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Review

RFID-plants in the smart city: Applications and outlook for urban green management

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ABSTRACT

A city may become smart and green through strategic deployment of Information and Communication Technology infrastructure and services to achieve sustainability policy objectives in which trees have to be involved. Plants not only constitute green space useful to contrast urban pollution effects or provide ecosystemic benefits to residents but they can also be used as bioindicators and their involvement in communication networks can represent a significant contribution to build a smart, green city. The concept of the Internet of Things (IoT) envisages that objects that surround us will be connected and there are no reasons to exclude urban trees from among the “wired object”. Radio frequency identification devices (RFID) may represent a prerequisite of IoT application and they can be used for tree protection and management, thanks to tagging experience carried out on various plant species. RFID tags can be easily associated with plants, externally or internally. This latter approach is particularly indicated if the identification of trees needs to be secured since its production, eliminating the risk of tag losses or removal. Interesting applications may be derived by implementing RFID tags in biomonitoring systems in order to guarantee a real-time data communication in which tags may act as antennas for multifunctional green spaces. Moreover, the virtualization of green areas using sensors and mobile devices can lead to the desktop management of the urban green with the possibility of implementing a real-time navigation throughout the areas. A complex relational network in which data can be collected thanks to geospatial methods can be integrated by an IoT approach in which RFID-plants can play a significant role.

A smart green approach

Nowadays, “smart city” represents a paradigm of a forthcoming future that will change – or is changing – a citizen’s life without possibility to go backward. In these next-generation cities all will be wired, shared, digital, user-friendly and rationalized but even if the perception of a well-established future prevail, things are a bit more fluid. As reported by Hollands (2008), debates about the future of urban development in many Western countries have been increasingly influenced by discussions of smart cities since the late 20th century (Eger, 1997). Actually there are numerous examples of cities designated as smart worldwide. The European Union (EU) has devoted constant efforts to devising a strategy for achieving urban growth in a smart sense for its metropolitan areas (Caragliu et al., 2009). Not only the EU, but also other international institutions and policy institutions (usually described as “think tanks”) believe in a form of development in which communities are wired and economic or social systems are Information and Communication Technologies (ICT)-driven. As Graham (2002) argues, ICT – including mobile and land line phones, satellite TVs, computer networks, electronic commerce and Internet services – are one of the main economic driving forces in cities and urban regions, producing numerous social and spatial effects. Actually, research on the local effects of the ICT revolution is available worldwide thanks to communities as The Intelligent Community Forum that produces periodic reports. In 2005, the Oslo Manual edited by the Organisation for Economic Co-operation and Development and EUROSTAT stresses the role of innovation in ICT sectors (Caragliu et al., 2009). Moreover the manual provides a toolkit to identify consistent indicators, thus shaping a sound framework of analysis for researchers on urban innovation. At a meso-regional level, a renewed attention for the role of soft communication infrastructure (institutions which are required to maintain the economic, health, and cultural and social standards of a country) in determining economic performance was observed. Moreover, even if the adjective “smart” clearly implies some kind of positive urban-based technological innovation and change *via* ICTs, it has also been utilized in addressing “e-governance” (Van der Meer and Van Winden, 2003)

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or environmental sustainability. With regard to environment, a city may become smart and green through strategic deployment of ICT infrastructure and services to achieve sustainability policy objectives (Maloney, 2012): energy and resource efficiency, carbon neutrality and cost-effectiveness are the common targets of these actions.

Unfortunately, trees are rarely a matter of debate in this contest, even if their importance in environmental sustainability is unquestionable. Plants do not only constitute green space useful to contrast urban pollution effects or provide benefits such as the short-term recovery from stress or mental fatigue, faster physical recovery from illness and eventually long-term overall improvement on people's health and well-being (Velarde et al., 2007). They can also be used as a bioindicator for air pollution assessment (Nali et al., 2009) and their involvement in communication networks can represent a significant contribution to build a smart, green city. The concept of living organisms (trees, herbaceous plants or lichens) used as watchmen for citizen wellness thanks to their connection to an urban information system is in agreement with a possible city of the future. Moreover, climate change raises new challenges in which plant ecosystems will increase their contribution to quality of human life in the next years. The urgency of evaluating plant response to future urban scenarios is underlined by international projects as TreeCity in which combined stress induction in controlled environments will simulate a 2050 scenario (Lorenzini, 2013).

