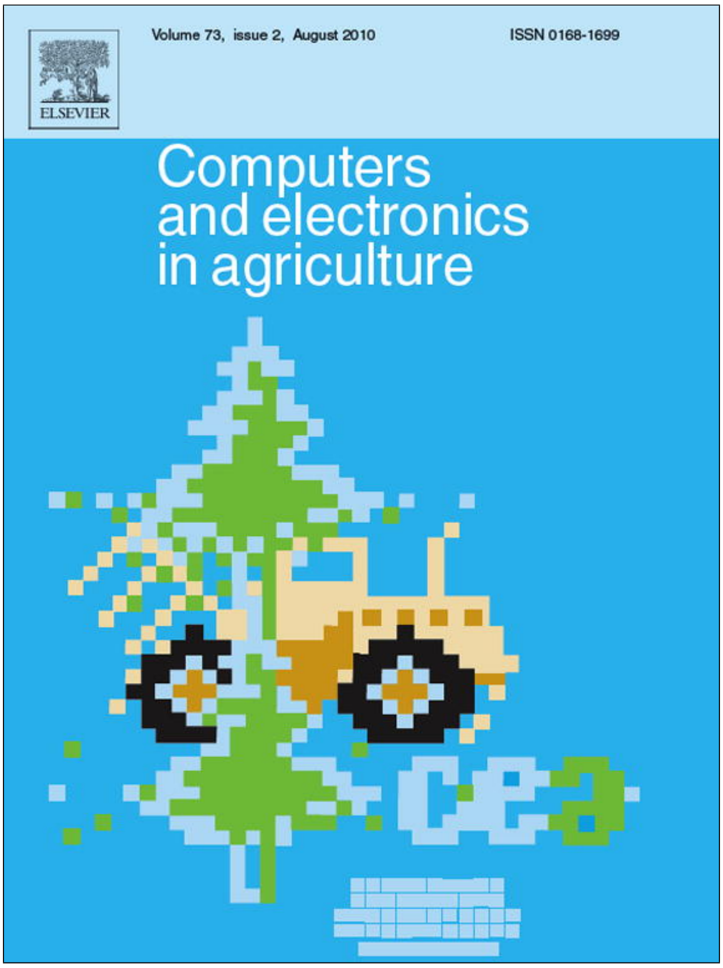
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The use of mobile devices with multi-tag technologies for an overall contextualized vineyard management

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ABSTRACT

This paper describes a Viticulture Service-Oriented Framework (VSOF) which turns around context elements or tags that are placed in the field and which can be decoded by mobile devices such as mobile phones or PDAs. The tags are used to automatically associate a field location to the relevant database tables or records and also to access contextual information or services. By pointing a mobile device to a tag, the viticulturalist may download data such as climatic data or upload information such as disease and pest incidence in a simple way, without having to provide coordinates or any other references, and without having to return to a central office. This work is part of an effort to implement a large-scale distributed cooperative network in the Douro Demarcated Region in Northeast Portugal, a region in which the effort makes particular sense due to the extremely variable topography and mesoclimates. The possibility of exchanging contextualized information and accessing contextualized services in the field, using well-known devices such as cell phones, may contribute to increase the rate of adoption of information technology in viticulture, and contribute to more efficient and closer-to-the-crops practices.

1. Introduction

Precision viticulture (PV) in the Douro Demarcated Region (DDR) is still at an early development stage despite the economic, social and environmental benefits that it could bring. The DDR is located in Northeast Portugal and consists mostly of steep hills (slopes reaching 15%) and narrow valleys that flatten out into plateaus above 400 m. The Douro river digs deeply into the mountains to form its bed, the vineyards being planted in terraces fashioned from the steep rocky slopes and supported by hundreds of kilometres of dry stone wall. These terraces and very steep slopes are the dominant element of the landscape, condition the layout of the vineyards and make transportation across the region difficult (Andresen et al., 2004). The DDR remains a remote, sparsely inhabited rural region, with an economy that is largely driven by the vine – or, more precisely, by a mosaic of vineyards with very variable topography and mesoclimates, and thus is an appropriate region for development of site-specific management (SSM).

Issues that are currently constraining the rate of adoption of information systems (Kitchen, 2007; Alvarez and Nuthall, 2006) include the need for applications that fit the farmers' working patterns, rather than the dependence on data handling procedures that are unfamiliar or unavailable to the farmers, and computer illiteracy. Further, agriculture-specific frameworks are often centered in the office rather than in the field. There is a lack of in-field support tools that effectively assist farmers in their daily practices: farming is not remotely done (Burrell et al., 2004). The interaction with information technology tools should occur closer to the crops, integrated in the farmers' daily routines, rather than *a posteriori*, in the office.

The pursuit of in-field solutions has lead to a large number of applications for collecting, processing and providing information to farmers. These applications, while potentially capable of performing operational tasks and/or providing decision support, remain limited in terms of their use in-field, a drawback that in part follows from their very nature: they are typically conceived for personal computers, as browser or standalone applications. Some recent examples can be found in Kuflik et al. (2009), Harwood and Hadley (2009) and Thorp et al. (2008).

A number of mobile-based solutions have also been discussed. However, they also exhibit limitations in the ability to access the contextual information, since typically they depend exclusively on

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Global Positioning System (GPS) coordinates to associate activities or operations to locations. A recent example can be found in Fang and He (2008), where a Pocket PC-based in-field fast information collection system is proposed. Charvat et al. (2006) proposes the MobilDat (Mobile Data Visualization and Updating), the goal of which is to design and implement a mobile solution and mobile visualization tool for sharing and updating spatial knowledge, focusing on forestry, interoperability and standardization methods and tools for mobile data management. Hornbuckle et al. (2006) describe a Pocket PC-based decision support system, intended to be used by farmers to improve surface irrigation system performance, which uses field-based inputs of the advancing water front collected with the GPS.

In the case of the DDR, the farmers' age and their low level of technological awareness are additional obstacles that must be addressed when designing a site-specific management (SSM) application. A critical question is how SSM will affect the economic and social structure of the rural communities. There is little scientific evidence to draw from, but the existing experience about the introduction of technology in agriculture and industry may provide valuable experience (Plant, 2001). It is safe to state that usability and contextualization are two characteristics of utmost importance in the development of any such technological tools.

