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Participatory Sensing for Nature Conservation and Environment Protection

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Abstract

In this paper, we introduce and define the concept of Participatory Sensing (PS), we collect a number of PS applications from the area of environment protection and nature conservation, we sketch the building blocks of a generic software architecture for PS, and we report on the implementation approach and the current status of the PartSense project which aims at providing reference solutions for professional PS applications.

1. Introduction

The emerging field of **Participatory Sensing** (**PS**, also called Human Sensing, Urban Sensing, Opportunistic Sensing) is about combining (1) the power of up-to-date **mobile computing devices** (Smartphones and Media Tablets) with their **GPS localisation** and their **built-in sensor and data-capture technology** and (2) the idea of using **crowdsourcing** for delegating a data-collection task to a larger number of people (your employees, registered volunteers, or even the general public).

In the recent almost 10 years, many very interesting prototypes, experimental solutions, and pilot applications of PS have been realized. However, taking into account the tremendous success of Smartphones and tablets in the last two years and the growing involvement of people in online communities and online communications, we expect the biggest opportunities for a wide uptake of PS ideas still to come. Further, many PS campaigns described in the scientific literature are already technologically outdated, they had only a limited duration, did not find a convincing uptake, were based on task-specific, one-shot implementations, or were very much focussed on US-based use cases. Hence, the objective of our current work is to bring PS one step further on the way from an art to a technology with well-defined terms, procedures, reusable software artefacts, well-understood use cases and widespread acceptance, also in Europe, and also with commercial applications (currently, many examples are general-public use cases with altruistic user motivations). These goals are pursued in the PartSense project (running January 2012 – December 2013). In this paper, we will shortly report on preliminary project results of PartSense (some more detail can be found in (Abecker et al, 2012b)). A second focus of this paper will be the collection of existing use cases and application examples found in the literature which address environmental protection or nature conservation issues.

2. Defining Participatory Sensing

Our working definition of Participatory Sensing aims at covering the full extent of ideas and approaches contained in the Participatory Sensing concept:

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In Participatory Sensing, (a) a group of people collects in a (b) data collection campaign (c) spatially referenced data and information, using (d) widely available mobile computing devices, exploiting the (e) built-in sensor mechanisms that these mobile devices offer. The data-collecting people send their inputs to a central server which further process them to some defined end. The kind and format of to-be-collected information is predefined in a data-collection scenario. For complex use cases, the central server can coordinate the activities of the people potentially acting as data collectors.

Concrete PS use cases vary along the dimensions (a) – (e) introduced above:

a. When starting a data-collection campaign, the **people collecting data** can either already be known (e.g., as *registered users*) or they may volunteer *anonymously* during the campaign (e.g., by downloading a Smartphone app). They may have a *formally defined relationship* to the campaign organizer (e.g., being his employees, the members of an NGO, or volunteers registered in a pool), but this is *not necessarily* always the case (in many scenarios, the data collectors come from the "general public").
b. A **data-collection campaign** normally takes place within a *spatially delimited area*. Temporally, a campaign may have a *fixed duration*, may be *open-end* or may be *implicitly defined* (e.g., collect until a certain amount of data has been gathered).
c. The **spatial reference** of information is for many applications sufficiently represented by a *point* coordinate (typically provided by the mobile device's GPS localization function, the result of which can manually be corrected if needed). Few applications also capture *GPS tracks* (for instance, a mountain-bike or a hiking trail). In general, it may also be a *polygon*.
d. We do not consider task-specific special hardware, but Internet- and GPS-enabled **mass-market consumer products** like Smartphones and media tablets (iPad, etc.) – in this respect, PS corresponds well with the *"bring your own device"* philosophy.
e. As **sensor technology**, PS mainly relies on the *built-in mechanisms of the mobile device*: text and speech input, audio, picture and video capture, GPS functions for localization, the three-axes accelerometer, gyroscope, ambient light sensor, compass, humidity sensor; in the near future, probably more, e.g., a barometer. In some cases, it may also be useful to employ mobile sensors that can be plugged into the mobile device for data transfer, e.g., for monitoring vital signs of people (for instance, sensor-wear garment that monitors heart rate, ECG, body temperature, impedance, etc.). There are some interesting mobile sensors that transfer their data via Bluetooth to a mobile phone that relays them.

