Pervasive Urban Crowdsourcing: Visions and Challenges

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Abstract

Pervasive computing technologies can enable very flexible situated collaboration patterns among citizens and, via crowdsourcing, can promote a participatory way of contributing to the wealth and quality of life of our urban environments. This position paper firstly sketches a future vision of pervasive computing rich and crowdsourcing-enabled urban environments. Then, it presents several case studies showing how such environments can be of great use and highly impactful from both the individual and societal viewpoint. Finally, it discusses several open research challenges to be faced for these ideas to become reality.

1. Introduction

Information and Communication Technologies (ICT) have always open up new application opportunities. Recent progresses in the area of mobile and pervasive computing and in the area of Web-based collaboration, respectively, are paving the way for:

- Innovative services to perceive detailed information about the surrounding physical and social world, and interact/act in it, i.e., pervasive situated services [Cas07];
- Innovative models and tools to engage a large number of persons (typically unknown to each other and distributed at a world-wide scale) in collaboration activities oriented to solve computationally-hard problems, a phenomenon also known as crowdsourcing [Sur04].

Bringing the above together and focusing on an urban-scale scenario opens up brand new scenarios and possibilities.

Let us consider coupling the sensing, actuating, and computing capabilities of pervasive technologies with those of humans, and integrating them all together via communication and collaboration technologies enabling crowdsourcing. Then, our cities can become as sorts of immense socio-technical organisms in which (via digital and/or human capabilities) any situation can be sensed and analyzed, and in which actions can be dynamically performed at any time via distributed collaboration, i.e., via pervasive crowdsourcing at the urban level.

In this context, the contributions of this position paper are as follow:

- We detail the urban organism scenario, outlining the role of pervasive computing technologies, of humans, and of crowdsourcing models (Section 2);
- We present three exemplary case study scenarios related to pervasive urban crowdsourcing, to show its great potentials of use and societal impact in various areas, namely city maintenance, childcare, and mobility (Section 3);
- We discuss, without the ambition of being exhaustive, some key challenging research issues to make the vision become reality (Section 4).

Eventually, section 5 concludes the paper.

2. Towards Socio-Technical Urban Organisms

In this section we detail how pervasive computing technologies and services, with the integration – via crowdsourcing – of human contributions, can make our urban environment become sorts of immense organisms in which a variety of innovative tasks and services can support increasing quality of life levels.

2.1. Pervasive Infrastructures and Services

The increasing deployment and exploitation of pervasive computing technologies is making our urban environments very rich in terms of sensing, actuating and computing devices. These include: sensing devices such as, e.g., sensor networks, cameras, RFID tags, location and proximity sensing, traffic sensing, pollution sensing; actuating devices such as, adaptive traffic lights and signs, traffic inhibitors, interactive displays; all of which typically embedding computational, communication, and storage capabilities.

Overall, the above trend is contributing to the emergence of a very dense ICT infrastructure embedded in the physical and social fabric of our cities. The infrastructure can clearly be put to the service of users for the provisioning of general-purpose ubiquitous services for better interacting with the surrounding physical world and with the social activities in it, a trend that is already in act [Cas07].

However, assume all the components of the infrastructure can be made somehow able to dynamically and adaptively connect and collaborate with each other via proper collaboration and middleware tools. Then, the infrastructure can somehow turn our urban environments in sorts of active organisms capable of autonomously and adaptively shape urban activities and urban life in a purposeful way (e.g., to adaptively route vehicles depending on current traffic and pollution conditions).

Pushing the vision forward, we will eventually assist to the emergence of a sort of urban-level intelligence, to externalize and enhance our physical and social intelligence, integrate it with that of the urban organism, and make it become pervasive and collective.

2.2. Humans as Devices

It is already widely recognized that, to enhance sensing and computing capabilities of our urban environments, users should play an active role. That is, they should contribute their own sensing and computing devices (as available in modern smart phones and cars) [Kra08], thus making the overall infrastructure as open and capable of value co-creation as the Web is. However, the contribution of humans can go farther than simply making devices available.