One approach to the problem of pushing the decision level closer to the practitioner is to tag site-specific elements, and design information and decision support systems that rely on them. This approach yields a reliable mechanism to quickly look up information or initiate a site-specific action. Due to the growing computational power of mobile devices, the decoding of tags is not a problem. Visual tags that depend on image processing algorithms are replacing the well-known EAN13 barcodes because of their ability to handle more data per tag area. Indeed, 2D visual tags and mobile devices are already being used in many activities. The traceability system described by (Seine et al., 2004) adopted 2D visual tags because they were the cheapest and they performed better in water environments than other identification (ID) technologies. The decoding can be made using widely available mobile devices, which gives consumers easy access to the product information and increases their confidence. Ampatzidis and Vougioukas (2009) have evaluated the use of RFID and barcode technologies in manual fruit harvesting to improve traceability. The feasibility of using linear and 2D barcodes was also explored by Froschle et al. (2009) in connection with poultry.

The aim of this work is to promote open-source and easy-to-use PV decision support and management services that eventually bridge the gap between in-field practices and office-centered applications. For this one needs real-time contextualized in-field information, which can be obtained by using everyday "on-hands" technology in an innovative way. There is no shortage of applications. In fact, this work was partly motivated by the number of daily viticultural tasks that can be effectively addressed through the use of information technologies.

For instance, fixing in each vineyard parcel a contextualization tag containing predefined static information about the parcel and an encoded Uniform Resource Locator (URL) makes real-time vineyard management a future reality. In this case, the tag data can be used to index remote web-based information and services; or it can be used as an entry point to a SSM application. By pointing his mobile device to the tag, the viticulturalist associates his position in the field with the database data. The association may work for upload as well as for download. The tag ensures that any data uploaded in the field becomes automatically associated with the correct database tables or records and, similarly, any data downloaded from the database will automatically match the viticulturalist's position in the field.

For example, it is known that phytosanitary treatments and human intervention should take place as soon as any anomalies are detected (Magalhães, 1989; Fregoni, 1999). In fact, the underlying problems can often be predicted by the farmers, who draw on their accumulated experience and the relevant climatic data, which plays a key role. After pointing his mobile device to the tag, the viticulturalist may access the climatic parameters (humidity, temperature, etc.) at the current location; he may then upload any relevant observations or conclusions to the database – without having to worry about linking the data to a field location. This is of interest whenever data obtained on-site (disease and pest incidence, yield, etc.) needs to be uploaded to a database, or when the database has to be queried in reference to a particular field location. The automatic contextualization provided by the tags not only simplifies the viticulturalist task, but also reduces the response time and essentially eliminates the risk of input errors and database inconsistencies.

The goal of this paper is to show how mobile devices and identification tags can be combined to render contextualized information and services to support in-field PV management practices. Section 2 overviews 1D barcodes or linear barcodes, 2D visual tags and Near Field Communications (NFC) compliant tags as key technologies to identify in-field elements and to access site-specific services. Section 3 presents the developed proof-of-concept framework application, which supports the vineyard practices. System architecture, client interface and the service-oriented platform are presented in Section 4. The fifth section draws conclusions, discusses what can be achieved with this approach and reveals some of the future work that is being undertaken to integrate these tools in a wider cooperative network.

2. Mobile devices and tags

According to Plant (2001), when a new technology is introduced in a field of activity the demands placed on the workers' skills increase. Mobile devices, mainly cell phones, are embedded in daily routines and represent the most common and widely used technology today. This suggests that educational level is not a severe barrier to their use and their adoption for site-specific management of vineyards may contribute to increase the technological awareness of the potential of PV, particularly in the DDR.

Studies have shown that in Portugal, at the first quarter of 2009, the cell phone/person ratio was 140.6%, which is approximately 20% above the European Union average (ICP-ANACOM, 2009). As a rule, everyone carries at least one mobile device. This wide availability makes the cell phone an ideal tool for interacting with information technology and on-demand services. This idea gets reinforced by the current evolution trends in mobile devices, which suggest an enormous potential in using these devices to support PV management practices. For these reasons, mobile devices can be a key technology to promote ubiquity in PV by accessing data and related services. Fig. 1 illustrates the expected scenario, in which a viticulturalist uses its mobile device to access on-demand services and perform several activities that rely on the interaction between the *in situ* user and the office back-end.

2.1. Tag-based identification technologies

Tags, as a machine-readable representation of data (Gao et al., 2007), have been largely used to represent data and to link physical objects to digital information. There are several tag-based ID technologies, such as barcodes, visual tags and radio-frequency identification (RFID) tags that in combination with an easy-to-use on-the-fly decoding system yields an effective, powerful and innovative way of providing contextualized information and on-

Table 1
Strengths and weaknesses of tag-based identification technologies.

	RF tags	Barcode	2D visual tags
Strengths	Automatic non-visual reading: can be decoded while inside objects.	Printable; low cost; suitable for visual decoding.	Printable; high data store capability; low cost; suitable for visual decoding.
Weaknesses	Not printable; cost; reading problems; RFID portable decoder.	Low data store capability; decoding in dirty environments.	Decoding in dirty environments.

Fig. 1. Ubiquity in vineyard management practices. In this example, a cell phone and a bidimensional tag are used by a viticulturalist as an identification element to access, *in situ*, contextualized on-demand services, supplied, for example, by a knowledge-based data repository. Disease and pest checks, treatments, green harvesting, and other practices can be recorded *in-field* much more easier.

demand services. Table 1 shows a comparison between different types of tag-based identification technologies.

Found almost everywhere, 1D barcodes, linear barcodes or simply barcodes are a tag-based identification technology that has the capability to store and represent data through parallel lines of different widths. They are massively used in retail commerce where a manufacturer can assign a Unique Identifying Number (UID) to a product, making automatic product management, tracking and inventory possible. In addition, a relational database can be created to relate this UID to relevant product information.