There are further aspects with respect to which PS use cases may differ:

- People may contribute to a data-collection campaign *anonymously* or *authenticated*.
- Participation in a data-collection campaign may be on *one's own initiative* or because the central *server proactively contacts* a person. Depending on the concrete use case, such a proactive request may be a nonbinding request or an obligatory task. If the server contacts potential data collectors, the selection of people may be role-, user-profile or location-based; typically, several factors are combined.
- Data-collection tasks may comprise the *first capture* of a data point, its *actualization* or *verification*.

Participatory Sensing promises a number of **benefits**: First, if a PS application is the very first step to integrate mobile software into existing workflows, the obvious benefits of mobile software applications can be realized: *elimination of media discontinuity* with its redundant data input, data transfer and error possibilities; *time savings*; exploitation of already existing traveling of people for additional purposes. Second, more specific for Participatory Sensing, is the *exploitation of Crowdsourcing* and the possibility to easily involve additional forces, like sporadic collaborators, freelancers, volunteers, or even the general public.

Regarding business cases and **application domains**, the literature shows a large variety of possible PS applications of PS (many are listed in (Zacharias et al, 2012)); the most of them can be sorted into one of the groups: (1) citizen feedback to municipalities; (2) nature conservation and observation, as well as environmental-data collection; (3) price comparisons; (4) sports and health monitoring; (5) traffic monitoring.

There are further application areas where PS technology could help, for instance, (i) for inspecting and maintaining large distributed infrastructures (like a large manufacturing plant, a building yard, a residential neighbourhood, etc.); or (ii) for disaster recovery in the case of a natural disaster, a terror attack, etc. (when, on one hand, many inhabitants and civil protection forces can collect real-time information about their local situation, and, on the other hand, tasks must be dispatched continuously to professional and volunteering relief forces). More application ideas that we are currently discussing with potential end users, come from the areas of forestry, brownfield sites documentation, and roadworks administration.

As the area of environment and nature observation plays a significant role in the PS literature, we will describe a number of examples from this area in the following section.

3. Participatory Sensing in Environmental Informatics Applications

We briefly discuss some of the most important environment-related PS application areas:

- **Mapping species:** For instance, the German *Artenfinder* app (http://artenfinder.de/) allows to document with a photo and additional information the sightings of rare animals and plants. It is currently used in two pilot projects in the two German Federal States.
  - Interesting features of Artenfinder are the provision of *compass* and *distance data* for a better localization of distant sightings, as well as the provision of *background information* for better determining the species at hand. The pilot projects are run in close cooperation with associations of honorary conservationists as data collectors and with specialists in the back office who evaluate the collected reports and forward the results to the environmental protection authorities.
  - Similar: *What's invasive* (http://whatsinvasive.com/) – allows collecting data about invasive species that newly appear in a certain area. Currently, data are collected in ca. 60 different parks, mainly in Northern America.
  - Before the great success of mobile devices, similar ideas had already been implemented with Web interfaces. For instance, *webfauna.ch* allows reporting of sightings of amphibians, retiles and mammals, using a simple Web interface. *naturgucker.de* / *enjoynature.net* is a community platform with many useful communication and data-management functions that allows to store and inspect nature observations (flora, fauna) of private people (typically, members of nature conservation or of ornithological associations). Sightings can be associated either with a point or with a region. Sightings of protected species cannot be inspected in all details. The *information system "Vogelzählung in Deutschland"* (German bird census) is a Web-based system, the delegation of concrete counting tasks and areas is centrally managed by the German umbrella organization of all ornithological associations.
- **Monitoring a specific area:** The *SenseTheBeach* app (http://sensethebeach.appspot.com/) is focussed on a specific geographic area and aims at collecting different kinds of information that are relevant for the overall good status of this area, such as information (i) on invasive species (red tide, seaweed), (ii) on wildlife (birds, jellyfish, dad animals), and (iii) on human impacts (crowded beach, unwanted vehicles, garbage/debris, sewer pipes/runoff).
- **Monitoring air quality:** many experiments about mobile sensing of air quality have been undertaken 2005 – 2010, especially in the US. This is particularly valuable in areas with a low density of civic government's monitoring stations. Extending the possibilities of public administration, PS also has the chance to measure indoor air quality, and it can be applied in developing countries where no governmental measurements are undertaken at all (Paulos et al, 2008).
  - However, it should be noted that air quality monitoring a little bit "stretches" our PS definition above, insofar as there are, up to date, no air quality sensors for mobile phones available; instead, one uses lightweight mobile sensors (that could, for instance, be built into a headset or a wristwatch) that transfer their data via Bluetooth to the mobile phone.