Summarizing, smart cities, by definition, appear to be "wired cities", although this cannot be the sole defining criterion. In fact, the next wave in the era of computing made of mobile devices and ever-wired citizen, will be outside the realm of the traditional desktop. In the Internet of Things (IoT) paradigm, many of the objects that surround us will be on the network in one form or another. Moreover, with regard to the influence of green spaces on environmental satisfaction and physiological status of urban residents (Qin et al., 2013), there are no reasons to exclude urban trees among the 'wired object'. Radio frequency identification devices (RFID) and sensor network technologies will rise to meet this new challenge, in which information and communication systems are invisibly embedded in the environment around us. This results in the generation of enormous amounts of data which have to be stored, processed and presented in a seamless, efficient, and easily interpretable form (Gubbi et al., 2013). This smart connectivity with existing networks and context-aware computation using network resources is an indispensable part of IoT and can in theory permeate every urban space, including green spaces. With the growing presence of WiFi and standard for wireless communication of high-speed data such as Long Term Evolution (4G/LTE), the evolution towards ubiquitous information and communication networks is already evident. However, to achieve an effective IoT, the computing paradigm will need to go beyond traditional mobile computing scenarios that use smart phones and portables, and evolve into connecting everyday existing objects and embedding intelligence into our environment (Gubbi et al., 2013).

Bases for a "smart green management" in agriculture using wireless sensor network applications are available. These systems offer the advantages of reducing wiring costs and effectively monitoring the environment. They are small in size and the cost of sensors or electronic labels such as RFID tags is limited. Moreover, they can be successfully implemented in precision agriculture (Wang et al., 2006) for spatial data collection for crop management and spatial-variability studies (Gomide et al., 2001) or other applications thanks to progress in software and hardware. The development of professional software for smartphone able to carry out analysis such as leaf area index with low cost/high portability technology (Confalonieri et al., 2013) could open new roads in research or monitoring applications. Web 2.0 collaborative workspace (Luvisi et al., 2012a) provided for useful data interchange and communications between labs during long-term trials and RFID tagging reduced the losses in plant identification during tree monitoring, in particular due to damage of traditional labels. Moreover, the quantity of documents sent or requested by researchers or inspectors during monitoring or management could decrease if users recorded data with workspaces, and the delay in sharing information can be reduced.

The RFID-plants

Technology

RFID technology represents one of the most interesting tools in industrial and logistic sectors. It represents a new system to increase process efficiency in supply chains. The extremely rapid development of RFID in recent years is due to many factors, but a great impulse came from companies such as Wal-Mart, Metro, Tesco and government agencies such as the United States Department of Defence which have implemented RFID systems, thus stimulating global interest in what RFID can do and where it can be used (Ngai et al., 2008). Generally, RFID systems create a network used by companies to retrieve goods along a worldwide supply chain. Companies can put various procedures into action on this IoT, even in multitasking (Violino, 2005). The aim of RFID technology is to acquire information about objects, animals or people (and plants) through microprocessors associated with them, as widely described with regard to its basic characteristics (Ngai et al., 2008).

Generally, an RFID system is composed of an electronic label – a microprocessor/antenna, called tag or transponder – a reader and a management system. RFID is fundamentally based on wireless communication, using radio waves which form part of the electromagnetic spectrum, and operates in unlicensed spectrum space, sometimes referred to as ISM (Industrial, Scientific and Medical). These operating frequencies are generally considered to be organized into four main frequencies: Low Frequencies (LF, 30–300 kHz), High Frequencies (HF, 3–30 MHz), Ultra High Frequencies (UHF, 300–3000 MHz) and Microwave (2–30 GHz). In order for the RFID readers and tags to communicate, they must be tuned to the same frequency. Radiofrequency choice is important because readers work with a single frequency or with a narrow portion of spectrum. Moreover, there is a lack of worldwide frequency standards save for HF. A typical RFID frequency for the LF band is between 120 and 145 kHz and was the first frequency used. It is still in use today for livestock identification. The HF band commonly focuses on a frequency of 13.56 MHz and, because of its spread, it is a worldwide reference. The UHF band has different frequencies, between 865 and 956 MHz (Ward and van Kranenburg, 2006). UHF systems have only been around since the mid-1990s and countries have not agreed on a single area of the UHF spectrum for RFID. USA uses 915 MHz, Europe uses 868 MHz while Japan uses 920 MHz. Many other devices use the UHF spectrum, so the agreement among governments on a single UHF band for RFID is not an easy task. Governments also regulate the power of the readers to limit interference with other devices. Tag and reader makers are trying to develop systems that can work at more than one frequency, to get around the problem. When choosing a tag for an RFID system it is necessary to take into account various aspects, including size and shape, duration, resistance to external physical and chemical factors, orientation and distance from the reader, malfunctions near metals and liquids, fulfilment of local regulations, and memory capacity. RFID tags can be broadly classified as either of active or passive type. The first type incorporates an internal battery to provide an extended transmission range. Conversely, the passive

