A Platform for Citizen Sensing in Sentient Cities

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Abstract. This work develops upon the concepts of *Sentient City* – living in a city that can remember, correlate, and anticipate – and *Citizen Sensor Networks*. We aim at technologies to interconnect people, allowing them to actively observe, report, collect, analyse, and disseminate information about urban events. We are investigating new methods and technologies to enhance administrators' capabilities in urban planning and management. We are proposing a platform to instrument citizens and cities, interconnect parties, analyse related events, and provide recommendation and feedback reports. The solution encompasses four types of elements: (i) mobile applications for intentional and non-intentional reporting of events; (ii) enhanced analytic models to centralize information, analyse the data, identify trends and operation patterns, and provide insightful information to decision makers; (iii) advanced social simulations to anticipate "what if" scenarios for infrastructure planning; and (iv) interfaces for monitoring, feedback, and recommendation. This research builds upon the IBM Smarter Cities project, part of the IBM Smarter Planet program. The outcomes of this research yield significant social contributions. By using it, administrators can make reliable decisions that will impact social services, traffic, energy and utilities, public safety, retail, communications, and economic development.

1 Introduction

Sentient City [12] promotes the concept of living in a city that can remember, correlate, and anticipate situations. Supporting this concept, *Citizen Sensor Networks*, described in [13], aims at technologies to interconnect people, allowing them to actively observe, report, collect, analyse, and disseminate information about urban events.

We are investigating new methods and technologies to enhance a capability in urban planning and management. We aim at a solution that will help city administrator's to answer questions like:

- How to manage the flow of people and things in a city?
- How to get citizens engaged to and aware of cities affairs?
- How to guide people in the city under extraordinary situations, such as large-scale events and natural disasters?
- How to identify economic activities and the process to boost their development?
- How to provide a useful feedback to citizens?

For instance, *IBM Intelligent Operation Centers*[1] support the centralization of critical information from multiple sensors that control the city, providing advanced collaboration,

[1] Ref: http://www-01.ibm.com/software/industry/intelligent-oper-center/

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deep investigations based on analytics tools, and executive dashboards support for city operations. *San Francisco 311*[2] provides a Twitter channel that accepts inbound requests for information, services, notifications, and feedback. *Rio de Janeiro's Citizen Support Central*[3] provides mobile and web solutions for on-spot reporting of issues like broken public lights, road potholes, damaged vegetation, irregular parking, request for trash removal, and others.

We are proposing a *Platform for Citizen Sensing in Sentient Cities* to instrument citizens and cities. It provides the tools to interconnect parties, analyse related events, provide reports, and simulate possible development scenarios. It also supports the interfaces to *recommendation systems* that will help in decision-making and coordination. The long-term goals established for this project are:

1. Development of *mobile applications* to provide the public interface for intentional and non-intentional reporting, monitoring, and feedback, as well as the back-end services required to support them.
2. Conception of *analytic models* for filtering reports based on correlation of observation data, variations of local context, and variations of user profile.
3. Formulation of *analytic models* for evaluating the level of impact and priority of reports based on sentiment analysis of the accompanying text, as well as image analysis ran over an optionally accompanying photograph.

This research builds upon the IBM Smarter Cities project, part of the IBM Smarter Planet program. The analytic models represent innovations being introduced in this research. They advance the state-of-the-art in analysing and correlating data in Citizen Sensing solutions.

This paper is structured as follows. Section 2 provides an overview of related technologies and previous works. Section 3 introduces our proposal for a *Platform for Citizen Sensing in Sentient Cities*. Section 4 presents results that demonstrate the support to interrelate data and decision making. The paper concludes with Section 5.

2 Background

In this section, we analyse the concepts and state-of-the-art in the topics of Citizen Sensing, Social Analytics, and Social Simulation.