- An interesting aspect is that air quality data can also directly be fed back to the end user who might adapt his traveling route in the city or be warned about critical pollution levels.

- **Monitoring noise:** Many projects have addressed the mobile collection of noise data in urban environments (NoiseSpy (Kanjo, 2010); Ear-Phone (Rana, 2010); NoiseMap (Schweizer et al, 2011); What's noisy (http://whatsnoisy.appspot.com/); Noisetube (http://noisetube.net/)). Such systems can complement, refine, or (partially) replace the widely used approaches of simulated maps, fixed installed sensor networks, or regular measurement initiatives with their known problems, such as high costs, too coarse observation grids or too rare updates. From the scientific-technological perspective, noise mapping offers some challenges, such as signal processing (incl. calibration) at the mobile device or map reconstruction from sparse data (Rana, 2010).
- **Monitoring plant responses to climate:** The Project *BudBurst* (http://neoninc.org/budburst/) is a citizen science campaign for the study of the timing of life cycle events in plants as they relate to the environment. With the help of volunteers, it shall be better understood what "calendar" plants use to begin flowering, leafing or reproducing. This shall help to monitor the trees, shrubs, and grasses in order to get insights how life is changing in response to a globally changing climate.
  - Here, an interesting differentiation is made between regular observations of daily monitored plants and single reports about plants one comes across only once of infrequently.
  - Another interesting idea is that of a Serious Game ("Floracaching") for focussing on specific species and for giving incentives (http://networkednaturalist.org/floracaching/).

These are the most prominent application areas of PS for nature and environment protection. Closely related seems to be the *FracTracker* initiative that collects data and information about the impacts of natural-gas / shale-gas drilling activities in the US. But, up to now, their data collection doesn't use mobile devices, but a Web GUI, so this should rather be seen in the tradition of Public Participation GIS.

This leads to the more general idea of using PS for **finding and documenting environmental damages** (like mining damages, illegal garbage dumps, cadavers, dry wood or sick trees, polluted waterbodies, etc.). However, we didn't find yet prominent application examples for this in the literature.

A further generalization step could also include **finding and documenting damages or maintenance-needs of man-made infrastructures** – for commercial applications, that could mean any infrastructure (like large premises or the railroad network of a public-transport company), for more environment-related applications, this could also mean dams or dikes, pedestrian walkways or bikeways, etc. The observation of constructions like dikes leads also to the idea of using PS when **natural disasters** are imminent or did already happen (floods, storms, wildfires, earthquakes, etc.). Here, citizen or volunteers may help the official forces to collect up-to-date information, prioritize and plan helping or prevention activities.

Another typical PS application area with an *indirect* impact on the environment is **personal transport and traffic**. Many projects aim at tracking status and problems of public transport, personal commuting behaviour and movement patterns, free parking lots etc. – which can, on one hand, support transport and urban planning, and, on the other hand, improve individual transport decisions in real-time, thus helping to save resources. Also included in the generalized environment concept, are all PS applications related to **health**. A prominent example is *MobAsthma* (Kanjo et al, 2009) which allows correlating individual asthma condition with exposition to air pollution. In general, allergic reactions and problems with the respiratory system are an interesting field for Participatory Sensing (see also the *PEIR – Personal Environmental Impact Report* (Mun et al, 2009)).