Table 1
Comparison of properties of different radiofrequency bands.

	Low Frequency (LF)	High Frequency (HF)	Ultra-High Frequency (UHF)	Microwave Frequency (MW)
Frequency range (MHz)	0.03–0.30	3–30	300–3000	2000–30,000
Typical frequency (MHz)	0.125–0.134	13.56	865–956	2450–5800
Read range (m)	Up to 0.5	Up to 1.5	Up to 10	Up to 10
Data rate (kbit s^{-1})	Up to 1	∼25	Up to 100	Up to 500
Tag cost	High	Medium	Low	High
Technical advantages[a]	- low interference by water/metals	- tags can be flat labels - lower tag costs than LF - worldwide standard frequency	- increasing diversity in tag sizes and shapes - lower tag costs - high read distance	- high read distance - active tags
Technical disadvantages[a]	- large tag size due to bulky antenna coils - short read range - slow read speed	- high interference by metals - difficult to read multiple tags simultaneously	- high interference by water/metals - line of sight required	- high interference by water/metals - battery lifespan - expensive
Typical applications	- access control - car immobilizer - animal ID	- access control - payment - book and clothing ID	- vehicle ID - toll road - supply chain management	- toll road - anti-counterfeiting
Advantages for urban green management applications	- low interference by water - easy to implant inside trees	- worldwide standard frequency	- long read range - inexpensive	- long read range - active tags
Disadvantages for urban green management applications	- short read range - expensive	- read range may be short - difficult to implant inside small-calliper trees	- high interference by water - difficult to implant inside small-calliper trees	- high interference by water - battery lifespan - expensive
Best potential use for urban green management	- small-calliper tree ID - kit for biomonitoring - *in situ* tree monitoring	- medium-calliper tree ID - smartphone applications - *in situ* tree monitoring	- large-calliper tree ID - data centre networks	- remote sensing systems - data centre networks

[a] Lou et al. (2011).

type lacks an internal power source and instead converts radio frequency energy, emitted by an RFID reader's transmit function, into electrical energy that powers the integrated circuit of the tag (Lou et al., 2011). Some properties of different radiofrequency bands are reported in Table 1.

RFID association to plants for urban green management

RFID tags can be associated with plants externally, also using electronic barcode systems which have been specifically developed (Kumagai and Miller, 2006). A similar approach was applied in Brazil for forestry management (Ellsworth, 2010). Each microchip, which is attached to a tree's base, holds data about its location, size and who cut it down. The chips allow land owners using sustainable forestry practices to distinguish their wood from that acquired through illegal logging that each year destroys swathes of the forest. User-friendly systems for external tree tagging provide for the use of commercial RFID nails that can be directly hammered into the trunk. External RFID systems may be associated to quick response (QR) tags. Interesting uses of QR involved educational applications for tree assessment. On a small scale, mobile technologies have been used on field trips to support students in exploring the natural world. A few examples from earlier research are support for visiting a botanical garden (Naismith et al., 2005) or learning about woodland ecology (Vogel et al., 2010). Smartphones may support, rather than distract, students in interacting with the physical environment such as urban green (Eliasson et al., 2013). Results show students ability in the use of smartphone and QR codes for identifying tree species and QR work as a learning tool that may be used for orienting students in their interaction with the physical environment.