Figure 1 provides an overview of the elements in generic Citizen Sensing solutions. First, there are the (i) *Sensors* to collect information from the real world. They are the entry points to "feel the pulse" of life in the city. The implementation of standard sensor platforms and open interfaces will greatly facilitate the deployment of citizen sensing solutions. The works in [3,11] emphasise the importance of ubiquitous sensors elements, arguing that this technology supports major breakthrough in the areas of *Human Dynamics* and *Crowd Coordination*.

There are two types of sensors that can be applied to different scenarios: (a) *Intentional Sensors* require end-user intervention, providing an interface for data entry; for instance, users tweeting in *San Francisco 311* and reporting issues in *Rio de Janeiro's*

[2] Ref: `http://sf311.org/`
[3] Ref: `http://www.1746.rio.gov.br/`

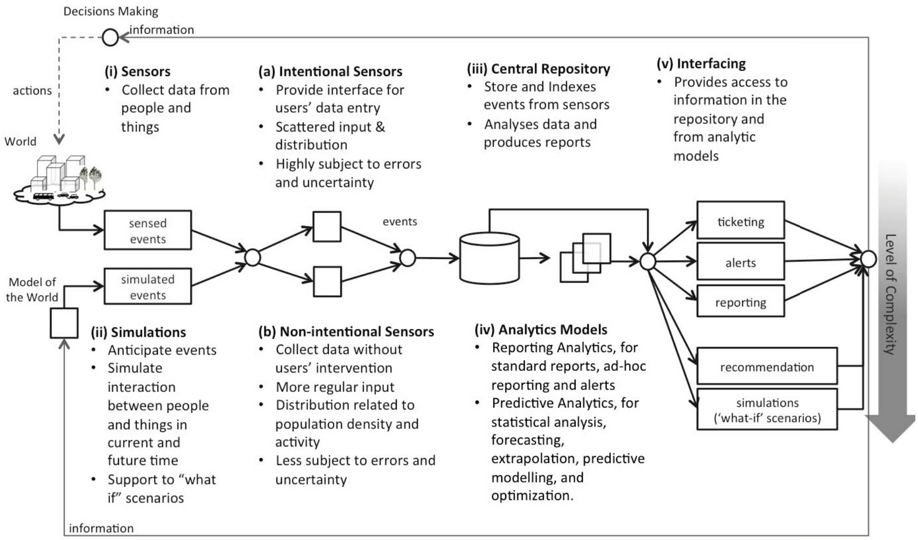

Fig. 1. Concept of Citizen Sensing Environment

Citizen Support Central; and (b) *Non-Intentional Sensors* collect data from the environment automatically; for instance, tracking systems that collect GPS information periodically, weather monitors, and others.

Second, there are (ii) *Simulations*, which are required to develop models to anticipate events and generate "what if" scenarios. The more information they entail in the *model of the world*, the more refined will be the simulation. We are seeking solutions in terms of traffic simulation, as e.g. [15], [6], and [9], including solutions focused on data extrapolation techniques such as [1] and [2].

Third, there are the (iii) *Central Repository* and (iv) *Analytic Models*. They provide the functionality to store, index, group, summarize, analyse, and cross-relate information. They deliver the solutions for *business intelligence*, making sense on the collected data beyond pure reactive and historical analysis. There is prior art showing the importance of such tools such as in [10] and [4]. These elements play central roles in commercial systems such as the IBM Intelligent Operation Centres [8].

Finally, there are the (v) *Interfacing Elements*, which provide access to data in the (iii) *Central Repository* and result from the (iv) *Analytic Models*. These solutions usually focus on visualization for ticketing systems, alerts, and reporting interfaces. A survey of existing information visualization is presented in [14]. More advanced systems provide recommendation interfaces, as for example [7]. Even more sophisticated, there are the interfaces to simulations required by solutions that provide "what if" scenarios.

In analysing the state-of-the-art, we concluded that current solutions focus on resolving only parts of the problem, such as on data collecting and analytic models. Therefore, opportunities exist to propose an all-encompassing solution for intelligent city monitoring and decision recommendation. This comprehensive solution must integrate the elements for sensing, simulation, central repositories, analytics, and visualization.