The fact is that humans are very powerful devices in themselves and – in several cases – have sensing, actuating, and computing capabilities well beyond those available (now and in the near future) with ICT devices [YueCK09]. For sensing, it is a matter of fact that there are situations and events that only human sensitivity and experience can recognize while ICT devices can't (think at discriminating two young boys fighting against two playing to fight). For actuating physical actions, the human body has levels of mobility and flexibility that hardly any device or robot can reach. For computation, many pattern recognition problems can be performed with much higher accuracy by humans that by any of the available algorithmic tools.

This said, the levels of intelligence and flexibility of our envisioned urban organism could become much higher by integrating the capabilities of ICT devices with those of human devices. The result could be a powerful Socio-Technical organism urban organism in which the ICT and the human capabilities are brought together in a single infrastructure and blurred to the point of invisibility. In an opportunistic way, and depending on needs and capabilities, one can think at inter-twining the complimentary capabilities of human and ICT sensing, actuating, and computing, in a process of extremely high value co-creation.

2.3. Pervasive Urban Crowdsourcing

The key point in enabling the vision of such integrated socio-technical urban organism is devising means by which to dynamically involve and engage in collaboration the needed human capabilities.

On the one hand, the idea of outsourcing computationally hard problems to humans by dynamic recruitment of volunteers, i.e., via crowdsourcing, has indeed recently attracted much attention [Sur04, Bra08, Eag09, Kra10]. In most of current histories of success, though, the problems to be solved are typically related to working on digital data (e.g., tagging pictures and videos [Eag09, Der10] or performing character recognition [ShaH10]), and are based on global (world-wide) recruitment models supported by Web technologies. Little attention is paid to solving situated physical problems, requiring specific sensing, actuations, or computations, in specific locations and times.

On the other hand, many recent works in the area of pervasive computing focus on situated participatory situated sensing models [Alt10, Red10, Yan10, Wil10]. The key point in these researches is how to involve people at some specific locations with sensing devices available (e.g. the camera of a smart phone) in supplying information about specific situations occurring around (e.g., taking a picture of the location and making it available). Still, beside possibly asking for adding some tags to the supplied information, little attention is paid to the possibility of dynamically recruiting humans in a pervasive and situated way to take advantage of their peculiar actuating and computational capabilities.

Our broader perspective is that pervasive computing technologies can support much more powerful, pervasive and situated, crowdsourcing models. That is, crowdsourcing models in which also the human capabilities of acting and computing in the physical world can be put at play in a globally collaborative urban organism (and, why not, also by dynamically putting on the table the possibility of exploiting privately owned physical resources). By sensing the needs of a city and of its citizens, by perceiving who's around that can help, and by dynamically establishing collaborative activities seamlessly involving ICT devices and humans pervasive urban crowdsourcing promises to be able to dramatically improve the way we live, work, move, and play in our towns. Yet, the broader application potentials of such idea are still widely unexplored, as they are the key challenges involved in realizing the idea.

3. Case Study Scenarios

Three specific case study scenarios are presented to show the potentials of pervasive crowdsourcing in urban environments.

3.1. Crowdsourced City Maintenance

It is a matter of fact that municipalities spend a lot of their money in trying to maintain at the best our urban environments. Activities include: garbage collection, maintenance of roads and public green, installation and maintenance of public lights, etc. In general, all the above activities involve a lot of human work, of which only a small portion calls for specific specializations, skills, or tools.

As of today, city maintenance activities tend to be:

- Very costly, due to the need for municipalities to employ on a permanent basis a large number of persons to perform them;
- Typically based on static planning of activities and on sporadic and sparse monitoring of situations;
- Consequently, not adaptive and slow in reacting to contingencies that may require the activation of unplanned tasks or the re-scheduling of planned ones;
- Promoting very little degrees of participation by citizens, which usually have no words (beside voting) to express their opinions and their real needs.