Two-dimensional or 2D barcodes represent another early step in the tag systems technological evolution. They have emerged as the natural way to encode large quantities of alphanumeric data and to link objects to web-based information and services, through the encoding of an URL (Toye et al., 2005; Parikh and Lazowska, 2006; Rekimoto and Ayatsuka, 2000). Among the most significant 2D visual tags implementations are QR Code, PDF417, DataMatrix and MaxiCode. Table 2 summarizes their main characteristics. The QR Code open-source solution emerges as the most suitable solution for applications that require the decoding of large quantities of alphanumeric data and fast scan speeds (Chaisatien and Akahori, 2006).

RFID is another well-known technology used in identification tags. It is often applied to a product for identification or tracking purposes. Although a very promising possibility, the massive incorporation of RFID tag readers in mobile devices remains unlikely in the near future (Seine et al., 2004; Toye et al., 2005; Falas and Kashani, 2007). Furthermore, despite the massive cost reductions of the past decade, RFID is still not cost-efficient for a variety of targets (Roussos and Kostakos, 2009). Nevertheless, mobile devices able to read RFID tags are emerging in the market, in the hope of simplifying the interaction between users and services and providing a contactless and secure payment method, e-ticketing being a likely application (VISA, 2009); It employs a technology known as Near Field Communication that stands for a new, short-range wireless technology evolved from a combination of existing contactless identification and interconnection technologies (Forum, 2009). The embedding of such technology in mobile devices will make available to the general public powerful contextualization mechanisms. It may also contribute to the goal of having a generic RFID reader embedded in each mobile device, pushing new solutions to product-based services.

2.2. Mobile devices as a tag decoding tool

There are two distinct approaches to the decoding of linear barcodes. The first relies on optical scanners and is based on widely available, well established infrared technology. The scanners read data encoded by lines and spaces of different widths. The second approach is based on the digital processing of the scanned image. But optical scanners, although often used as readers, are not yet widespread among the general public and remain unsuitable for daily, in-field agricultural tasks. In contrast, decoding software able to operate on scanned images or on real-time images is becoming available on an increasing number of mobile platforms with built-in cameras and Java support. This makes them powerful tools for reading barcode data and associating them with products and services. Several barcode readers are freely available: i-enigma, Semacode, Kayva and UpCode, among others. In fact, the trend is to offer mobile devices and smartphones with built-in scanning software for linear and also 2D barcodes (Ebner, 2008).

The decoding of 2D barcodes is typically performed by visual inspection systems to achieve a very high data decoding rate. This is important for sensitive applications like airport luggage control and the handling of passenger boarding passes (ITSC, 2008). The use of mobile devices with built-in cameras to read 2D barcodes is currently a popular research topic with several practical applications (Rouillard, 2008). Java software running on mobile devices

Table 2
Capacity, features and standards for 2D visual tags (Gao et al., 2007).

	QR Code	PDF417	DataMatrix	MaxiCode
Developer (country)	DENSO (Japan)	Symbol Technologies (USA)	RVSI Acuity (CiMatrix USA)	UPS (USA)
Numeric (characters)	7.089	2.710	3.116	138
Alphanumeric (characters)	4.296	1.850	2.355	93
Binary (bytes)	2.953	1.018	1.556	–
Main features	Large capacity Small size High speed scan	Large capacity	Small size	High speed scan

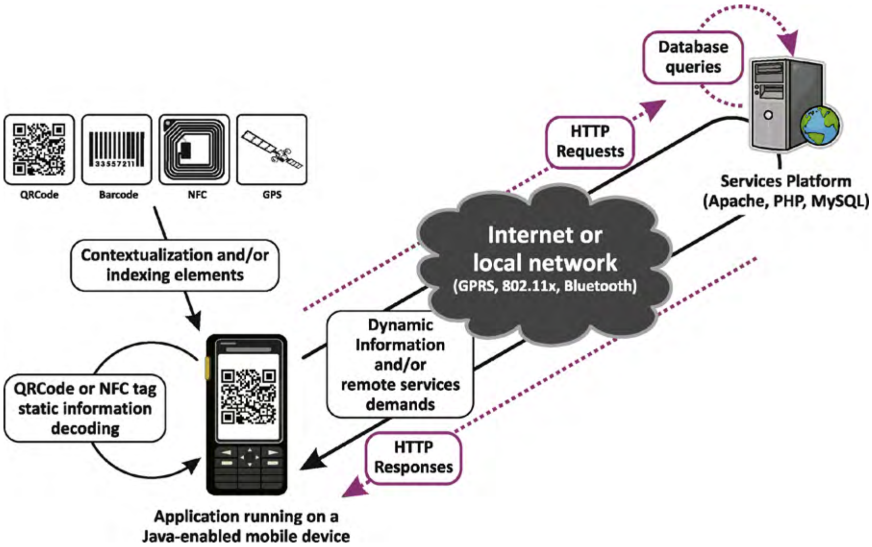

Fig. 2. VSOF architecture overview, illustrating the mechanism of accessing a remote database through the specific HTTP request and response to render dynamic information and remote services, indexed by a contextualization mechanism.

and smartphones for coding and decoding 2D barcodes, such as QR Code, Semacodes, and DataMatrix, already exist and are freely available, making them a consensual answer (Rohs and Gfeller, 2004; Falas and Kashani, 2007) to the low cost decoding problem.

RFID technology requires a rather different methodology to decode RFID tags since it relies on radio-frequency data transfer between two devices. To this effect, the reader and the tag exchange data through an inductive coupling that is also used for powering the passive tag. RFID readers can also work as standalone devices that communicate with a host system through some sort of interface (Roussos and Kostakos, 2009). This technology has evolved to mobile devices through the use of NFC. One of the very first commercial cell phones to incorporate this technology is the Nokia 6212 Classic model, which may contribute decisively to a more widespread use of RFID-based solutions.

The fact that mobile devices are becoming able to decode 1D and 2D barcodes as well as RFID tags shows the potential of the devices in the context of ubiquitous precision viticulture. Mobile devices have reached a stage of development that makes them potentially able to support on-demand services and to assist in a number of management tasks in precision viticulture.

3. Framework for viticulture management services

The Viticulture Service-Oriented Framework (VSOF) intends to overcome the general difficulties that occur when engineering and agronomics are brought together. The VSOF is a framework that supports some common PV practices, by means of a comprehensive approach based on farmers' day-to-day routines, across all seasons and pushing SSM tools to the field. This is carried out with the help of a friendly interface specifically developed to be used in mobile devices, accelerating *in situ* information processing. An overview of the proposed VSOF architecture is depicted in Fig. 2, which illustrates the interaction between the contextualization and/or indexing elements and the remote services platform.