Next, we outline our proposal.

3 Proposal

We are proposing a *Platform for Citizen Sensing in Sentient Cities* that entails the elements for (i) sensors; (ii) data processing and augmentation; (iii) flexible data repositories; (iv) innovative methods for data analysis; and (v) extended interface. Figure 2 depicts the system architecture. The solution advances the state-of-the-art in urban planning and management by providing:

– *End-to-end Solution* for Citizen Sensing and social engagement, that can be scaled to cities of any size and applied to coordinate large events (e.g. crowd gatherings, sports games), emergency relief coordination, infrastructure planning, traffic monitoring, and others.
– *Enhanced Analytic Models* to identify trends and operational patterns in social interactions, anticipate emerging situations impacting society, and provide insightful information to decision makers.
– *Advanced Social Simulations* to be able to simulate interactions between the population and city infrastructure, supporting the anticipation and composition of "what if" scenarios.
– *Recommendation Systems* that leverage from these technologies and work closely with city leaders and deliver recommendations on how to make the city smarter and more effective.

The solution is being architectured to scale to cities of any size. It will be applied to deliver solutions to the complex scenarios involving the coordination of large events (e.g. crowd gatherings, sports games), emergency relief coordination, infrastructure planning, traffic monitoring, and others.

The elements of the solution are detailed next.

