Taxonomy of Work Spaces for Sensor Driven Jobsite Management

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ABSTRACT

Research prototypes for Jobsite sensing are often developed for a particular scenario and address one or more domain specific challenges using one or more of the sensor choices. However, numerous operational challenges remain and are a barrier to wide spread adoption of sensing technologies. Choices made during the sensor deployment process have a huge impact on the information generated from sensor data. Consequently the deployment choices impact the decision making process that is supported by the information. This paper revisits the concept of a work space and redefines it as a basic unit of job site management from the sensing perspective. A set of parameters are proposed that can help managers in effective planning and control of sensing on jobsites. A case example is presented to identify sensing requirements for heat stress management on a jobsite.

INTRODUCTION

Data sensing and analysis is one of the main areas of application of information and communication technologies on construction jobsites. Ubiquitous nature of computing coupled with the increased sensing capabilities has shown promise to improve jobsite practices. Safety and productivity have been identified as key domain areas for construction where data sensing and analysis research can have an impact (Becerik-Gerber et al. 2013). Sensor driven data collection in these domains primarily consists of recording locations of assets on a jobsite at any given time. This data can then be aggregated, categorized, and fused with other information to support decision making processes. Jobsite sensing supports domain applications ranging in complexity from automation of existing manual practices to innovative information and knowledge extraction which is not possible in the absence of these sensors. A broad review of literature on jobsite instrumentation in the construction domain shows experimentation and adoption of a range of sensing technologies including (but not limited to) High Definition Video, Time of Flight instruments such as 3D Laser Scanners and Range Cameras, Wireless Sensor Networks, GPS, various generations of RFID sensors including Ultrawide Band (UWB) based Real Time Location Systems, and more recently Microsoft Kinect Sensors and Physiological Monitoring Systems. Other researches in AEC/FM domain use sensors related to thermal imaging, environmental sensing, and sensors for gauging energy consumption. Although research is reported for actual use and deployment of some of these sensors (RFID, GPS, Video Cameras) on jobsites, limited guidance is provided for practitioners to scale solutions for their own respective jobsite to achieve any given construction management purpose. For most emerging technologies, published researches that report on use do so in controlled experimental settings. Deployment in these scenarios is mostly ad-hoc in nature and is aimed at full sensing of the experimental area.

Operational challenges for jobsite sensing can be grouped under two main sensor categories. Some technologies depend on line of sight for accurate and effective use while others sensors depend on reliable radio communication. This paper revisits the concept of a work space and formalizes the same in the context of jobsite sensing. A brief review of the literature is presented in the next section focusing on work spaces on construction jobsites. The paper proceeds with identification of features and characteristic of work spaces followed by a task oriented classification. In the later sections, connectivity and coverage are formalized as two key concepts for managing sensing on jobsites. A case study is presented for identification of sensing needs for a jobsite to monitor heat stress. The paper ends with recommendations for future research.

LITERATURE REVIEW

The concept of a space on a construction jobsite can be used to define the bounds or location where a particular task or activity is scheduled to be undertaken. Workspace is widely recognized as one of the resources for construction operations to avoid potential time-space conflicts with other activities (Akinci et al. 2002a). Although macro level spaces (such as storage etc.) and paths are recognized as important spatial planning constructs, emphasis in these analyses has been on micro level spaces for proximity identification to avoid time space conflicts (Akinci et al. 2002b). A volumetric representation of a space is used to indicate proximity bounds for component installation at any given time instance. An integration of these volumetric spaces with time data from schedules allows for automated identification of potential conflicts using simulation based analysis. At the macro level, extensive research has been done at many leading institutions in the domain of jobsite layout planning (Andayesh et al. 2013; Sadeghpour et al. 2006; Su et al. 2012), equipment paths (Caldas et al. 2006), and positioning of assets such as cranes (Tantisevi et al. 2007; Tantisevi et al. 2008).