4. A Generic Software Architecture for Participatory Sensing

From a comprehensive requirements analysis (Abecker et al, 2012) and existing PS frameworks, an initial functional architecture has been derived (see Fig. 1) the building blocks of which we will shortly discuss:

Campaign definition: For setting up a new data-collection campaign, the basic parameters of the campaign must be defined, in particular: (i) Which kind of information has to be collected? (ii) How is the user interface structured? (iii) Who is authorized, wanted or requested to collect data? (iv) When should data be collected (timespan, data-collection interval, frequency of data collection)? (v) From which geographic area should data be collected?

User management: In PS scenarios with registered users, the user management can have varying levels of complexity. A simple solution would just store the user's basic technical data (technical system configuration – hardware, software). For scenarios with a *proactive* assignment of tasks to users, it may be useful to have more information about the users' typical movement patterns and their motivational structure (in which kinds of campaigns would they participate and why?). Going further, information about past user activities could also help to assess / predict the quality of their actually contributed data.

Task-software creation: For the major mobile operating systems, the required apps should be created automatically, based on the specifications of the campaign definition.

Task dispatching and task-dispatching planning: When data-collection tasks are *proactively* assigned to (potential) users, these users must be identified and contacted (e.g., by e-Mail or SMS). The identification of potential assignees has to match user data with requirements from the campaign definition (for instance, only users with specific hardware equipment might be relevant). If the system knows the users' movement patterns, only users can be contacted who are really bound for the considered data-collection area. If the system has even access to dynamic movement / localisation data, a user might just be contacted when entering a collection area or when coming closer to a spot of actual interest (e.g., because there a many missing data from this sport, or because already sent data must be verified). If much information about potential users, data-collection task and possibly also current campaign status is available, smart planning strategies and matching algorithms between task profile and user profiles can be employed (Reddy et al, 2010). Obviously, there are also many PS application scenarios with an only *passive* server where task assignment is only on the user's initiative by downloading the data-collection app.