The VSOF framework uses visual and NFC tags, as well as GPS coordinates, to render contextual or indexed on-demand services related to tagged objects or products. The principle of operation is simple, and depends only on the availability of suitable decoding technology on the used mobile device. For instance, when a certain parcel of vines needs to be specified in order to obtain some information, GPS coordinates can be used, if available. Otherwise, if the parcel has been indexed by a 2D barcode (similar to the one depicted in Fig. 1), the mobile application can decode the visual tag and supply the required information. Furthermore, the 2D barcode can even be replaced by a NFC tag and still convey the required information. Although the decoding of multiple tag technologies is supported by the same software application, QR Codes and NFC tags provide additional and powerful features. On one hand, these elements can be used as a service indexing mechanism; on the other, they can also be used to store specific and static information, being decoded offline by the same software application.

The VSOF framework is very flexible, and the process of rendering dynamic information and services that builds upon the tagged elements is almost straightforward. The mobile device application only has to use the decoded tag information to access a cooperative knowledge-based system where an information repository is accessed through HTTP requests. In the case of 2D barcodes and NFC tags, additional data processing is unnecessary since the capacity of these tags is sufficient to store a complete URL. However, linear barcodes and GPS coordinates do not have this ability. The difficulty can be circumvented by an additional procedure, by means of which an unique related URL is generated.The connection between the mobile device application and the information repository is always needed whenever a real-time interaction is required. This can be accomplished using any wireless technology such as GPRS (General Packet Radio Service), 802.11x or Bluetooth, whatever is available at the moment in the mobile device surrounding environment. For in-field operation, the user can also access the remote repository by using any specific access point, if available in range (deployed as an in-field cluster-head and gateway for wireless sensor networks, as described in a previous work (Morais et al., 2008), equipped with a 802.11 access point and Bluetooth). Offline operation is also possible with all the four supported indexing technologies. To this effect, the user can store tag information and/or GPS coordinates and postpone operation until connected.

3.1. The use of context mechanisms in PV practices

The feasibility of the above referenced contextualization mechanisms has been successfully evaluated in PV environments for more than one year, using the experimental application prototype and VSOF. The simplest linear barcode is embedded in all products used in phytosanitary treatments, which is used to access useful

Fig. 3. Photograph of one vintage tub with a visual tag context element used in an integrated management application.

and important information about the product and its prescription. In addition, the developed application can be used to decode bottle linear barcodes for tracking purposes as well as to retrieve information about grapes and parcels from where that wine was produced.

2D barcodes (specifically QR Codes and DataMatrix) have been also used to convey dynamic information. The additional level of indirection brings one additional benefit: the use of the same printed tag. Besides vineyard grapes and bard identification (which is regarded as static information, thus being obtained directly from the tag) QR Codes have been used in a management application of vintage tub rentals, where they are used to track tubs (Fig. 3). With several free online sites to encode data in QR Code format (for instance in http://reader.kaywa.com/), these tags are being used in many other applications where static information is required as well as URLs to access dynamic services. Specific canopy management, farm integrated management and data entry points to SSM tools are among the most used applications of QR Codes under our PV perspective, where GPS has often to be discarded due to its lack of resolution.However, GPS coordinates remain useful for other purposes. They have been used to register the in-field variability as geographically encoded data, or to record points at which phytosanitary products have been used. Many other applications of GPS are described in the literature. The examples include yield measurement systems (Auernhammer et al., 1994) and ground speed measurement in variable-rate application equipment (Neményi et al., 2003; Keskin and Say, 2006).

Since the use of NFC technology requires a new device, its use in agronomics is limited to applications where this technology presents an important key advantage over barcodes. Visual codes can be decoded by a mobile device equipped with a camera, but NFC tags may be written by a compliant device. This distinctive factor makes the NFC system a complement to the range of available tag technologies that can be used to access the VSOF. To this effect, the feasibility of using NFC tags in oak tanks or barrels in a wine aging management application in a DDR wine cellar is being evaluated. In this scenario, a NFC compliant device has been used not only to obtain winemaking related data but also to update tag information after performing operations on the barrel such as the dates of each analytical control and wine corrections.

This is going one step beyond the passive tag, which simply associates data and position. In this case the tag is already an active element, able to work as a data destination instead of a mere data source.

3.2. The VSOF object model

The VSOF follows the physical representation of a whole-basis farm, and is an UML (Unified Modeling Language) class model. It represents the conceptual overview of the management framework main classes and translates the physical construction of a vineyard main objects. These classes are the main entities that support the core of vineyard in-field information system. Fig. 4 presents the simplified diagram of this model.

The main class is the `Farm` object, composed by parcels (similar to a vineyard management zone), which in turn are a composition made from bards which are composed by vines (canopies). There can be several viticulturists working on a farm, so the `Viticulturist` class supports this association and an authentication process. This example focuses the available services associated to the selected parcel, such as phytosanitary treatments and vineyard interventions, each one described by its own class. For example, the `PhytosanitaryTreatments` class translates applied parcels' phytosanitary treatments and has three generalizations: `Diseases`, `Plagues` and `Anomalies` classes, each one translating a different vineyard treatment.

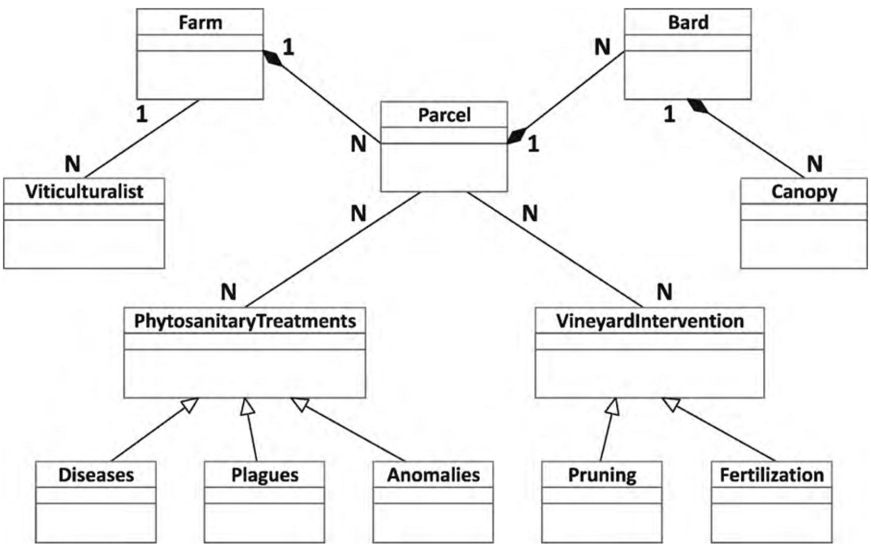

Fig. 4. UML main classes diagram of the VSOF repository.

