The Physical Semantic Web for knowledge-based M2M interactions in precision agriculture

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The *Physical Web* (PW), proposed by Google Inc., improves the interaction of mobile users with the physical world. Objects are associated with either unique identifiers (ID) or URLs (Uniform Resource Locators), advertised through the *Eddystone* beacon protocol toward nearby mobile devices. URLs target to Web pages with information about the objects and possibly related services (*e.g.*, a movie poster can link a ticket booking). Unfortunately, the PW allows only a distance-based beacon ranking, regardless of the characteristics of objects. By advertising object descriptions, instead, a ranking could be performed in a more meaningful way w.r.t. user's profile and preferences. For this purpose, the *Physical Semantic Web* (PSW) proposal enhances the PW leveraging the *Semantic Web of Things* (SWoT) vision [1]. In the SWoT, intelligence is disseminated in the environment by storing fragments of semantic annotations into heterogeneous micro-objects. Without relying on centralized infrastructures, user agents on mobile devices are able to dynamically discover the most relevant results through semantic matchmaking grounded on inference services in Description Logics (DLs). While the PW requires direct user-thing interaction, the PSW also supports autonomous machine-to-machine (M2M) cooperation, disclosing several useful application scenarios for smart cities and communities. Previous effort in this field has been done in multiple scenarios and adopting several technologies. Particularly, [2] reports on a decentralized information discovery and management through radio identification.

This work presents a case study in precision agriculture based on the integration of PSW technologies in ROS (the Robot Operating System) [3]. In the proposal, a team of autonomous agricultural robots (endowed with sensors and actuators), are able to process raw data and produce useful knowledge that can be shared. Task allocation is automated to reduce human effort and optimize the use of land and water resources.

The Physical Semantic Web framework. The PW relies on Bluetooth Low Energy (BLE)[1] beacons to expose object identifiers. Over BLE, the open *Eddystone* application-layer protocol defines five formats for beacon frames: Unique IDentifier (UID), URL, encrypted or unencrypted TeLeMetry (TLM), and Ephemeral IDentifier (EID). All messages share a common PDU (Protocol Data Unit) format. In particular, Eddystone-URL exposes an encoded schema prefix and a compressed and encoded URL with length up to 17 B, while Eddystone-UID is a unique 16 B code, split in a 10-byte namespace ID (to group beacons) and 6-byte instance ID (to identify individual items). Mobile devices scan the environment and discover Eddystone-URL resources as a background service in the operating system, without dedicated apps; Google has provided reference implementations for iOS, Android and Node.js. Eddystone-URLs target informative Web pages or interactive Web apps, hence hey require both an available Internet connection and explicit user interaction. In several real-world advanced scenarios, however, mobile objects must take decisions and coordinate themselves on-the-fly in unpredictable environments where Internet is not available. In such cases, point-to-point infrastructure-less connections allow wireless low-power ubiquitous networking. To this aim, the PSW exploits Eddystone-UID beacon messages to enable peer-to-peer communication. The PSW framework adopts the Semantic Web languages to express information with machine-understandable unambiguous meaning. Background knowledge on the various domains is formalized in shared conceptualizations, named *ontologies*, which provide the vocabulary to express factual knowledge and support automated reasoning. Every object can materialize information in a semantic annotation and expose it to nearby devices via BLE. Eddystone-UID frames support local annotation exchange via point-to-point connections: namespace ID denotes the reference ontology, while instance ID identifies the particular annotation. Eddystone-URL can be used to expose annotations through the standard PW mechanism. Mobile agents discover nearby beacon UIDs and URLs, collecting only the corresponding semantic annotations which refer to ontologies they are referring to. Semantic matchmaking occurs between each object annotation (*resource*) and the agent's *request*, ranking resources by semantic relevance. The framework exploits *Concept Abduction* and *Concept Contraction* non-standard inference services, which have efficient implementations for mobile and embedded devices on moderately expressive Description Logics [4]. If a request R is conflicting with a resource S, Contraction detects which part G (for *Give up*) of R is contrasting with S. If one retracts G from R, a compatible contracted version K (for *Keep*) is left. On the other hand, if R and S are compatible, but S does not match R completely, Abduction determines what additional features H

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[1] https://www.bluetooth.com/what-is-bluetooth-technology/bluetooth-technology-basics/low-energy

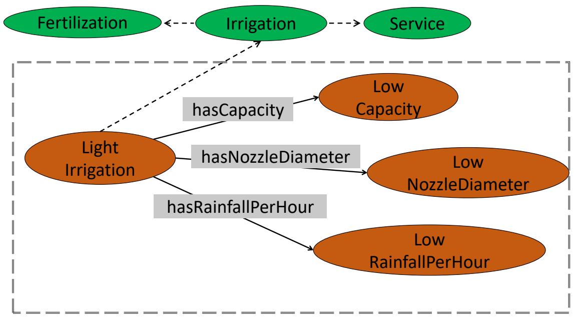

Fig. 1. Beacon annotation example

(for *Hypothesis*) should be assumed in S in order to reach a full match. *Penalty functions* compute semantic distance metrics from G and H. The final ranking score integrates semantic distance with context-aware attributes, such as beacon distance and user's records: the matchmaking outcome is a list of annotations ranked by relevance.