Therefore, even in the case of highly efficient municipalities' administrations, it is often the case, we, as citizens, are quite unsatisfied with the way things work. Beside the most common reaction of accepting the state of things and mumbling, sometimes citizens happen to react by getting proactive in trying to improve things and supply the low performances of the municipality. For instance, a group of neighbors can spontaneously organize to share the load of cleaning their own street.

The key point we emphasize here is that, in future urban organisms and with the help of pervasive computing technologies and crowdsourcing models, the above participatory and proactive approach to city maintenance can become a systematic one.

First, pervasive sensing devices can help identifying in a dynamic and prompt way any possible need for city maintenance; let it be a broken lamp or a hole in a street. Clearly, citizens can contribute to these fine-grained monitoring capabilities with pictures and sensorial data from their smart phones (e.g., by sending a geo-tagged picture about a very full garbage can) or, exploiting their peculiar sensing capabilities, by imputing textual information on them (e.g., by detecting and signaling the presence of oil in a street, a situation that can be hardly captured by a camera).

Following, upon need, citizens can be involved in making available their computation and actuation capabilities to fix problems (e.g. by volunteering to sweep the oil from in their front street). Clearly, this requires – other than the capability of identifying problems – also that of dynamically identifying, for any sensing, computation, or actuation need, which (group of) citizens can be, at a given place and at a given time, dynamically recruited. For instance, a young man doing gardening is more likely to help cleaning the oil from the street that a grandfather taking care of his nephews. Yet again pervasive computing technologies can be of great help, by tracking the location and activities of citizens (at least of those having authorized this) and by dynamically proposing them tasks to be undertaken (e.g., via a simple message on the mobile phone). And also, in case of collaborative tasks, by supporting the coordination of dynamically formed groups.

We emphasize that a model of crowdsourced city maintenance dramatically changes the current way of doing. It can contribute in reducing the stable employees of the municipality (with notable savings in expenses), it can support more dynamic and effective planning of maintenance activities, and can be a very effective way to make citizens strongly feel part of the community.

Last but not least, should the approach becomes a systematic one, and if the dynamic recruitment of workforce will be supported by economic incentives, crowdsourced city maintenance could become one of the seeds that will produce, in the near future, a radical re-thinking of the very concept of work. While researchers in many areas already argue about the revolutionary impact of crowdsourcing in the work market [Bra08, Kra10], we think that moving crowdsourcing from the Web world of digital information down to the real world of physical work can be even more disruptive.

Clearly, for this scenario to become reality there are a number of technical challenging issues to face, which are also shared by the following two scenarios. We discuss these in Section 4.

However, it is clear that a big (non-technical) challenge for this and for the following scenarios is related the social acceptance of the model, especially in consideration of the dramatic changes in the concept of privacy it carries on.

3.2. Let the Children Play

The oldest readers may remember that we were used to move around our cities in full autonomy since we were 7-8 years old: the streets were our everyday playgrounds. Now this is mostly unconceivable, and seeing a child of eight walking alone in a city would let us think (s)he is abandoned or in trouble. Our cities can have definitely changed in the past decades (more traffic, more dangers, less familiar neighborhoods, less safety overall), and so has our state of mind.

The key argument here is that the urban organism can be of great help to decrease the potential dangers for children, increase the safety of our neighborhoods, and consequently let us feel much more comfortable about the possibility of children walking around alone and playing in the streets.

Along the lines of the previous case study, we can envision:

- The possibility of fine sensing the activities of children, and human sensing here is of primary importance (we already stated how it is difficult to discriminate if two children are playing or fighting).
- The existence of actuators (humans, and not to exclude robots) to perform actions aimed at preventing dangerous situations being foreseen by the overall infrastructure of the urban organism;
- The dynamic recruitment of people willing to act as sorts of "baby sitters" for a while, to take care of groups of children with their peculiar sensing and actuating capabilities.

Beside economic incentives, the key role of crowdsourcing here could be that if inducing a sense of responsibility in citizens. It is common sense, while walking in a park, to get alerted in seeing children alone or in potential dangers. However, being explicitly requested of taking care is much different, and can prevent people from simply passing by and ignore the situation.