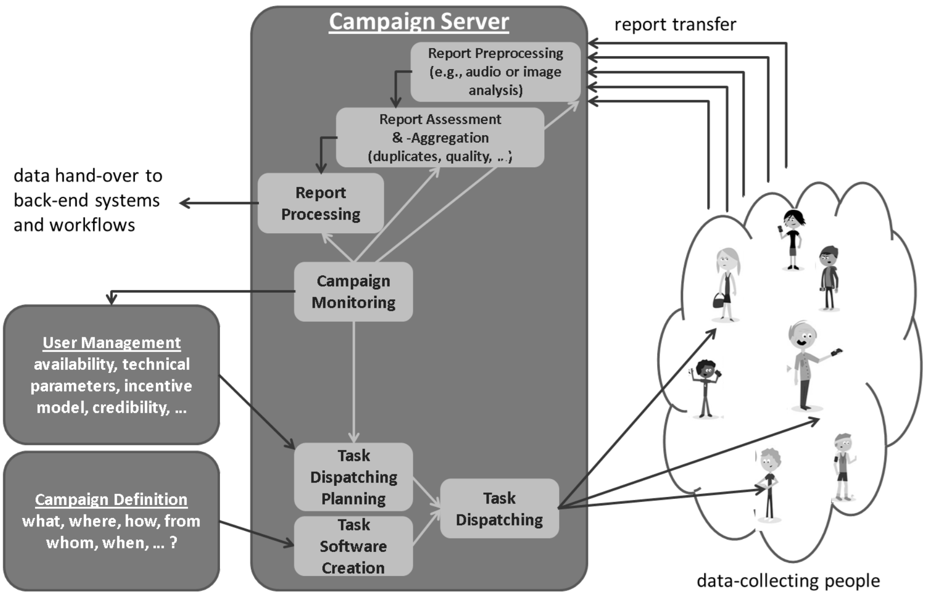

Figure 1
Generic Functional Architecture of Participatory Sensing Software

Data collection and report transfer by end users: With the downloaded app, end users collect (*manually* with their personal involvement, or *automatically*, done by the app) the data requested in the campaign definition. Normally, the app *immediately* sends the reports to the server using the connection of the mobile device. In some cases, the report transfer may be done *delayed* (for instance, if one has to work without network connection for some time). Such a delayed data transfer may be started automatically (when the network connection has been restored) or by hand, it may also use other media or communication channels (USB stick, LAN, etc.). In early applications started before the huge success of Smartphones, data input is done manually through a Web browser. The data collection itself is done by the mobile device's sensor hardware and data-input mechanisms, maybe extended by upcoming cheap and lightweight mobile sensor systems that can easily be connected with a mobile device for data transfer.

Data-processing pipeline: Fig. 1 exemplarily shows three generic elements of a data-processing pipeline. In principle, this pipeline must be configured specifically for each application, but it may also be very simple in many cases. The depicted steps are as follows: (1.) Depending on the kind of collected data, some *pre-processing* may be necessary: For instance, applying image analysis algorithms to photos, or using interpretation software for QR codes. (2.) Once the data is in the appropriate internal data structure, additional steps for *report assessment and analysis* can follow: For instance, *duplicate* (or nearly duplicate) reports might be eliminated. Aggregation of similar reports may also lead to a stronger or more general statement that can be derived from several simpler reports. In many cases, *quality assessment* for incoming reports may also be crucial (some reports may be „spam" or outliers, possibly indicating an error or faulty observation). Based on such quality assessments, reports may be weighted (especially important observations), eliminated (useless or already processed reports), or specifically treated (e.g., peculiar reports may be checked manually or lead to a verification task for another user). (3.) From the report-processing built into the PS-platform, the reports (or some results of their processing) will be passed on to one or more *back-end systems* (workflows, business applications, data-storage and analysis systems). If we have a stand-alone PS system, it will have its own report storage and some sort of data presentation, visualization/inspection, reporting, analysis and/or processing.

Campaign monitoring: The server may monitor the run of a data-collection campaign wrt. predefined criteria (like collection of a sufficient quantity and quality of data). Monitoring may lead to measures like changing parameters of the incentive mechanism (if too many or too few data has been collected, or if a specific sub-area must be covered better); observations may also lead to the creation of new data-collection tasks, e.g., for verifying outlier data or for getting more detail on especially important reports.

5. Project Implementation and Status

In the PartSense project, we aim at implementing a generic PS software framework along the lines sketched above, taking into account up-to-date hardware and software trends, and taking care for potentially critical success factors of PS in practice. From the technical point of view, the PartSense implementation work starts from *two existing development threads* which will be merged step by step.

One of these starting points is the *KA-Feedback* system which is in operational use in the German 300.000-inhabitants city of Karlsruhe, since Spring 2012. It gives the citizens the possibility to use their iPhone for collecting and sharing time-stamped, geocoded textual and/or visual information about a number of pre-defined environmental and infrastructure problems in their urban environment, by sending feedback on local problems (like road-surface damages, overfull rubbish bins, broken street lights, etc.) to the municipal administration. KA-Feedback is based on a generative software system that – for the specific parameters of a given citizen-feedback scenario – configures a native iOS app to be downloaded by interested citizen (Borges et al, 2012). Similar applications for other cities can easily be derived.

The KA-Feedback server provides two Web GUIs: (i) for the general public (showing the collected information with the municipal administration's answers in a map view and in a list view), and (ii) for the municipality's system administrator and report–processing agents. Incoming reports are – depending on the type of reported problem – also directly sent by e-Mail to the responsible agent. The system administrator configures the concrete KA-Feedback application profile by defining so-called "Senslets" – each of which giving the possibility to report one specific kind of data/information (Abecker et al., 2012b).