These kinds of applications, even if not originally designed for urban green management, can be applied to ornamental trees or urban forestry. In these cases, the limits of external tagging may not be relevant. While external tags can be damaged more easily during cultural practices carried out in nurseries or orchards in which hundreds or thousands plants are grown in small areas, more attention can be addressed to urban trees. Similarly, even the external tag cannot offer the best guarantee for commercialized plants due to plant movements or attempt to fraud, urban trees could be less sensitive to these issues. Actually, industry makes available wristbands or RFID barcodes provided by software designed for plant management – commonly ornamental plants, flowers – confirming the interest around this system (Swedberg, 2011). The adaptability of the tag to all weather conditions or environments and the portability of software on smartphone devices make this approach to plant traceability user-friendly.

If the identification of plants needs to be secured since its production without risk of tag loss, the internal insertion of tags is needed. Keeping in mind plant anatomy and morphology, different techniques and tag positions have been proposed for implanting tags, although it does not seem to be possible to standardize internal RFID tagging in plants. Active tags were not used for plant labelling, because they are expensive, their function is limited by battery lifespan and requires increased size for battery. LF or HF communicates best with items containing water (Lou et al., 2011) and LF glass tags seems to fit well inside plants, thus these kind of tags were preferred for labelling trees (Bowman, 2005; Luvisi et al., 2010a, 2011). Aside from the type of RFID application, the geographical region where the application will be used is important when selecting the right frequency, as different regions have different standards and regulations and a standardization for tree identification was not yet proposed.

For large-calliper trees such as adult cypresses (Luvisi and Pagano, 2011), the insertion of tags after trunk drilling did not require particular attention with regard to position or extension of drilling, thanks to the fully developed anatomy of the trees. Damage to plants was not reported and tags working at 131.6 kHz were used to memorize an identification number associated to informational sheets stored in a digital database. A similar approach involved the Arizona's saguaros (*Carnegiea gigantean*), an arborescent cactus species which can grow to be over 20 m (Associated Press, 2008). In this case, National Park Service officials had imbedded tags in saguaros, Arizona's signature plant, to protect them from thieves who rip them from the desert to sell them to landscapers, nurseries and homeowners. The peculiar plant tissues permitted the use of syringes to implant glass tags. The primary objective of RFID tags was deterrence, but the chips also helped track down and identify stolen saguaros. The tagging of cypresses or saguaros responded perfectly to needs for health status monitoring of adult trees which

Table 2
RFID association to trees. ET, external tag; IT, internal tag.

Purposes	Education/tourism	Avoid theft/protect property rights	Traceability of certified plants	Disease monitoring	Breeding/clonal selection
Trees	- botanical garden trees (ET)	- Amazon forestry trees (ET) - saguaro (IT) - plane tree (IT)	- peach tree (IT) - grapevine (IT) - olive tree (IT) - lemon tree (ET/IT)	- cypress (IT) - peach tree (IT) - grapevine (IT) - olive tree (IT) - lemon tree (ET/IT) - mango (ET)	- lemon tree (IT) - grapevine (IT)
RF band	- low frequency - ultra-high frequency	- low frequency	- low frequency[a]	- low frequency[a]	- low frequency[a]
Advantage	- easy to read - easy to replace - improve interactive experiences	- irremovable (IT) - long term tracking - easy to read (ET)	- irremovable (IT) - long term tracking - easy to read (ET)	- irremovable (IT) - long term tracking - easy to read (ET)	- irremovable - long term tracking
Disadvantage	- visible - exposure to environmental stress	- short read range (IT) - exposure to environmental stress (ET)	- short read range (IT) - expensive - exposure to environmental stress (ET)	- short read range (IT) - expensive - exposure to environmental stress (ET)	- short read range
Additional features	- integration with other tags - smartphone applications	- integration with other tags (ET)	- integration with other tags (ET) - integration with production management systems	- integration with other tags (ET) - integration with monitoring stations	- integration with web-2.0 collaborative workspaces

[a] Prototypes of ultra-high frequency tag were tested in grapevine or olive tree.

are important for the community or are considered national monuments, and were both carried out by local governments. Not only local governments need to protect their trees, but also company or public utility agencies which want to defend their property rights. It is the case of a hybrid plane tree resistant to lethal canker stain with the authenticity of each tree guaranteed by a tag in the trunk (INRA, 2008). Unfortunately, no data are available with regard to reading performance of tags considering the tree development, which may increase the reading distance until loss of tag readability.