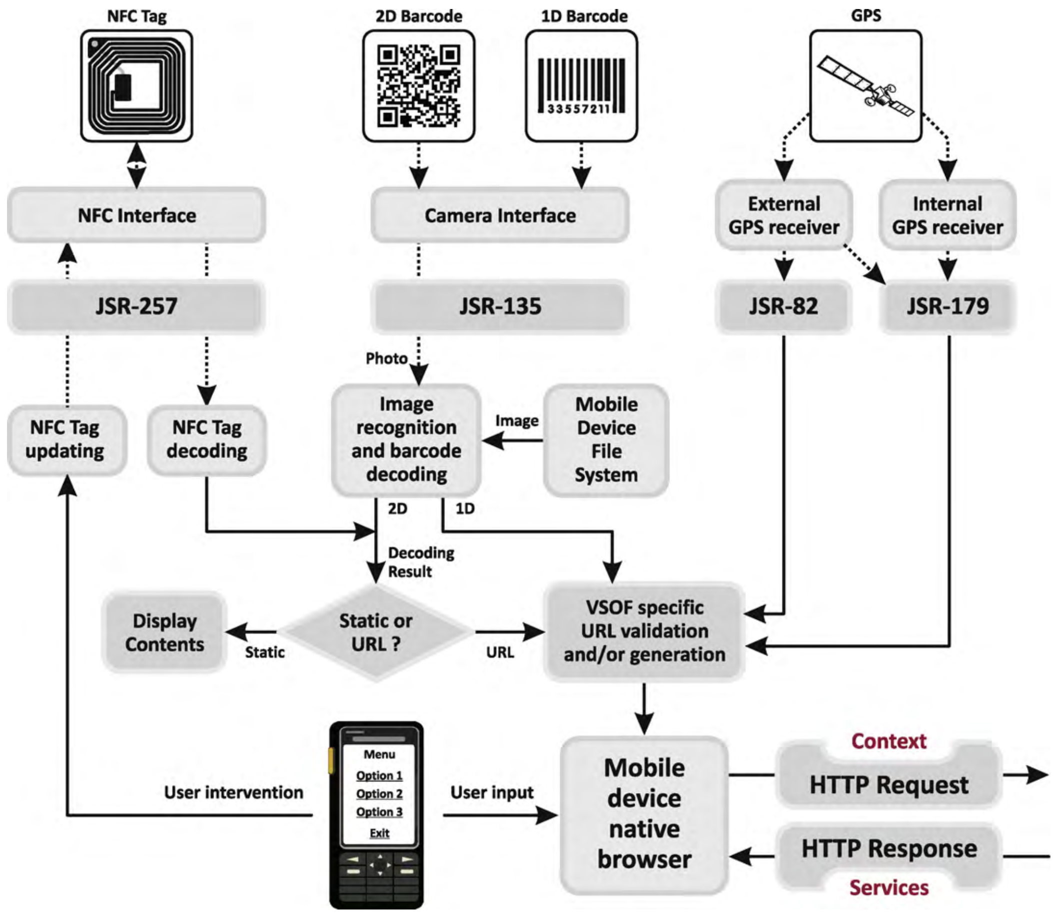

Fig. 5. Mobile device application functional overview, illustrating the data flow between the several contextualization elements and the mobile device native browser to access VSOF on-demand services.

3.3. Mobile device application

The mobile device application is the VSOF client software (called the Viticulture Management Mobile Client – VMMC). This client software performs three major functions: (i) tag decoding, (ii) association of tag data to an application item and (iii) accessing and interacting with the VSOF by issuing specific HTTP requests and receiving the contextualized HTTP responses.

Full access to VSOF services is limited to registered users. Guests may use the VSOF platform to access public data and tourism services. The VMMC application starts with the user authentication. Personal info may be stored in a RecordStore (RS), which is also used to store the user profile.

The functional overview of the VMMC application is depicted in Fig. 5. The decoding engine is responsible for retrieving tag and/or GPS data from the corresponding Application Programming Interface (API). To allow barcode decoding, the selected device must support the Mobile Media Application Programming Interface (MMAPI), or simply Java Specification Request 135 (JSR-135), that enables access to native multimedia services. JSR-135 support is available in virtually every mobile device with a built-in camera. After selecting 2D or 1D barcodes capture mode, the VMMC application seeks for a valid pattern. During this phase, several recognition scans are performed. If a tag is not detected, an auto-zoom request is issued and the process is repeated. If JSR-135 is not supported in a specific device model, the application can load a captured photo and decode it in an offline mode.

NFC support is provided by Java JSR-257, which is a standardized API that enables NFC applications to control the NFC interface. In a NFC compliant device, data from the JSR-257 API is handled by the VMMC in the same way JSR-135 is. At this stage of NFC technology integration, the interest of using these tags is to contextualize PV management tools, with the aim of in a near future integrating e-commerce tools and secured-based services that may assist these practices.

The VMMC application also allows the use of GPS coordinates to index an open-field location and is thus suitable for retrieving a location-based VSOF service. To support the use of a GPS receiver, the mobile device must support JSR-82 as the common interface to an optional GPS external receiver. Embedded GPS receivers are supported by JSR-179 API that also supports external devices using, for instance, a Bluetooth connection.

In the case of linear barcodes and GPS, the VMMC generates a specific HTTP request, where such data are used to index a related set of available services. 2D barcodes and NFC compliant tags may be used to store structured data, such as static information about tagged product, URLs or both.