KA-Feedback is (up to now) a platform-specific (iOS), simple realization of parts of the functional PS architecture shown above, specifically designed for the use case of citizen feedback. It has no user management (download of the app and sending of reports can be done by everybody), no task-dispatching planning (because users download the app on their own initiative), and no campaign monitoring. KA-Feedback has a use-case specific campaign-definition GUI, the task-software creation is based on which. The report-processing pipeline is very simple (storing the reports and showing them in the two GUIs sketched above; sending e-Mails to the responsible departments of the municipality).

The second starting point is the recently released disy *"Cadenza Mobile"* mobile GIS software suite (Hofmann et al, 2012). It allows use, change and acquisition of GIS data (complex application data combined with a spatial reference, visualized and editable in application-specific maps) on mobile devices (media tablets because the Smartphones' screen is very small for a complex map application). By integrating "Cadenza Mobile" into the PartSense project, we aim at widening the scope of PS applications from very simple collection tasks with data collectors from the general public, towards more professional applications for businesses or public administrations. "Cadenza Mobile" allows creation and editing of complex application-data objects, associated with line or polygon geometries (instead of only points), managed in the spatial-data management and reporting software disy "Cadenza Professional". Notably, "Cadenza Mobile" allows (1) exporting parts of a Cadenza application database together with their GIS-data, (2) editing in *offline mode* with a mobile device, and (3) re-importing it into the database of the desktop system. This offline-working functionality is important because in many outdoor working scenarios (in forestry, agriculture, regional planning, roadworks management etc.), we cannot expect to have a broadband mobile Internet connection, powerful enough for a reasonable way of mobile working with GIS data. "Cadenza Mobile" offers exactly the *same visual appearance of application-specific maps* in mobile and in desktop mode, but in contrast to a simple WebGIS in a mobile browser, it fully exploits the *multitouch gesture controls* of a mobile touchscreen device.

"Cadenza Mobile", up to now, did not yet implement specific PS functionalities, but rather laid the foundations for transferring PS ideas to more heavyweight GIS-data scenarios. It also pays special attention to a technical topic highly relevant for a widespread success of PS frameworks, namely *cross-platform development.* The core of the "Cadenza Mobile" app development is realized in a platform-neutral manner using *HTML5 / Javascript* and the *Phonegap / Apache Cordova* framework. Phonegap allows creating platform-specific apps (currently, we work with Apple-iOS and Google-Android). Functions that cannot easily be realized with HTML5, can be developed as native code for the respective systems and made available (again in a platform-neutral manner) to the HTML5 core through the Phonegap abstraction layer. This mechanism enables an economic app development for different mobile operating systems. Further technologies that have proven to be useful for Cadenza Mobile development are the *Senchatouch* mobile-Web-GUI framework and the *Open Layers* Web-mapping frameworks.

6. Summary and Conclusions

We have presented the emerging field of Participatory Sensing. Coming from a first comprehensive definition of PS, we discussed the main building blocks of a functional software architecture for PS applications and have shown environment-related applications. Up to now, our development led, on one hand, to a simple, but pragmatically useful, implementation (KA-Feedback) which is in operational use for an urban citizen-feedback system since a couple of months. Though it is limited to Apple Smartphones, it works well and got already much positive feedback from citizen and from administration, also from other municipalities. On the other hand, the disy "Cadenza Mobile" software will be a basis for further widening the scope of PS applications towards business applications with more complex spatial characteristics of data. The Cadenza Mobile development is based on a cross-platform approach employing a comfortable software stack for mobile GIS applications on different technical platforms, up to now, with a focus on offline usage. Subsequently, PS functionalities from KA-Feedback experiences will step by step be transferred and/or coupled to Cadenza Mobile.

Longer-term future work (also including empirical experimentation), should focus on the presumably most critical realization points for more sophisticated PS applications: (i) privacy and security of personal data in the case of registered users; and (ii) quality and quantity of collected data – which is closely related to incentive mechanisms employed for acquiring user participation. Both are the basis for intelligent planning, monitoring, and control.

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