Social Sensing in the Field: Challenges in Detecting Social Interactions in Construction Sites

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ABSTRACT

Construction industry is a sector that is renowned for the slow uptake of new technologies. This is usually due to the conservative nature of this sector that relies heavily on tried and tested and successful old business practices. However, there is an eagerness in this industry to adopt Building Information Modelling (BIM) technologies to capture and record accurate information about a building project. But vast amounts of information and knowledge about the construction process is typically hidden within informal social interactions that take place in the work environment. In this paper we present a vision where smartphones and tablet devices carried by construction workers are used to capture the interaction and communication between workers in the field. Informal chats about decisions taken in the field, impromptu formation of teams, identification of key persons for certain tasks, and tracking the flow of information across the project community, are some pieces of information that could be captured by employing social sensing in the field. This information can not only be used during the construction to improve the site processes but it can also be exploited by the end user during maintenance of the building. We highlight the challenges that need to be overcome for this mobile and social sensing system to become a reality.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous; J.7 [**Computers in Other Systems**]: Miscellaneous

General Terms

Measurement, Design

Keywords

Mobile Phone Sensing, Process Management, Social Psychology

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1. INTRODUCTION

The recent advances in mobile and ubiquitous computing have made a tremendous impact on our society. These new technologies have transformed our approach to personal and social aspects of our lives. They have even changed the ways in which we run our businesses. And while the majority of modern industries have adopted these new technologies, the changes in construction industry have been relatively less radical. Construction industry is renowned for its slow uptake of new technology and relies heavily on old and previously successful business practices. It is estimated that the per annum capital expenditure of construction industry in UK is about £60 billion with £10-£20 billion being wasted due to inefficiencies in the technology and processes used by the industry [14]. These inefficiencies arise due to the size and the complexity of construction projects especially in the public sector. For example, construction of a new airport or an underground tunnel station usually involves several companies, contractors and suppliers.

In order to curtail these inefficiencies and to better manage large scale construction projects, there is a recent push in the industry, driven by government legislation [5], to adopt *Building Information Modelling* [10]. Building Information Modelling (usually referred to as BIM) is a software system for storing, updating and managing information about all aspects of a building. It provides the potential for a virtual information model to be handed from the design team to the contractor and then to the end user, each adding their own additional discipline-specific knowledge and tracking of changes to a single model. To facilitate this model, information needs to be successfully captured at the construction site. Commercial software suppliers are therefore developing solutions for on site information capture that leverage the current smart mobile devices like modern tablet computers and smart phones. This move towards adopting BIM is therefore gradually introducing mobile computing in a new work environment where even the use of mobile phones was not allowed due to safety concerns.

This change presents us with a unique opportunity to measure and analyse the organisational dynamics of workers at a construction site by leveraging the smart mobile devices used by these workers to interact with the BIM model or for other tasks. Currently on a construction site much of the communication and interaction between colleagues is not captured or recorded resulting in little or poor information about how teams of workers coordinate and work together. A construction site is usually tens or hundreds of miles away from the administrative base where decisions are made. Therefore, developing an understanding of how information flows from on site workers to project managers in an office can also lead to improved management. Olguin et al. [16] have shown that individual behaviour can be used to predict group performance. Gloor et al. [9] also showed that understanding the communication pattern between individuals in a work environment can be used to design interventions that enhance productivity.

In this paper, we present a vision where on-site smart mobile devices used by construction workers and managers, monitor the interactions between workers to extract the formation of teams, identification of key persons for certain tasks, and for tracking the flow of information across the project community. This information is collected and analysed at a back end system and can be used to infer new practices and techniques for improving performance and deeper understanding of the construction process.

2. MOTIVATION & VISION

2.1 Understanding the Industry needs

During the last year, we have been working closely with domain experts from major construction companies in the UK, within the framework of a newly established Innovation and Knowledge Centre for Smart Infrastructures in Cambridge [2]. The construction industry is currently undergoing a major transformation, motivated by two main forces: the need to reduce the cost of construction as a process, and the requirement for a significant cut down on the carbon footprint of the whole industry. Through a series of discussions and brainstorming sessions with domain experts we witnessed a new attitude towards new technologies. Construction companies are re-evaluating their current practices within their industry and are ready to embrace technologies that have the potential to revolutionise the way the whole industry functions.