When dealing with small trees, such as those typically found in nurseries, tag implantation inside organs of small size requires specific methods. A report regarding tags implantation in *Citrus* spp. at nursery stage (Bowman, 2005, 2010) is an example of a plant tagging procedure that was reliable, durable and secure. The method involved an upright T-cut above the graft union during active tree growth, followed by an insertion procedure that was similar to that for budding of citrus nursery trees. Other implanting experiences were borrowed from grapevine applications (Luvisi et al., 2010a,b) as reported in *Prunus* spp. (Luvisi et al., 2011). In this case, the tag was inserted after direct drilling of the pith from the distal cut of the rootstock just before grafting, followed by tag localization below the grafting point, while an alternative procedure was carried out after grafting and consisted of a “U” cut performed laterally on the rootstock below the grafting point, involving tissues from bark to pith. Then the tag was located inside the pith, and the cut tissues were manually reassembled.

All previously reported trials on small-calliper trees involved small tags (12–14 mm length, 2–3 mm diameter) operating at low frequency (125–134.2 kHz). Conversely to application on large-calliper trees, some data about tag readability after plant growth are available. Bowman (2005) reported the signal penetration varied significantly depending on the scanning devices and, in a more limited way, on the wood type. Considering plant growth, the reading of tags can be assured in most woody plant species for 10 years or more, when appropriate RFID scanners are selected. These performances appear to be insufficient for applications with urban green applications where plants are implanted to live for decades. Limits are caused by the antenna component of the tags which are too short to guarantee a sufficient reading distance at low frequency, independent of the RFID reader used. The possible solutions may involve the use of larger tags provided with longer antennas or change of the band frequency. Obviously, larger tags may be not tolerated by small-calliper trees and their use can be limited to applications similar to those for cypress or saguaros. Even the change of band, such as UHF, is not an easy task due to the lack of tags whose dimension or shape permit their implanting following tested methods. A UHF tag has been developed for grapevine application (Luvisi et al., 2012b), in which a prototype was assembled using a commercial UHF transponder. The commercial tag was cut to take a smaller form by removing parts of the antenna. With this procedure the reading distance of the modified tag was halved but was still longer than that of glass tags. The UHF transponders used for implanting were produced by rolling the UHF transponder around a thin bamboo stick covered by a polyolefin film, obtaining a transponder of 40.0 mm in length and 2.4 mm in diameter. Tests were also carried out on olive trees: a prototype was implanted in 2- or 4-year-old plants through direct drilling of the pith (3.5 mm drill bit) to a depth of 40 mm, followed by microchip insertion, locating the microchip below the graft union (Luvisi et al., 2012c).

Some RFID associations to trees are reported in Table 2.

Specifically designed methods for tag implanting are available for urban green or forestry application but previously described trials highlight some limits. HF is probably the best frequency for internal RFID tagging in plants, thanks to low interference caused by water and a good compromise between size and range compared to LF. Moreover, the use of a standard frequency such as 13.56 MHz should help develop specific systems for urban green management. Only external tagging guarantees a durable traceability system for smart city applications but, considering the intrinsic limits of this approach, ideas for better solutions are desirable. Overcoming the implanting limit, the RFID technology is ready for managing the urban green or forestry, thanks to the attitude of integration with other technologies.

Some applications of RFID in urban green are schematized in Fig. 1.