Of course, technical challenges and the issues of privacy arise in this scenario too. However, more in evidence here is the issue of trust: for the idea to become widespread, there must be high-levels of confidence in the proper functioning and reliability of the overall urban organism infrastructure and of all its parts (human included).

3.3. Zero-Stress Mobility[1]

Whether you move by car, by public transport, or in some multimodal way, getting around can be very stressful in most of the cases and in most of the cities. You often have to queue, experience delays, and spend a lot of time in finding a suitable parking slot.

Even in this case, the urban organism can be of great potential help to notably reduce mobility stress, if not to support the achievement of a "zero-stress" mobility model.

Consider the existence of traffic sensors to detect the traffic situation, the position and expected schedule of public transport vehicles, as well as the current availability of parking slots. Consider the availability of actuators to influence the flow of traffic (such as adaptive car navigator systems, adaptive traffic signs and lights). All of these can notably help mobility, and most of these technologies are already under study and/or being prototyped.

However, consider that drivers and citizens can enter the above scenario by dynamically signaling their needs or, upon signaled needs, by making available their services and private resources to satisfy them. Then, one can think, for example, at:

- Pushing car pooling to extreme levels, by enabling users to signal their desired routes and by enabling drivers passing by to take care of them (possibly with some economic incentives). This can dramatically diminish the number of circulating vehicles;
- Making available private cars or motorbikes for short term periods, when unused (and possibly being paid for that), with a notable impact on traffic and parking space availability;
- Making available private parking space for the periods in which the owner is away (and possibly being paid for the renting), thus increasing the overall parking availability:
- For public transport, dynamically sense the needs of customers and, also by evaluating all possibly alternatives (as from the above items) dynamically re-schedule timetables and routes to provide an overall better service to citizens.

The concept of crowdsourcing in this scenario is a bit different from the previous two scenarios, in that it mostly involves the participation of citizens in making available private resources, rather than physical work or sensing capability. Such factor, while potentially inducing notable benefits, can induce a change in the concept of private property for resources such as vehicles and parking slots. Without undermining the legal aspects behind the concept, it will definitely make it perceived as more fluidly, as vehicles and parking slots will become, de facto, globally shared resources of the overall urban organisms. And citizens will increasingly perceive the importance of contributing to the community.

4. Research Challenges

For pervasive urban crowdsourcing to become reality in our future urban environments, and eventually make them become truly like sorts of organisms, many technical research challenges have to be faced.

[1] The term "Zero-stress mobility" has been suggested by Alois Ferscha.

Foundations. First of all, as in any emerging area, there is need of laying down brand new foundations for the modeling and understanding of large-scale Human-ICT organisms and their adaptive collaborative behaviors. As already recognized in the more general area of Internet-scale crowdsourcing [Kra10], and thus directly applicable also to pervasive urban crowdsourcing, such foundations should build also on experience and success stories, and should account for the lessons form applied psychology, sociology, and social anthropology; other than from systemic biology, ecology and complexity science.

Diversity in Collaboration. As of now, most studies related to collaboration and coordination in pervasive environments focus on systems with a limited and fixed number of components' classes. However, this is far from even approximating the increasing diversity of components (devices, services, and resources) of future urban organism scenarios, and their being so radically heterogeneous in nature (including both ICT and human services working together towards some goal) and availability (some services being ready-to-use and some to be recruited on need) and their continuous evolution. Novel collaboration models must be supported to account for such diversity, and novel models for describing services and resources must be defined, capable of accounting for such diversity yet without making their description excessively complex. All of which to be properly supported by suitable middleware infrastructures.

The Changing Role of Middleware. To properly support the complex, heterogeneous, and dynamic collaboration patterns of the emerging scenarios, the role of middleware in supporting collaboration should change. In particular, such role should somehow shift from that of simply supporting service discovery, context-awareness, and orchestration, to that of acting as a: *(i)* recommendation engine – to proactively support applications in finding or recruiting on need (among a multitude) the services/capabilities they need to operate, independently of their actual human or ICT nature; *(ii)* dynamic planner, to dynamically establish the most appropriate collaboration patterns depending on the current situation and on the nature, characteristics, and constraints of the available services [Cas10]. All of which also with embedding the necessary mechanisms to support the resulting interactions patterns in an effective and secure way, and flexibly accounting for the peculiar and novel privacy issues that emerge in these scenarios.