A key motivation for our vision is the acknowledged lack of the use of new technologies in capturing and understanding construction processes. Current practices typically rely in self reporting and form-filling exercises, which can result in inaccuracies and missed information. Indeed, there is a clear gap between the reality in the field as experienced and addressed by field workers, and the information that is transferred to the back-end offices. More importantly, experience and knowledge is often hidden within the social interactions and activities performed by field workers, without necessarily being deemed important enough to be reported. For example, an efficient work practice performed by a certain work team, may never be acknowledged and reported by the field workers, merely because the members consider it *a natural way of doing things*. However, capturing such experiences could allow the management team to identify *good* practices that could be transferred to other teams in the field.

The introduction of mobile social sensing in construction sites, is an attempt to infuse the industry with the technologies that will ultimately allow the mining of "hidden" knowledge and experiences from the field. Our goal is to offer a new set of tools for industry experts that would allow the identification of inefficiencies in work practices, and improve awareness and visibility across all sectors in a construction project.

2.2 Social Sensing in Construction

Our vision is of a construction environment where every worker is equipped with a smart mobile device that is capable of capturing social interactions and activities performed in the field. The captured information is then collected and analysed in order to extract meaningful information about the behaviour and practices of the workers in the field (Figure 1).

More specifically, smart-phones carried by construction workers are tasked to collect a range of sensor data during the construction process. Key sensing modalities that the system should be able to capture include: location and co-location of personnel, capturing discourses between workers in the form of audio or textual data, and augmenting captured data with sensing modalities (i.e. pictures) that may be generated as part of the work process. The incorporation of information captured by sensing technologies deployed in the field [7] can allow the collection of even richer datasets. Borrowing from techniques employed by mainstream social networking applications, the system could allow user initiated check-ins, in a manner similar to location-based "check-ins" offered by applications such as Foursquare. Such "check-ins" could include work related information: i.e. "check-in" a newly discovered crack on a part of the building. Co-located workers can then be associated with the particular check-in, while a future inspection in that location can reveal the history of check-ins for that particular fault.

We envisage a system that is able to assemble low level sensed data and fuse them into high-level social events. Such social event data sets can include location information and involved workers along with additional contextual data. The complete set of collected information can then be analysed using existing social networking techniques to mine valuable information. For example, the analysis of social contacts between workers, can reveal the social graph and the potential paths where information generated in the field can reach the back-end management team. Moreover, an analysis of the social graph can identify persons that hold important information about certain activities, or maintain key social links between working teams.

We believe that the introduction of social sensing in construction, could open a new domain for applying targeted mobile social analysis techniques within the context of specific industries.

3. CHALLENGES

In this section, we outline the challenges that arise for social sensing in the field due to the unique nature of our application environment. Overcoming these challenges would allow the vision of social sensing in the field to become a reality and a useful technology.

3.1 Interaction Capture

Capturing interactions between different workers at a construction site is one of the main goals of our social sensing system. These interactions can provide an insight into the real social network of workers, the strength of ties between them, the flow of information from workers to management and organisational dynamics. We intend to extract this interaction information from verbal face to face communication, textual correspondence in the form of emails and co-location of the participants.

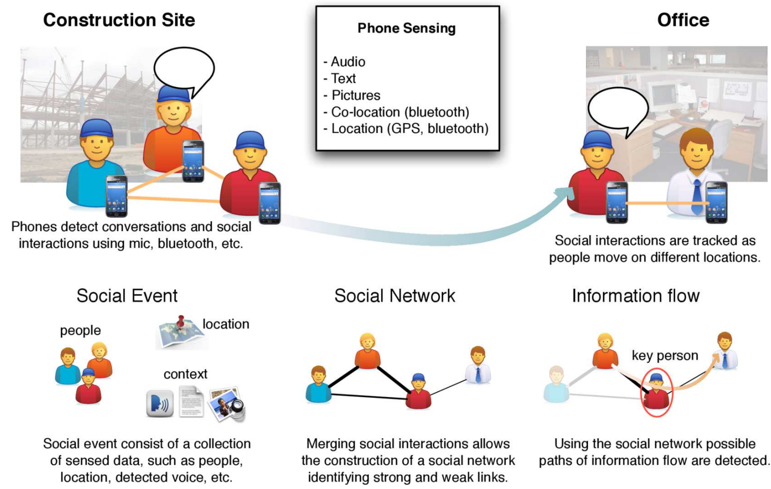

Figure 1: The vision of social sensing in construction sites.