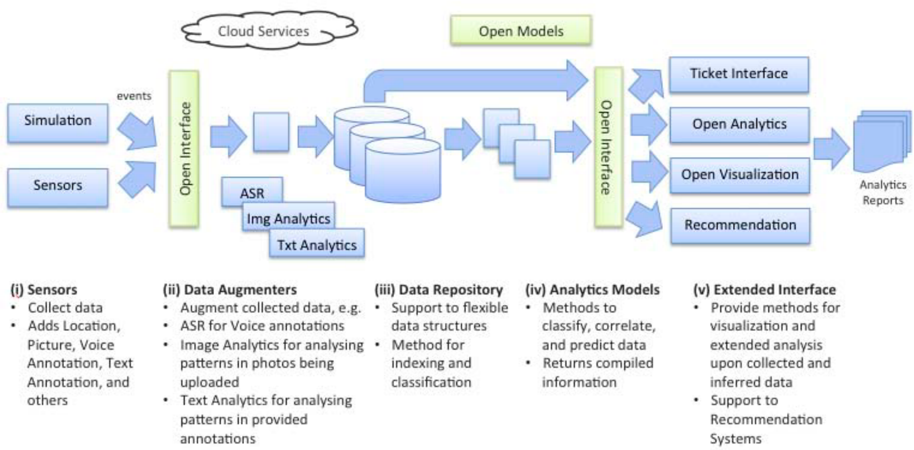

Fig. 2. System Architecture

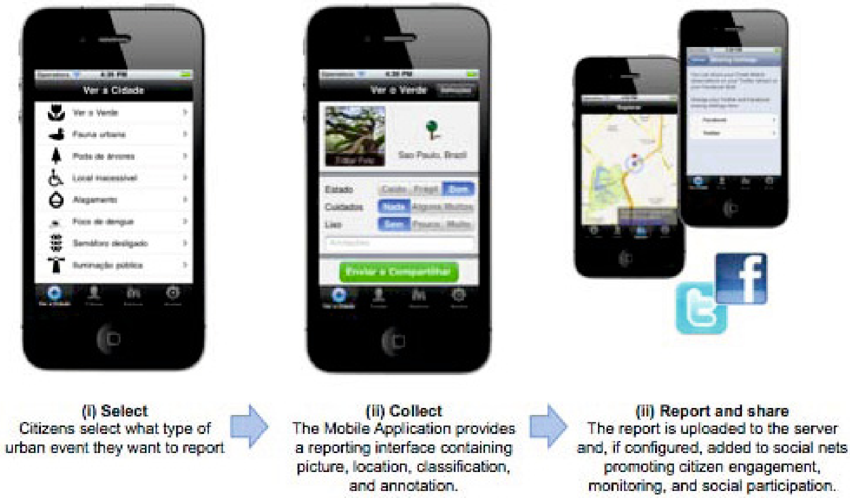

Fig. 3. Mobile Citizen Sensors

Sensors Module. We are providing a configurable Mobile Sensor Application to support intentional and non-intentional Citizen Sensors. Figure 3 depicts the current prototype for the (i) *Sensors Module*. The *Citizen Watcher* application (in Portuguese, "Ver a Cidade") allows for citizens to report urban situations on the spot using their own smartphone devices. Examples of possible reports involve: aggression to urban vegetation, fauna, requests for gardening, reports of inaccessible areas, floods, traffic, road potholes and others.

The Mobile Sensor Application is freely available from regular mobile application stores[4] and connect to the (iii) *Data Repository* module through regular mobile Internet connection and open interfaces.

Using this platform, municipalities can easily promote the use of *Mobile Citizen Sensing*. The reports will be uploaded to customized Cloud Services providing open Web and mobile access to the data.

Data Modules. There are two sets of functional modules for (ii) *Data Augmenters* and (iii) *Data Repositories*, accessible through a open interface.

The (ii) *Data Augmenters* provide methods to augment received data as, for instance, by adding contextual information and converting data formats. In this module, we are incorporating methods for voice recognition to support voice annotation. Voice annotations are transcribed on the server by using IBM Voice Recognition technology.

Both voice and transcriptions are stored in the (iii) *Data Repository*, forming a database of rich annotations. This can be used to run text analytics on citizen's moods whilst reporting the events, allowing for extended analysis of the reports. Moreover,

[4] Note: only an iOS version is available at the moment. We intend to produce an Android version soon and, possibly, a Windows Mobile version in the short term.

we are including solutions for image recognition and image analytics that provide the pre-classification of the user generated annotations. This combination of technologies provide a key contribution to the overall solution, making it more pervasive and easy to use.

The (iii) *Data Repositories* implement the data store, indexing, and organization. In our architecture, this component is implemented upon IBM DB2 pureXML technology, providing methods for flexible data structures supporting data input from different sensors and simulations.

Analytics Modules. This model provides the methods to classify, correlate, and predict information upon the data stored in the (iii) *Data Repositories*. It is composed of analytic models based on data being collected and simulation for urban scenarios. In Section 4 we are presenting an illustrative scenario of the application of analytic models in the context of Smarter Cities.

Analytic models for Smarter Cities is a new concept and still field for research. For that, we are implementing a number of innovative models for both (i) *reporting analytics*, such as standard reports, *ad-hoc* reporting and alerts; and (ii) *predictive analytics*, for statistical analysis, forecasting, extrapolation, predictive modelling, and optimization.

In that regard, we are researching on methods and techniques for filtering reports based on correlation of observation data, variations of local context, and variations of user profile. Context can be defined by additional information that may be used to augment reports, such as time, location, and surrounding events, while user profiles are categorized in terms of end-users' demographics, psychographic information, and statistical analysis of previous contributions made to the platform[5].

Additionally, we are investigating on models for evaluating the level of impact and priority of reports based on sentiment analysis of the accompanying text, as well as image analysis ran over an optionally accompanying photograph[6]. This solution provides a pre-classification of the user generated annotations, in which the severity of certain observations can be recognized based on the pictures being uploaded along with the reports.

Finally, we are including open interfaces for analytics and visualization. It will allow for third-party developers and the public in general to have access to (public) data and create their own analysis and reports. We see openness and free access as pivotal in this platform. We believe that, by promoting free access, it will boost collaboration and analysis from different points of view. This approach will contribute to both (i) the sense of transparency and social inclusion and (ii) further development of analytic models for Smarter Cities.