Autonomous interaction of devices in precision agriculture. In order to assess and clarify benefits of the PSW proposal, a case study in precision agriculture has been developed. Agricultural processes can be automated to reduce effort and improve efficiency of resource management. In the reference scenario, several products –characterized by a set of features– are farmed in different fields, managed by a team of sensor and actuator robots, capable of producing useful knowledge from data processing. Sensing robots collect data in the field and create semantic-based annotations. These descriptions are processed by a mobile matchmaker to identify the most suitable actuators to perform required actions. Robot control unit prototypes have been implemented for the ROS *Indigo* platform [3], running on UDOO Quad[2] boards equipped with UDOObuntu 2.0 Minimal Edition[3] and a Java[4] runtime. Bluvision iBeek beacons[5] are exploited to expose annotations. Source code is on GitHub[6]. Annotations of both required actions and provided services refer to the *ONTAgri* [5] ontology, which has been selected and slightly extended. ONTAgri is organized in two main parts: (i) system concepts such as sensing and actuation units; (ii) agriculture concepts like soil characteristics, crop stages and service descriptions. In the case study, crop-specific actions or services are described by means of context-aware features, using conjunctive expressions related to measured soil parameters, crop type, growth stage and weather conditions. The actuation capabilities, *e.g.*, irrigation and fertilization, are expressed as subclasses of the *Service* class, each having further subclasses. In order to relate services to actuator devices, their descriptions are annotated as a conjunctive expression of the actuation capabilities (usually independent from the specific crop type) needed to completely accomplish the service. For example, a light irrigation intervention in a rice field is described in Figure 1. Processing occurs in two stages: (i) identify all farming services required in each area; (ii) detect the most suitable actuators for each service. For example, let us consider a field divided in three zones assigned to beans (Zone A), wheat (Zone B) and rice (Zone C). A monitor robot in each zone gathers soil parameters, composes a request identifying required actions by exploiting the Mini-ME embedded semantic matchmaker [4]. The action annotation is exposed via PSW. Three actuator robots provide irrigation and fertilization services: they retrieve descriptions from nearby beacons and execute semantic matchmaking to select the most useful zone for intervention. For instance, zone C needs low nitrogen fertilization and heavy irrigation, because the soil moisture level is low, nitrogen concentration is high and rice plants are flowering; in DL formulae:

$$\mathbf{ZoneC} \equiv Watering \sqcap \exists\, hasRainfallPerHour \sqcap \forall\, hasRainfallPerHour.(HighRainfallPerHour) \sqcap \forall\, hasCapacity.(HighWaterCapacity) \sqcap \exists\, hasCapacity \sqcap \exists\, hasNozzleDiameter \sqcap \forall\, hasNozzleDiameter.(HighNozzleDiameter) \sqcap NitrogenFertilization \sqcap \exists\, hasNitrogenQty \sqcap \forall\, hasNitrogenQty.(LowNitrogen) \sqcap \exists\, hasPhosphorusQty \sqcap \exists\, hasPotassiumQty \sqcap \forall\, hasPhosphorusQty.(MediumPhosphorus) \sqcap \forall\, hasPotassiumQty.(MediumPotassium).$$

Each actuator robot in proximity discovers the beacon and exploits matchmaking to rank the retrieved annotation (request) w.r.t. the provided capabilities (resource). In this way, the actuators self-schedule according to their characteristics. For example, Robot A_3 selects zone C, where a heavy irrigation and a light nitrogen fertilization service are required, because its description is:

$$\mathbf{RobotA_3} \equiv \forall\, hasCapacity.(HighWaterCapacity) \sqcap \forall\, hasRainfallPerHour.(HighRainfallPerHour) \sqcap \forall\, hasNozzleDiameter.(HighNozzleDiameter) \sqcap \forall\, hasJetLenght.(HighJetLenght) \sqcap \forall\, hasNitrogenQty.(LowNitrogen) \sqcap \forall\, hasPhosphorusQty.(MediumPhosphorus) \sqcap \forall\, hasPotassiumQty.(MediumPotassium) \sqcap WaterSprinkler.$$

Conclusion. The proposed Physical Semantic Web approach enhances the Google Physical Web, applying the Semantic Web of Things vision to the real world. Smart objects are capable of autonomic knowledge discovery and M2M interactions in the environment. The developed case study in precision agriculture allows evaluating benefits of the proposal.

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[2] http://www.udoo.org/udoo-dual-and-quad

[3] http://www.udoo.org/udoobuntu-2-minimal-edition

[4] 32-bitARMJava8SERuntimeEnv.(build1.8.091-b14)

[5] http://bluvision.com/wp-content/uploads/2015/12/Specs-iBEEK1.6

[6] http://github.com/sisinflab-swot/psw-robotics