Verbal communication between humans is a very rich modality and even with the computational capabilities of currently available smart devices, it is challenging to capture and analyse it in complete detail. Speech recognition and processing [12] is a vast and established field of research. Pentland [18] has also developed non-linguistic features that can be extracted from the verbal communications between humans. He refers to these features as social signals and has shown that these signals can be used to predict the behaviour of the humans involved in the conversation. However, these technologies have been used in an office environment. A construction site is a very challenging environment for any speech processing algorithm due to the noisy conditions. An active construction site is full of noise from different tools and any verbal interaction capturing would have to be robust to these noisy conditions.

Huberman et. al. [11] and Tyler et. al. [21] have shown that by just inspecting the headers of the emails exchanged between employees of an organisation, it is possible to detect communities and community leaders in the organisation. Huberman et. al. [11] also showed that it is possible to model the flow of information between the employees after the community structure has been uncovered. However, due to privacy concerns these studies were limited to email headers only. Our aim is to inspect not only the users who interact with each other but also the content of the electronic communication between them. This will provide us with insights about the tasks of the construction process or parts of the building that are discussed among the workers and the particular types of people in the organisation that are involved in these discussions.

3.2 Localization

Previous approaches to social sensing have relied on different sensing modalities for detecting both co-location and location of humans. For example, earlier wearable platforms like Sociometer [6] and Uberbadge [13] used infrared sensors to detect co-location and face to face communication. Uberbadge [13] also used infrared beacons for determining the coarse location of badge wearers. Olguin et al. [15] also experimented with bluetooth transceivers for detecting co-located employees. However, they reported issues with this approach that arise from the relatively long range of bluetooth radio. This results in false detections of employees that were not co-located. In order to overcome these issues, they used received signal strength (RSSI) to estimate distance to fixed bluetooth beacons and triangulation to estimate location. However, they do not report on the accuracy of this approach. Rachuri et al. [20] also use proximity to bluetooth beacons for estimating the coarse location of employees carrying small phones in a small number of offices.

Since we intend to use the smart phones and tablet computers carried by workers, we cannot use specialised sensing modalities like infrared for detecting co-location or location of workers. Although these mobile devices are equipped with bluetooth transceivers, the software stack usually does not allow scanning and detection of new devices without user interaction due to security reasons. And while this issue can be addressed by using a modified software stack on all the devices carried by construction workers, false detections due to the large range of bluetooth transceivers is difficult to overcome. We, therefore, require a localisation system that can provide continuous location information to all the devices at a construction site with the granularity of few meters. This location information along with other modalities can be used to detect co-location and face to face communication. For example, if the devices carried by two workers are within few meters of each other and simultaneously detect conversation, the devices can mark this as face to face communication.

Location systems are an active field of research and over the past few years several different approaches have been proposed. These range from systems that require specialised hardware [1, 23, 3, 19] to commodity off-the-shelf equipment [4] that is already integrated in current smart mobile devices. Each of these approaches exhibits different strengths and weaknesses. For example, the location systems with specialised hardware usually generate fine grained location estimates, although the additional hardware makes them unsuitable for our particular application. On the other hand, location systems that use integrated wireless capabilities of devices generally do not achieve fine grained accuracy. Such systems also require significant time and effort to deploy and are not robust to changes in the environment.

The unique nature of our deployment environment dictates that the localization system for our social sensing application must satisfy certain requirements. Since social sensing will be running on smart mobile devices carried by construction workers, the location system must use the integrated wireless transceiver without any additional hardware. The infrastructure for the localization system, for example the beacons, must be easily deployable. The system must be robust to changes in the environment. It must be low cost and must be able to run off batteries without requiring external power. And it must be able to track the devices with a granularity of only few meters despite all the constraints.