Simulation Module. This module allows for the creation of prediction and "what if" scenario simulations. For instance, we are developing simulations to predict scenarios for early warning systems. This is based on previous work like [5], aiming at solutions for the coordination of large-scale events. The objective is to understand the likely problems that could occur and be prepared to respond. The environment encompasses the

[5] IBM patent pending.

[6] IBM patent pending.

description of city's infrastructure, population behaviour, crowd dynamics, law enforcement, emergency units, and others. We are implementing a bottom-up approach where we are modelling individuals' behaviour and their group attitude.

We are proposing agent-based simulations, where a population is instantiated with a number of general parameters according to culture and environmental conditions. These parameters will indicate which are the valued priorities of the people and, therefore, create certain preference orderings for actions given the current conditions. We will also model how the actions influence all the environment parameters and thus change the world and the context of the agents to make decisions.

In this line of research, we intend to establish how natural social groups, norms, and regulations can be used to provide some centrally controlled mechanisms to guide "realistic" crowd behaviour. For instance, a group of people with the purpose of going to a football stadium for a soccer match will not be easily deterred from its path, but people coming out from the match might be easily guided.

The simulations will be calibrated by using real data from areas where the population is well-known (using statistical data), e.g. what is the average income, unemployment rate, etc. All these parameters influence the value priorities. The outcomes of the simulation can then be compared with those in reality, e.g. how much garbage is produced, how do people dispose of their garbage, how much water is used, how many people own cars and use them every day, etc.

The inherent support to simulations in the composition allows for the creation of next-generation analytics solution that goes from "understand what has happening and inform" to "understand what is likely to happen and optimize".

Next, we describe case scenarios where we apply the proposed technology to coordinate resources and anticipate events.

4 Illustrative Scenarios

Let us consider a scenario where citizens using the *Mobile Sensor* module provide intentional reports for (i) garbage on the streets, (ii) areas of inundation, and (iii) traffic jams. The observations are collected by citizens and uploaded to the *Data Repository*, including the report, a text annotation, a photo, and the location. In this scenario, the proposed platform provides important and non-trivial insights that can be applied in the prediction of traffic conditions.

In this context, Figure 4 presents the data collection performed in a same area for the period of 15 days. Markers on the maps pinpoint the counters for each occurrence. The graphs on the right side present the variation of occurrence counters during the time period.

The analysis is as follows. On the third day, only a few garbage reports have been registered. Thus far, neither traffic jams nor floods have been reported. This observations suggests that garbage alone does not have an influence on congestions.

On the eighth day, the number of garbage occurrences increased. In addition, some spots of road inundation have been reported. In this circumstance, traffic jams started to be registered, specially around the road inundation locations. Hence, one can infer, based on both common sense and on analysis of the data, that the number of occurrences

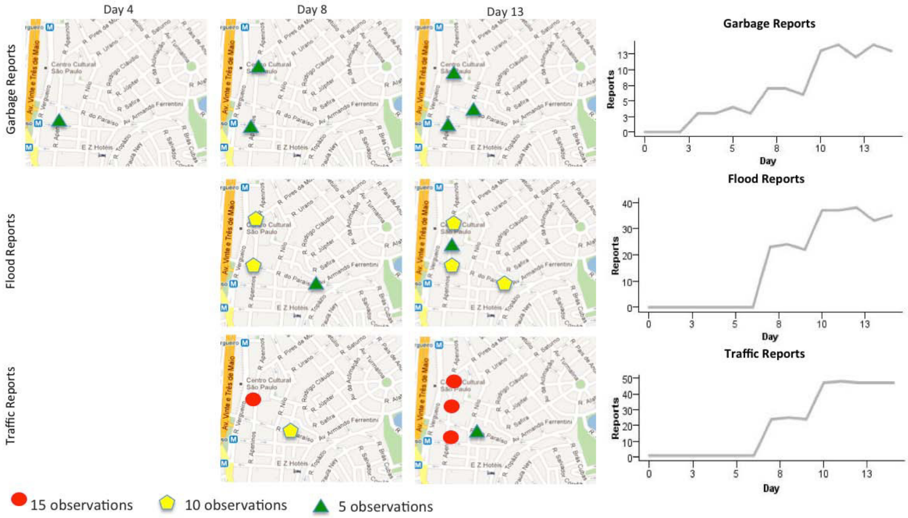

Fig. 4. Example of application based on the platform

of traffic jam is linearly proportional to reports of road inundation, but it is not related to garbage in the streets.