Advanced Context-aware Models. While the need for context-awareness is already a recognized issue in pervasive collaboration and middleware research, for the urban organism to perform well and to properly involve in sound collaborative activities all needed actors, more comprehensive levels of awareness are to be supported than traditionally enforced in context-aware pervasive computing [Bet10]. In traditional context-aware computing it is typically up to each component to access and digest the information it needs to take adaptation and collaboration decisions. This approach falls short in the presence of large-scale systems for which a very large number of contextual information is available (there included social sensing tools [Ros10]). The middleware infrastructure must be able to digest and analyze all this data and eventually make available expressive and compact representations of complex multi-faceted situations [Bic10], to help identifying which situations requires which actions, which devices and humans are available to perform them, and which collaboration patterns better suits the current situation.

The Power of the Masses. As pervasive computing infrastructures are becoming very large scale, sources of huge amounts of data, and involving a large number of human contributions, it can become necessary to understanding the "power of the masses" principle as far as participatory collaboration processes are involved. For instance, this can imply understanding how and to which extent even very simple emerging phenomena of self-adaptation and self-organization, now typically studied in small-scale systems, can – when involving billions of users, services, or data items – express forms of effectiveness and adaptivity (or, which is the same, of observable "intelligence") much superior than those obtained today with more traditional forms of distributed computing and artificial intelligence techniques [Hal09]. Or viceversa, how and to which extent such collective phenomena can get out of control, calling for proper tools to direct the collective behaviors of the system (or of its subparts) in a decentralized way.

Design of Economic Mechanisms. To get the best from future urban organisms scenarios, there must be means to ensure that all available components (devices, services, human actors) are both prone to put their capabilities at the service of the collectivity and capable of opportunistically and effectively collaborate with each other. Although in some cases private resources and human capabilities can be made available for free, the need to ensure satisfactory degree of participation calls for identifying and designing novel interaction mechanisms to incentive and support adaptive interactions among the many and diverse components of the system. Several proposals, typically based on auction mechanisms, have appeared to promote cooperative and/or opportunistic sharing of sensing devices [LeeH10]. However, due to the specific characteristics of crowdsourcing work models [HorC10], it is very likely that brand new incentive and pricing mechanisms will have to be identified, towards a more general approach to pervasive crowdsourcing, and possibly leading to the definition of a peculiar pervasive computing economy.

In addition to all the above, the fundamental issues of users' acceptance, privacy, and trust, will have to be somehow addressed by scientists in disciplines other than computer science, as well as by policy makers. Thus, as important as they are, they are out of the scope of this paper.

5. Conclusions and Future Work

Our future urban environments will be rich in pervasive computing technologies and will be able to provide useful digital services to citizens. In this paper, we have shown how, by integrating these with the peculiar sensing, actuating, and computing capabilities of humans via crowdsourcing collaboration models, urban environments can become sort of immense organisms in which all individual organs can collaboratively contribute capabilities and services aimed to support – in many aspects – increasing levels of quality of life.

To turn the potentials of this idea into reality, though, a number of fascinating and innovative open research challenges are to be undertaken, as those we have sketched in this paper, the many we may have missed in identifying, and the many that other than computer scientists wull have to tackle.

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References

[Alt10] F. Alt, A. S. Shirazi, A. Schmidt, U. Kramer, Z. Nawax, "Location-based Crowdsourcing: Extending Crowdsourcing to the Real World", ACM Nordic Conference on Human Computer Interactions, Reykjavik (IC), Oct. 2010.

[Bet10] C. Bettini, et al., "A Survey of Context Modeling and Reasoning Techniques", Pervasive and Mobile Computing, 6(2):161-180, 2010.