Following the flowchart of Fig. 5, and after the decoding or retrieving GPS coordinates, the VMMC generates a specific URL to access the remote VSOF server. While 2D barcodes and NFC compliant tags can be used to store structured data such as static information about tagged product, URLs or both, linear barcodes and GPS coordinates do not store a valid URL. In those cases, the VMMC application generates a specific HTTP request, where such data is used to index a related set of available services. To this effect, the application issues the appropriate HTTP request (the context key in Fig. 5) to VSOF, through the device native browser. The HTTP response from the VSOF (the required service in Fig. 5) is a web-page generated accordingly with the tag context, being different for each tag. In addition, information management, such as general-purpose

Table 3
Conversion between 1D barcode and GPS data into a valid VMMC URL, to access the VSOF remote server.

1D barcode data (EAN13)	GPS coordinates	Generated URL (for VSOF registered users and guests)
5601009941636	N/A	https://193.136.42.240/vsof/secure/index.php?barcode=5601009941636;sessionid=Dd97Sw8R4JyKrhsNQstftYh8TCs69wPG (VSOF registered user)
5601009941636	N/A	http://193.136.42.240/vsof/index.php?barcode=5601009941636 (guest user)
N/A	lat = 41.286855° long = −7.736793°	https://193.136.42.240/vsof/secure/index.php?lat=41.286855&long=-7.736793;sessionid=r357wPGx2QkKcQTss54YQ3KFZQGKZtHC (VSOF registered user)
N/A	lat = 41.286855° long = −7.736793°	http://193.136.42.240/vsof/index.php?lat=41.286855&long=-7.736793 (guest user)

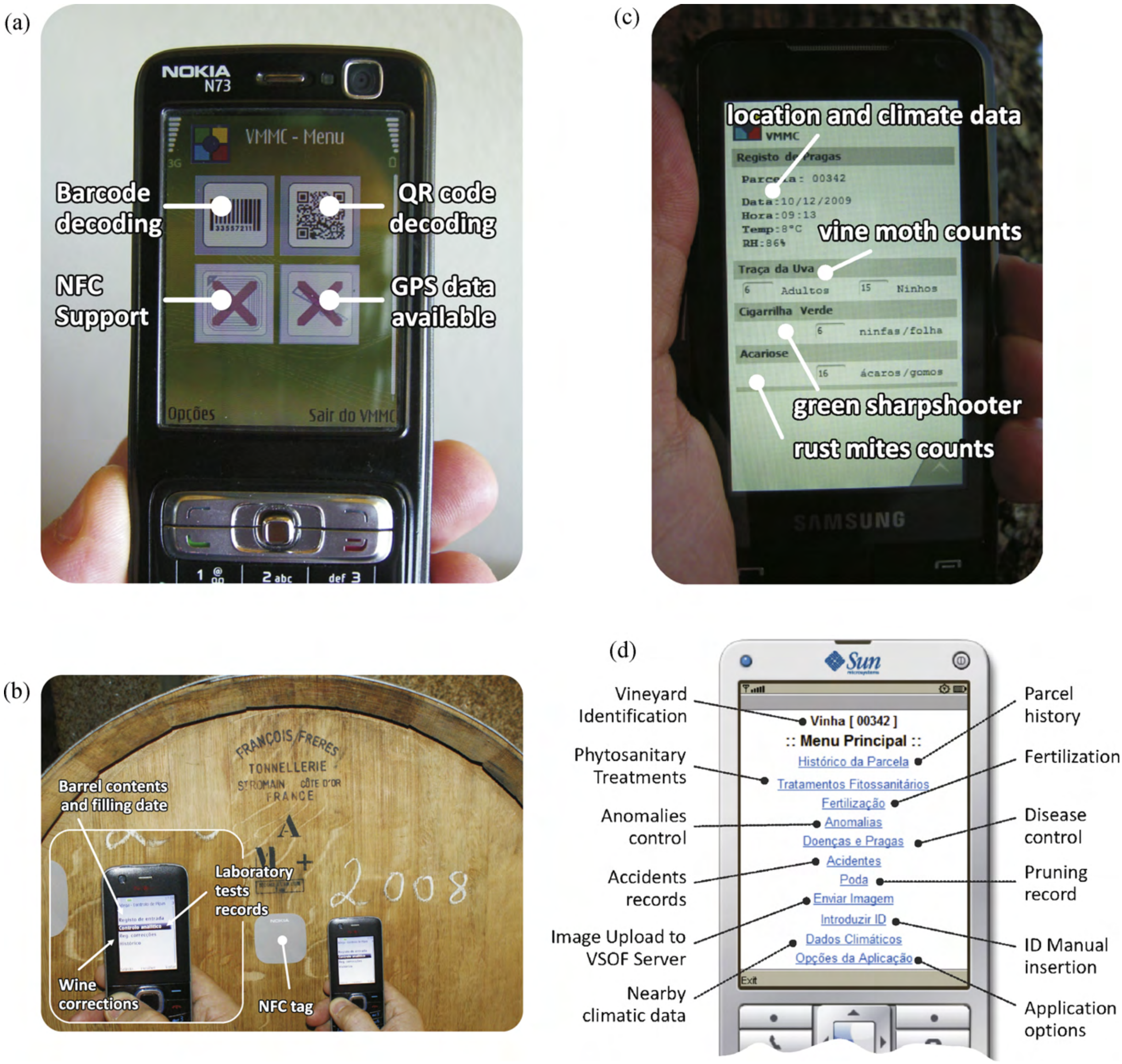

Fig. 6. Overview of the VMMC application provided by the VSOF, running on several Java-enabled cell phones. (a) Starting page of the VMMC, illustrating the available indexing technologies on the target mobile device. (b) Oak barrel in a wine cellar where a NFC compliant tag is used to invoque the VMMC application to render and update wine corrections and laboratorial tests data records. (c) Example of the interface to register most common grape vine diseases (vine moth, green sharpshooter and rust mites). (d) Screen capture of the main menu of the VMMC application, developed in the NetBeans IDE 6.1 platform and running on a SUN Microsystems emulator (presented in Portuguese and translated to English).

data entry capabilities are also provided, as part of the interaction between the viticulturalist and the VSOF. Static information, such as text messages, stored in 2D and NFC compliant tags, are presented directly on the mobile device display. Table 3 shows two examples of URL generation based on 1D barcodes and GPS coordinates, either for VSOF registered users and public access.