RFID-plant applications for urban monitoring

RFID-plant may represent an optimal candidate to be included in tree inventories, thanks to their easy integration within digital environments. Tree inventories are an essential tool to protect and enhance urban and rural forests which help ensure healthy

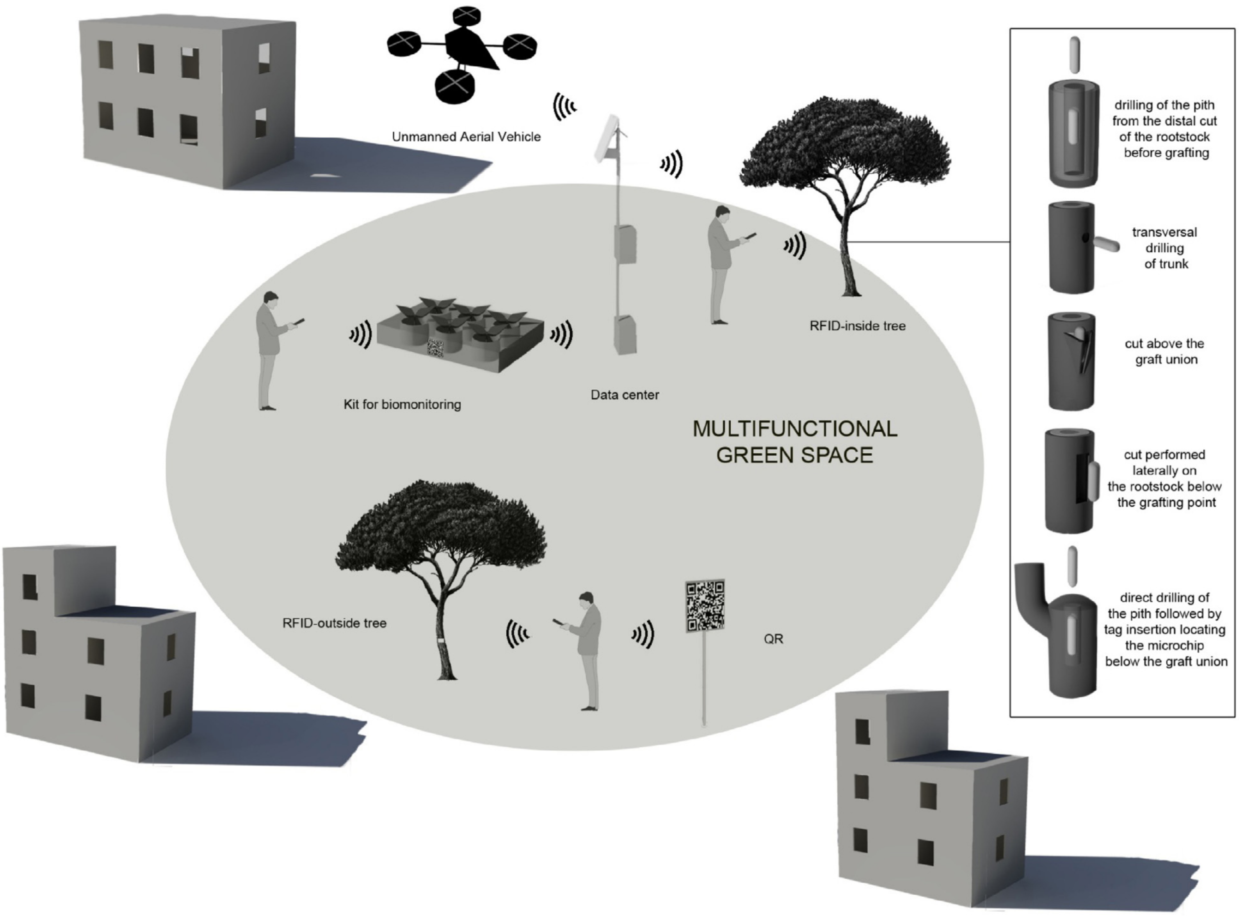

Fig. 1. Applications of RFID tagging for urban green management and their integration with other technologies.

forests for generations to come (Harkess, 2005). They are useful to help maintain diversity in the street tree population, assess the health of the urban forest, and communicate with property owners. Considering that inventories need to be updated regularly in order to help schedule tree maintenance work, determine planting sites, and manage invasive insects, RFID tags can be used as a safe system for tree identifications. Even if effective management of the urban forest calls for municipalities to have a tree inventory of their urban resource, no reports of development of a management plan based on tree inventory are available in major North America and Europe cities (Keller and Konijnendijk, 2012). These difficulties may be related to the absence of international standards in data collection that may help development of urban forest tools and reduce the costs of data collection and analysis, similarly to RFID systems developed for livestock management.