[Bic10] N. Bicocchi, et al., "Self-organized Data Ecologies for Pervasive Computing Services: the Knowledge Networks Approach", IEEE Transactions on Systems, Man, and Cybernetics, 40(4):789-802, 2010.

[Bra08] D. C. Brabham, "Crowdsourcing as a Model for Problem Solving", International Journal of Research into New Media Technologies, 14(1):75-90, 2008.

[Cas07] G. Castelli, A. Rosi, M. Mamei, F. Zambonelli, "A Simple Model and Infrastructure for Context-aware Browsing of the World", 5th IEEE International Conference on Pervasive Computing and Communication, White Plains (NY), March 2007.

[Cas10] G. Castelli, M. Mamei, F. Zambonelli, "The Changing Role of Pervasive Middleware: From Discovery and Orchestration to Recommendation and Planning", Tech. Rep. No. 36/10, DISMI, Università di Modena e Reggio Emilia, Nov. 2010.

[Der10] M. Demirbas, M.A. Bayir, C.G. Akcora, Y.S. Yilmaz, H. Ferhatosmanoglu, "Crowd-sourced Sensing and Collaboration Using Twitter", WOWMOM Symposium, Montreal (CA), 2010.

[Eag09] N. Eagle, "txteagle: Mobile Crowdsourcing", in Internationalization, Design, and Global Development, LNCS No. 5623, Springer Verlag, 2009.

[Hal09] A. Halevy, P. Norvig, F. Pereira, "The Unreasonable Effectiveness of Data", IEEE Intelligent Systems, 24(2):8-12, 2009.

[HorC10] J. J. Horton, L. B. Chilton, "The Labor Economics of Paid Crowdsourcing", arXiv: 1001.0627v1, Jan. 2010.

[Kra08] A. Krause, E. Horvitz, A. Kansal, F. Zhao, "Toward Community Sensing", 7th International Conference on Information Processing in Sensor Networks, Washington (DC), 2008.

[Kra10] R. Kraut, M. L. Maher, J. Olson, T. W. Malone, P. Pirolli, J. C. Thomas, "Scientific Foundations: A Case for Technology- Mediated Social- Participation", IEEE Computer, 43(11):22-28, Nov. 2010.

[LeeH10] J.-S. Lee, B. Hoh, "Dynamic Pricing Incentive for Participatory Sensing", Pervasive and Mobile Computing, 2010, to appear.

[Red10] S. Reddy, D. Estrin, M. Srivastava, "Recruitment Framework for Participatory Sensing Data Collections", 8th International Conference on Pervasive Computing, Helsinki (SF), LNCS No. 6030, Springer Verlag, 2010.

[Ros10] A. Rosi, S. Dobson, M. Mamei, G. Stevenson, J. Ye, F. Zambonelli, "Social Sensing and Pervasive Services: Applications and Perspectives", Tech. Rep. No. 37/10, DISMI, Università di Modena e Reggio Emilia, Nov. 2010.

[ShaH10] D. Shahaf, E. Horvitz, "Generalized Task Markets for Human and Machine Computation", 24th AAAI Conference on Artificial Intelligence, Atlanta (G), 2010.

[Sur04] J. Surowiecki, "The Wisdom of Crowds: Why the Many Are Smarter Than the Few and How Collective Wisdom Shapes Business, Economies, Societies and Nations Little", Brown, 2004.

[Wil10] W. Willett, P. Aoki, N. Kumar, S. Subramanian, A. Woodruff, "Common Sense Community: Scaffolding Mobile Sensing and Analysis for Novice Users", 8th International Conference on Pervasive Computing, Helsinki (SF), LNCS No. 6030, Springer Verlag, 2010.

[Yan10] T. Yan, V. Kumar, D. Ganesan, "Crowdsearch: Exploiting Crowds for Accurate Real-Time Image Search on Mobile Phones", ACM Mobisys, San Francisco (CA), 2010.

[YueCK09] M. C. Yuen, L. J. Chen, I. King, "A Survey of Human Computation Systems", International Conference on Computational Science and Engineering, Vancouver (CA), 2009.