketing, the contents of the generated messages shall be:

- informative, but not technical;
- coherent with the farmer communication strategy and objectives;
- easy and fast to understand, in natural language (of the target user);
- nicely written, including expressions and emoticons that are typical of the human behavior;
- varying and not repetitive, even when plant conditions are unchanged.

Nowadays, despite the impressive improvements of *AI*, natural language processing, and chat-bots, the automatic generation of such contents is too challenging for an autonomous system. Therefore, a simplified approach based on pre-defined message templates has been adopted. A key advantage is that the farmer and the communication staff have the full awareness and the chance to customize the contents that are deployed to end users. The message templates are written and labeled with multiple-classes mapped to the plants state and emotions closed dictionary. Therefore, the system selects one of the message template according to the current plant emotion when not *neutral*, else to the plant state. When multiple candidates as available, one is selected according to pre-defined priorities. Since the plant state/emotion might not change for some time, in order to avoid repeating the same message, a set of variations of the same template can be defined (i.e., the system randomly selects one of the available variations). Moreover, the message template can be defined for a specific communication channel, as there might be relevant differences in terms of semantic, formatting, and limitations of its contents (e.g., Twitter allows a limited number of characters). Finally, templates are translated in different languages. For example, some messages are: "*I'm happy and growing nicely today!*", "*Brrr, how freezing: I risk a cold if it goes on like this*", "*Damn, I really expected to get some rain today! The sun is always shining from two weeks*", "*Unusual temperatures for this season: it's too hot, I'm worried about the climate changes*".

VII. Experimental Validation

The Talking Vine system is actually under experimental validation at the farm "Azienda Agricola F.lli Pisoni" in Trentino, Italy. In particular, the "Reboro" field or 8000 m^2 has been equipped with 10 wireless sensor nodes (Fig. 2) that acquire: temperature, humidity, and pressure of the air, leaf wetness, wind direction and speed, rain level, and soil temperature and moisture at two levels. The wireless network is based on *LoRaWAN* 1.0.2 (Class A) working at 868 MHz, the *LORA* gateway acts as forwarder and it is connected to a private *LORA* software cloud infrastructure by means of *4G* mobile network. The Talking Vine database has been populated with more than two hundreds plants and one hundred of message templates (i.e., prepared with the tight support of farm owners and communication staff). Among the customers who adopted a vine of the vineyard, 28 users have joined and activated the Talking Vine experiment [22]. Since the activation of the service, on March 17th 2021, almost two thousands messages have been sent by the plants to their users by means of dedicated Twitter and Telegram channels (Fig. 3).

VIII. Conclusion

In this paper, a novel service that aims to design a simplified digital model of a plant capable of simulating emotions and social interactions, has been introduced. The Talking Vine service exploits distributed wireless sensing and derived high-level information such as agronomical threats to estimate the vine state and synthesize virtual emotions, that are translated into rich text messages. The messages are latter deployed to stakeholders (i.e., owner user) by means of instant messaging platforms.

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