Even if not directly associated to plants, RFID tags could be implemented in biomonitoring systems in order to guarantee a real-time data communication. Data from pollution sensitive plants may be sent *via* wireless signalling concerning their management or environmental status. Interesting applications may originate by tagging site specific devices for air pollutant monitoring such as kits for ozone biomonitoring (Lorenzini, 1994). In this case, a specific application for a mobile device (as smartphone app) can be developed in which digital monitoring sheets are linked to the tagged kit. A real-time survey can be compiled by the inspector and sent by the mobile device to a central database able to virtualize the assessments on maps. The increasing resolution of portable cameras on mobile devices and the availability of post-processing software for image reading, can also lead to the development of apps able to “scan and read” the bioindicator device. Thus, data can be semi-automatic recorded with the help of the inspector but development of automatic systems is presumable. Moreover, the data centre of a multifunction green space may act as a monitoring station for other environmental parameters such as Index of Atmospheric Purity observed on bioindicators, such as lichens, (Lorenzini et al., 2003; Nali et al., 2007) that develop on RFID-trees present in the green space. A similar approach was applied in site specific management tools for precision viticulture (Cunha et al., 2010).

Other applications of RFID to plants may be related to the increase in automation of hi-tech urban green monitoring such as tree tomography (Nicolotti and Miglietta, 1998), thanks to the proficiency of operators in ITC tools. Identification of RFID-trees can be used to log inspections in the assessment software and to certify the evaluated trees in order to carry out transparency of policy.

The development of small unmanned aerial vehicles (UAVs) can lead to potential applications of this technology in agriculture, including crop scouting, pest distribution mapping, bare soil imagery, and irrigation and drainage planning (Ehsani and Maja, 2013). Moreover, since UAVs fly at low altitudes, they can collect very high resolution images that can be integrated with RFID technology in order to dialogue with tagged plants or data centres. Aerial remote sensing systems enabling aerial 3D measurements of canopy structure and spectral attributes are available with red–green–blue spectral attributes for each point permitting high frequency observations of tree canopy (Dandois and Ellis, 2013). This methodology produces large sets of highly overlapping aerial photographs acquired at below 150 m altitude using common digital cameras mounted on an inexpensive, below 2 kg weight, hobbyist-grade unmanned aerial system (UAS). Data collected by UAS may be directly linked to the tagged tree or data centres using UHF active tags or transmitted *via* wireless to online databases linked to the RFID tagged plants. As suggested by Dandois and Ellis (2013) inexpensive technologies for multispectral 3D scanning of vegetation can lead to a new era of participatory remote sensing by field ecologists, community foresters and the interested public. The integration of UAS into the national airspace is challenging for aviation authorities such as US Federal Aviation Administration. Certificate of waiver or authorization can be requested for public aircrafts, even if routine operation of UAS over densely populated areas is prohibited in USA. In Europe, basic national safety rules are applied, but the rules differ across the European Union and a number of key safeguards are not addressed in a coherent way. The European Summit of 19 December 2013 called for action to enable the progressive integration of remotely piloted aircraft systems (RPAS) into civil airspace from 2016 onwards (Communication 207-2014 of European Commission). RPAS form part of the wider category of UAS, which also includes aircraft that can be programmed to fly autonomously without the involvement of a pilot. RPAS, as the name suggests, are controlled by a pilot from a distance. This Communication focuses on RPAS for civil use and responds to the call of the European manufacturing and service industry to remove barriers to the introduction of RPAS in the European single market.

Perspective of geospatial methods integrated with RFID technology for urban green management

The urban forest includes trees along streets and other rights-of-way, trees in parks and residential yards, and in forested recreational areas near population centres (Rowntree, 1984). In the urban context, geospatial tools such as GPS and the Geographical Information System (GIS) can provide timely and extensive spatial data to arrive at plant attributes that can be adapted for applications including data fusion, virtual reality, three-dimensional visualization, internet delivery, and modelling (Ward and Johnson, 2007; Wu et al., 2008). The virtualization of parks by combining GPS technology and computer-aided design (CAD) is an interesting possibility: it is currently possible to easily record geographic profiles of fields and use them in CAD software to draw structural elements. Geostatistical approach can involve application of environmental assessment such as the air pollution biomonitoring networks and related data modelling (Gorelli et al., 2009). Moreover, combining decision support tools with recent computer visualization techniques may be a workable option. Visualization tools able to produce dynamic simulations of prospective forested landscapes were developed in which architecture as well as its connection to forest resources spatial decision support system are described (Falcão et al., 2006).