However, as we can see in the snapshots of the thirteenth day, the number x of flood observations increased and the number of traffic reports clearly had a superlinear growth in x. Therefore, the original conclusion is not precise. Modelling traffic as a function of rain may still be the correct approach, but if a decent formulation cannot be identified, cross relation of variables may bring some important insights. In particular, in the presented scenario, we can see that the number of garbage reports also grew significantly in the time period. If a large amount of garbage accumulated on the streets, it is possible that culverts have become clogged, leading to a scenario where floods were more likely to occur.

This fact suggests that garbage occurrence may be relevant in the context of traffic jam prediction, and therefore one should also consider the possibility of modeling traffic jams as a function of flood and garbage occurrences.

Finally, it is interesting to notice that, if data suggests a strong dependence between garbage, rain, and traffic jams in a certain area, it may indicate infrastructure issues in the regions (e.g. culverts need maintenance, garbage collection has not been adequately performed in the area, etc.). We conclude that the extended analytic capabilities provided by the *Platform for Citizen Sensing in Sentient Cities* provide useful information for city administrators to identify trends and operational patterns beyond the obvious. This allows for anticipating emerging situations impacting society, and provides insightful information to decision makers.

5 Conclusions

We are creating a decision-support system for urban planning and management that provided important tools and methods for city administrators. The proposed solution encompasses sensors, data processing and augmentation, flexible data repositories, innovative methods for data analysis, extended interface, and simulation support. We are creating a solution that can be scaled to cities of any size, applied to the coordination of large events (e.g. crowd gatherings, sports games), emergency relief coordination, infrastructure planning, traffic monitoring, and others.

We presented the application of extended analytic capabilities to provide useful information in a scenario where citizens use the *Mobile Sensor* module to report (i) garbage on the streets, (ii) areas of inundation, and (iii) traffic jams. The analysis allows for understanding the cross-relation of events. It implied that there is a strong dependence between garbage, rain, and traffic jams in a certain area, that may indicate infrastructure issues in the regions. This sort of analysis is valuable for decision makers, justifying the implementation of the proposed platform by the municipality.

We foresee the application of the proposed technology to provide analysis in different areas of interest, as for example:

- *Accessibility Applications*: If people with disabilities are equipped with non-intentional sensors, it is possible to identify locations that were frequented by them and, more important, locations that were not. This data may be used by municipalities for the identification of inaccessible places.
- *City Occupation Analysis*: The solution can estimate the volume of people present in a certain area in a certain time span. Based on this information, it is possible to identify which regions are under-occupied at certain periods of time, what is the profile of the group of citizens that come to these places, and others.
- *Infrastructure Needs*: It is possible to determine the paths followed by citizens. If the platform is enriched with data describing which transportation vehicles the person used, it is possible to discover how people go from one place to the other, their origins and destinies and the timestamps of these events. With this information, governments may able to identify potential improvements in infrastructure and services related to public transportation.

As this work continues to develop, we are targeting to incorporate data available from external sources to the (iv) *Analytic Models*. For example, data can be imported from Open Data repositories[7] and social networks, such as Facebook and Twitter (e.g. a citizen posting a status about his neighbourhood being affected by road inundations whenever it continuously rains for more than a couple of hours).

Finally, we stress that the outcomes of this research yield significant social contributions. Being able to broadly coordinate resources and anticipate events, city administrators can make reliable decisions that will impact social services, traffic, energy and utilities, public safety, retail, communications, and economic development.

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[7] Ref: `http://datacatalogs.org/`

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