3.3 Energy Consumption

Since the primary purpose of smart mobile devices in a construction site is to allow the workers to interact with a BIM model or to conduct other tasks as part of their work at the site and the social sensing system must exist only as a background task on these devices, it is necessary that the social sensing system must be designed to be extremely energy efficient. Current smart devices are not designed to be used as monitoring devices which makes it challenging to sample and process the data from different sensors in an energy efficient manner. Energy efficient mobile sensing is a relatively new field and while some approaches to energy efficient sensing on smart phones [22, 20] have been proposed, these approaches trade-off accuracy for energy. We believe that there are opportunities to improve energy efficiency in our context by incorporating domain-specific knowledge about the activities performed in a construction site. Specialised adaptive sampling techniques could use contextual "hints" about work activities performed in the field where sampling needs to be increased or decreased accordingly. Such approaches could lead to reduced energy cost while maintaining high accuracy when sensing important events. Our social sensing system must be able to run on current smart mobile devices for the duration of a work shift at the construction site which is usually eight hours with continuous and accurate sensing of interactions, co-locations and communications between workers.

3.4 Privacy

Privacy is always a big concern whenever social and mobile sensing of human subjects is involved. Smart mobile devices have become truly ubiquitous. For example, Patel et. al. [17] have shown that a mobile phone is usually within an arm's reach of a user for about 60% of the time and 70% of the time it is within the same room as the user. And when such ubiquitous devices are equipped with interaction and communication sensing capabilities, it is necessary to respect the privacy of the users. Although, we intend to use social sensing in a construction environment and potentially on devices that will be confined to the work space, we will have to deal with the privacy issues because we intend to use verbal communication for interaction capture. We hope to deal with user privacy by using non-linguistic features of verbal communication and do not rely on the content of the conversations between employees. We can also constrain the social sensing system to operate only within the construction site or office space where users are less likely to engage in private or personal activities. The social sensing system will be disabled as soon as the users carrying these devices leave the construction site or the administrative office. The textual communication will also be limited to the business email account of the user.

3.5 Acceptance

Although we have discussed privacy issues in the previous section, the perception of a sensing system by the workers or the employees of the organisation is an important aspect that must be given careful consideration. For example, if the employees feel that the purpose of a social sensing system is to monitor the individual personal performance in the work environment, they will not feel comfortable and will try to misuse the system. Efstratiou et al. [7] have reported on the experiences of deploying sensing technologies in construction sites, where even the form factor of the sensing devices can play a significant role in the acceptability of the technology by the field workers. Improving acceptability of such system may require a multifaceted approach spanning from issues with UI design and system functionality, to ways of educating workers and providing information about the system. Also, it is important to orchestrate the deployment of such system with acceptability in mind from the onset. An early negative experience from field workers could damage acceptability irrecoverably, even if the causes are addressed in later versions of the deployed system.

3.6 Information Mining

The key motivation in our vision is the potential of extracting valuable information through social sensing, that could improve the way the construction industry operates today. We believe that direct application of existing techniques, such as community detection [8], tracking mobility patterns [24], etc. can reveal important details that are at the moment "hidden" from the data capturing approaches employed today. However, we believe that the collection of such data will open new challenges for novel data mining techniques that are applicable to the specific domain. The range of issues and problems that need to be addressed, will evolve as domain experts get a better understanding of the types of information that can be extracted through these datasets. As examples, we identify some areas where information mining techniques over the social data could by applied:

Discovering irregularities in work practices. By establishing what is the typical patterns of work practices detected by the system, it would be possible to "flag" outliers in the dataset. Such outliers could be indications of potential problems in the construction process, or unanticipated events in the field.

Accident prediction. Existing regulations require workers to report accidents or "near misses" (events that could have been real accidents) on a daily bases. Using such data as ground truth, analysis could lead to the design of prediction tools that would indicate possible activity in the field that may lead to accidents.

Collaboration recommendations. Finding out which individuals or teams perform better when working together. Such information can assist in the management of the workforce and improvement of overall performance.

4. CONCLUSION

In this paper, we presented our vision of a social sensing system to be used at building construction sites. This system can be used to understand group dynamics and information flow at these complex work environments by capturing interactions and communication between individual workers. We consider this work as a first step towards a bigger vision of applying social sensing and analysis in specialised business contexts. So far social sensing studies have been restricted in office environments. However, introducing social sensing in industrial or construction environments requires new approaches and techniques in order to successfully deploy such systems. In this work we have highlighted some of the key challenges in deploying social sensing systems in construction sites. We believe that this work can lead to new opportunities both for the research community but also for the real industries where the output of such systems can have a significant impact.

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