The VMMC application prototype was tested with the Nokia models N73, N80, N95 and 6212 Classic, HTC model Touch, Samsung model Omnia and SonyEricsson model K800i mobile devices. According to the Java specifications, any mobile device compliant with the specification CLDC 1.0 (Connected Limited Device Configuration) and MIDP 2.0 (Mobile Information Device Profile) has the minimum requirements to run the VMMC application. The installation procedure of the prototype management application requires it to be transferred once to the target mobile device, through any available data transfer technology.

4. Site-specific management application prototype

To promote ubiquity within our PV scenario a site-specific management application, that serves as proof-of-concept for the VSOF, has been developed. The main goal was to illustrate the feasibility of using different tags to contextualize on-demand services, available in a cooperative knowledge-based network. It was conceived to help DDR viticulturalists and winemakers to register

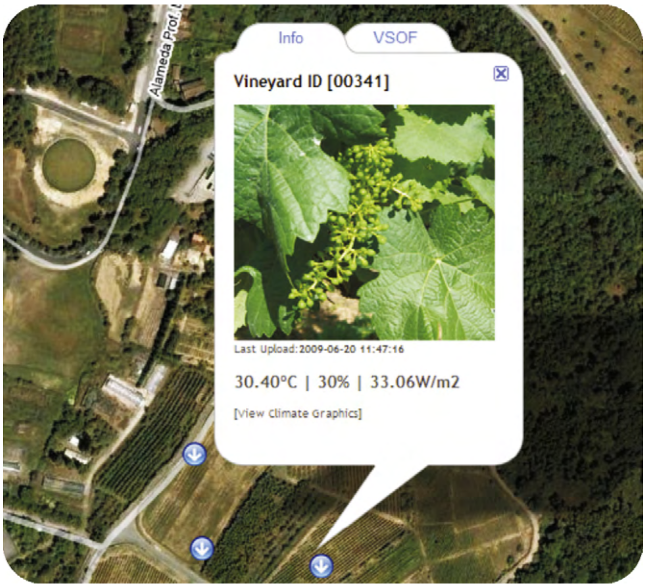

Fig. 7. Screen capture of the management application interface. For each tagged point, the most recent VMMC application uploaded photo is shown in the `Info` tab of the pop-up balloon.

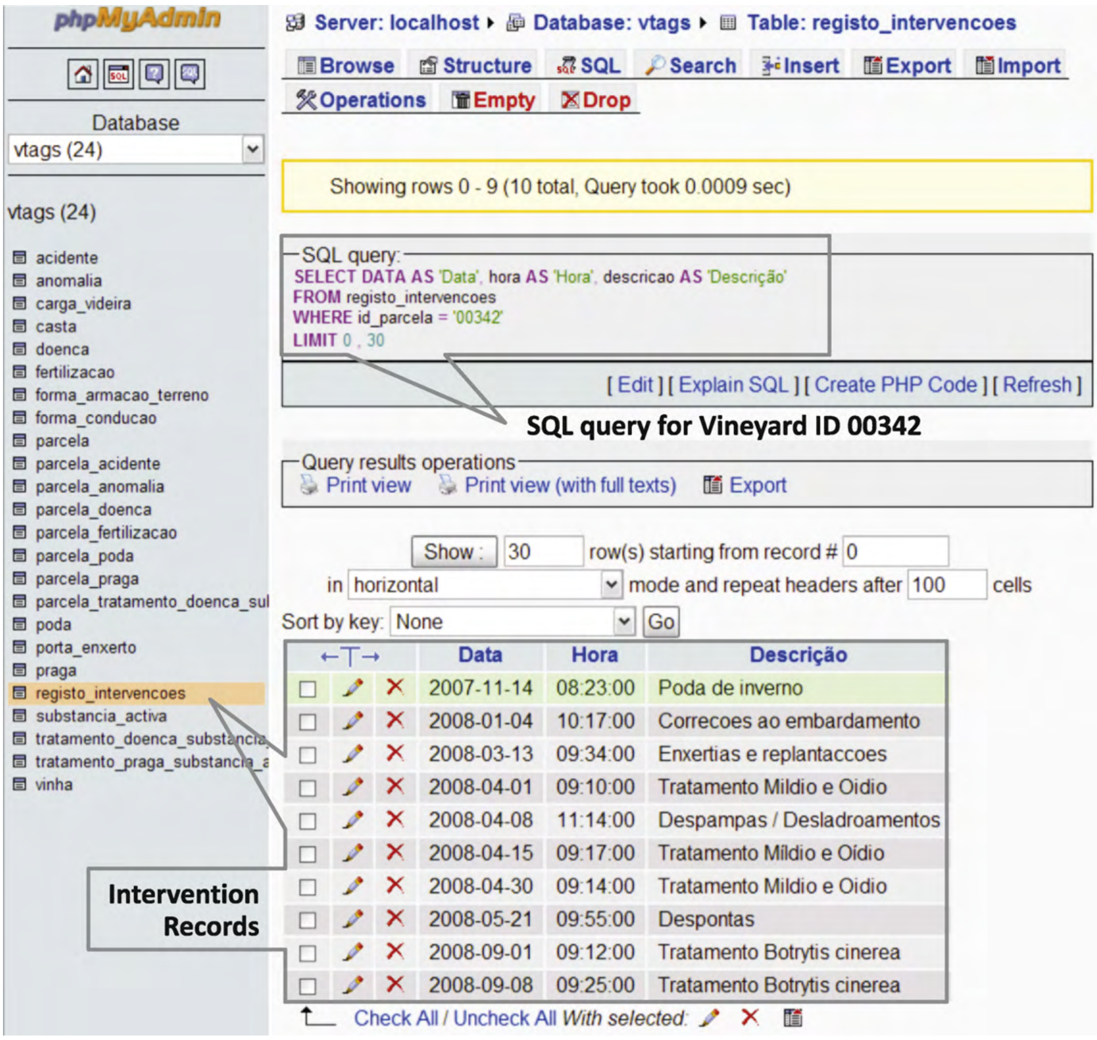

Fig. 8. Screen capture of the `phpMyAdmin` interface to the `MySQL` database where all VSOF intervention records are handled by the mobile device VMMC application.

and read, *in situ*, site-specific information about vineyard management, including interventions and treatments. Simultaneously, an image upload and storage service was also implemented as a part of an automatic disease detection system. This particular feature allows an automatic picture-to-location indexing service which may be useful to register interventions and other vine characteristics.