This approach to urban green management or forestry monitoring can be extended to plants tagged with RFID, in which geo-referred data from transplant machines can be matched to RFID labels on individual plants. Potentially, subjects containing a transponder will be identified by a code, associated with the transponder itself, and they will be located with GIS on a three-dimensional electronic map, recreating a virtual park. The advantages of this approach are linked to the possibility of remotely monitoring trees, filing and managing useful data associated with the plants (*e.g.* identity, sanitary status, certification, and cultural practices particularly using technical and plant health files), and having a durable, safe and detailed park information map. Moreover, mobile devices like netbooks, tablet-PCs or smartphones could represent optimal instruments for consulting and updating the virtual park from the field, while time-consuming operations can be carried out using a desktop device. This strategy has been described for contextualized vineyard management (Cunha et al., 2010) where tags were placed in the field and decoded by mobile devices such as mobile phones or Personal Device Assistants (PDA). Geo-referring was performed which automatically associated a tag to a field location in the relevant database tables or records and also permitted access to contextual information or services. The proposed system can be considered user-friendly: by pointing a mobile device at a tag, the user can in a simple way download information such as climatic data or upload information such as disease and pest incidence. The possibility of performing these operations from the field without having to provide coordinates or any other references avoids having to return to a central office for retrieving information or instruments. Even if this system is not directly linked to plants, it represents an interesting approach in integrating RFID in tree management or biomonitoring systems and the availability of tag implantation methods for various ornamental trees offers further options in urban green or urban forest management.

Finally, the virtualization of green areas, the use of sensors and mobile devices can lead to desktop management of the urban green by the government with the possibility to implement a real-time navigation throughout the area. Advanced software packages for tree virtualization, such as TreeView and L-Vis, have been available since the last century (Seifert, 1998). TreeView allows for the three-dimensional interactive visualization of forest stands, while L-Vis enables prospective forest representations by integrating individual tree growth models. These softwares can be implemented for large area applications, as indicated by Falcão (2004), who developed a prototype with linkages to other modules of a decision support system (DSS) and reported visualization and real-time navigation capabilities using a 500 ha test forest area. Tests with OnyxTree (Falcão et al., 2006) permitted application of the visualization tool to a very large landscape with about 95,000 ha and a dense forest coverage. The availability of updated software and increased PC performance lead to significantly improved virtualizations.

Real-time navigation in the urban forest provided by sensors and RFID-implanted plants may represent a future prospective for the next-generation management of the urban forest health. An urban forest is sustainable if it maintains biodiversity, productivity, regenerative capacity, vitality, and the potential to fulfil relevant ecological, economic, and social functions (Wiersum, 1995). Complex relation networks which data can be collected thanks to geospatial methods (Ward and Johnson, 2007) can be integrated by an IoT approach in which RFID-implanted trees can play a significant role.

Concluding remarks

A city in which trees are wired to local government agencies for their protection and management can represent an interesting approach for a smart and green future. Technologies such as RFID and wireless networks can move not only objects closer to citizens but also trees. A sort of communication can be established between people that benefit physiologically and psychologically from green spaces and the plants, throughout a middle system managed by local – or not – government. This communication is not based on a mere romantic contact between urban residents and their green neighbours but on a concrete approach to multifunctional green space management that can lead to a better organized plant protection and maintenance. In this context, RFID-trees may represent an important component in which the tag wires the plant to the information systems in an inward-outward communication process. On one hand the information system can manage the plant subjected to cultural or protection practices, on the other hand the plant can send environment data to the information systems. Even if tagging methods for ornamental trees need to be enhanced or revised, data relative to plant tolerance to tag implanting are encouraging.

Nowadays smart green cities – or what they will become – are not inspired by hyperstructures based on Paolo Soleri's arcology theory (Gray, 1979). Some futuristic project, such as vertical farms, in which the green world permeates the urban area is possible thanks to high technological solution.

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