Fig. 6 gives an overview of the implemented services available in-field through the use of VMMC and VSOF. Fig. 6(a) shows a photograph of the starting page of the VMMC application, where there are presented the technologies supported by the mobile device for tag decoding. In this case, the VMMC is running on a Nokia N73 mobile device which has JSR-135 support only (NFC support and GPS data are not available in this model). To demonstrate the feasibility of using the VMMC application to register and read relevant information about wine corrections, the VSOF has been complemented with an oak barrels management application for a wine cellar, which uses NFC compliant tags to store winemaking data on the barrels themselves. For each barrel, Fig. 6(b) shows the available options in the VMMC application, running on a NFC compliant mobile device (Nokia 6212 Classic), with the following brief descriptions (translated from Portuguese):

- `Registo de entrada` (Input record): Wine grape varieties and date when cask was filled.
- `Controlo analítico` (Laboratory tests): Analytical tests performed and dates (pH, sugar contents, percent alcohol, available sulfur, acidity, among others).
- `Registo de correcções` (Wine corrections): Fining agents and preservatives used during the wine aging process.
- `Histórico` (History): Last month operations history records.

To further demonstrate the feasibility of VMMC/VSOF for in-field management practices, a set of services that are contextualized by any available indexing mechanisms (Fig. 6(c) and (d)) has been implemented.

Fig. 6(c) illustrates how the weekly inspections that need to be carried out on vines are managed. This is a textual input example: the user can register some common grape wine disease checks such as the caterpillars of the vine moth (`traça da uva`, *Phalaenoides glycine*), one of the most common pests of the grape vine, green sharpshooter (`cigarrilha verde`, *Draeculacephala minerva*) counts per leaf and the mean number of rust mites (`acariose`, *Calepitrimerus vitis*) per bud. As always, when a tag is decoded or GPS coordinates are used, all subsequent services are automatically contextualized, without the need for any further in-field element processing.

Besides helping viticulturists' daily in-field operations, this management tool can also provide a helpful scheduling mechanism for vineyard interventions and help to predict the occurrence of future vineyard's phenological states, through a continuous analysis of in-field registered data and interventions. Moreover, it can generate automatic reminders when a particular operation should be done.

Fig. 7 shows a screen capture of the user management application interface VSOF. This interface is based on the Google Maps API, showing the position of each vineyard tag, each one corresponding to an entry point in the VSOF database. By double-clicking each tag, a balloon pops-up showing the most recent data uploaded by the VMMC application. Along with the photo and link provided to the climate data, available in the Info tab, the VSOF tab displays all the data regarding the selected parcel interventions. This MySQL database is managed using the well-known, open-source front end, phpMyAdmin, Fig. 8. This data repository materializes one year of continuous recording of in-field operations, yielding a valuable experience and a sustained approach for the framework and prototype validation. In the example illustrated in Fig. 8, the SQL query was generated to retrieve all interventions regarding vineyard ID = 00342 for the 2007/2008 season.

5. Conclusions and final remarks

The feasibility of an integrated framework that supports the daily activities of viticulturalists *in the field* has been demonstrated. The system combines contextualization elements (tags) placed in the vines with readers based on widely available mobile devices. This circumvents one problem shared by many decision support tools and farm management applications: the gap between the computer-based management, carried out in the office, and the farm interventions, obviously accomplished in the field.

Since in the target region (the DDR, in Northeast Portugal) the required mobile devices are very common, their need does not represent a strong or artificial constraint. In fact, given the level of computer illiteracy in the region, these mobile devices are the technology with which more farmers are highly familiar.

In addition to this, usability and design issues – although not our main concern – have been carefully addressed. The implementation of the proposed SSM tools represents a major step forward in bridging the gap between the farmers and their requirements and the technology offered to them.

The potential applications of the presented framework as a site-specific management tool for PV practices have been highlighted and a comprehensive set of prototype applications, that enhance the usability and usefulness of mobile devices in agricultural applications, has been presented. By embedding these "handy" tools in everyday agricultural practices, the vision of a truly ubiquitous, technology-intense PV can become a reality.

One innovative aspect behind the VMMC application is its multi-tag technology decoding support, which is an important advantage when tagging or indexing different objects to initiate a site or object specific action. Towards the integration of agricultural tools in one framework, the VMMC application can also be used, without changes, in many other tasks, such as public information services or other contextualized data entry points within the whole-farm concept.

Yet another advantage of tagging in-field key points follows from the dynamic nature of the information delivered. Indeed, new services can easily be added at the VSOF server side without changing the tags. As a result, the same VMMC application becomes capable of offering new contextualized services. For example, the end-user could request the weather data at a certain point, according to the closest sensors of a wireless sensor network (Morais et al., 2008).

The continuing technological advances in mobile devices and their user interfaces may in the near future suggest new directions for research or answers to difficulties met today. Usability and user interface are certainly one of the areas in which more work should be done, accompanying the evolving technology (consider the iPhone and Voice Control, for example). As for the difficulties, it has been noticed that some LCD screens become difficult to read outdoors, in bright sunlight. Transflective displays, however, do not show this problem: they depend on LED backlighting indoors but have a reflective surface that produces very readable images even under direct sunlight. This technology will improve the usability of the described system and help to boost its rate of adoption.

The work described is part of a long-term effort to introduce PV in the DDR. The outstanding characteristics of the region, marked by a deep symbiosis between wine and tourism, makes it an excellent test bed for innovative management techniques applied both to PV practices and tourism services. To the best of our knowledge, this is the first work in which in-field site-specific management concepts based on tags are applied to viticulture environments. However, the connection between the wine and tourism in the DDR region opens a wide range of possibilities: since most of the farms support wine tourism, the tags could be used by tourists to access public information and commercial services.

The results so far are being truly encouraging. The flexibility of the proposed framework has revealed a potential that remains largely untapped, and is currently being explored to support PV and offer a number of additional benefits, such as e-commerce, tourism and other location-based services.

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