From a task scheduling perspective, although traditional critical path method (CPM) based scheduling techniques do not support this construct of spaces, more recent scheduling methods incorporate space as a fundamental unit of work scheduling (VicoSoftware 2009). This approach allows for easy integration between the schedule data and model data from BIM based models thereby improving the simulation processes. Researcher continue to explore effective ways to incorporate spaces as a planning construction using CPM based schedules (Chavada et al. 2012).

Sensing on construction jobsites spans both macro level and micro level spaces. Data collection for productivity and safety applications also includes paths of moving equipment. To facilitate the deployment of sensor on construction jobsites, there is a need to revisit the work space concept from a sensing perspective. A purpose driven approach is needed where location and number of sensors need to be determined to provide the necessary data from the macro level, micro level, and the paths on a given jobsite. The words space and work space are used interchangeably throughout the manuscript to refer to unique work bounds that require sensing.

SPACES FOR SENSING

This manuscript introduces three sets of parameters that help identify, manage, and characterize a work space for sensing.

Features. Features are parameters that help uniquely identify and locate a space on a jobsite. Generic representation of spaces has been visited in the literature where a space is represented by its location on a jobsite and its volumetric dimensions. A similar approach is adopted here where a space can be uniquely identified by its **location** and **geometry** (including **dimensions**). The location is a single point representing the center of mass of the volumetric region and the geometry is the information that represents the physical extents of a space. For the sake of simplicity, the geometry can be abstracted as a cube or cylindrical region. A space can be either a **physical** space where the bounds are physically defined by one or more project features or logical where the bounds are arbitrary. A space is **fixed** when the location, dimensions, and geometry of the space do not change over the period of time for which the space is to be sensed. Any changes in these parameters would impose different sensing requirements. The parameters described in the features group are sufficient to uniquely distinguish and identify the logical, physical bounds referred to by a space.

State. State variables associated with a space provide the constructs necessary to plan and manage sensing of workspaces. A logical space can be **mobile** (such as area surrounding a work crew) and can be an effective means to provide minimal sensing. A space is **sensed** when one or more sensing technologies are deployed in its physical or logical bounds. The concept of coverage introduced in the next section elaborates more on the sensed nature of a work space. A space is **connected** when it is possible to communicate with sensors or workers in its bounds. The concept of connectivity is further formalized in the next section. At any given instance in time, a space is considered **active** if any project tasks are scheduled in its bounds and workers or assets are expected to be occupying the physical jobsite area referred to by the space. The parameters describing the state of the workspaces on a jobsite provide a snapshot in time and allow a decision maker to unique identify the location of workers, sensors, and deployment strategies currently in effect at the jobsite.

Characteristics. Characteristics of a workspace provide an operational definition of the purpose for which the jobsite is being sensed. This manuscript describes characteristics of spaces on a jobsite that would impose different sensing requirements in the context of heat stress management. A space can be **shaded** where the workers or assets in its physical bounds are not directly exposed to the sun. An **elevated** space has different heat exposure as compared to spaces at the datum level. A space is considered **occupied** if there is a heat generating source occupying the space (such as equipment). A worker is not considered a heat generating source since the heat generated by a single worker is not sufficient to have a major impact on sensing requirements of spaces that are otherwise similar. However, a space is considered **crowded** if there are too many workers occupying its physical extents and would have an impact on heat stress management requirements. A space is **open** if the movement of workers and assets in and out of its bounds is not restricted by any physical barriers. **Confined** spaces require specific entry precautions and have associated protocols that must be followed when work is to be carried out in their extents. Heat stress management is a unique purpose where the **time of day** would also have an impact on the sensing requirements for a particular space. Based on the climate in the geographical region where the jobsite is located, heat exposure can vary in a space during a single. The parameters defined under characteristics are unique to the purpose for which sensing is to be carried out. The state information can be sufficient to identify sensing requirements in some situations. For example, time and motion studies using any location sensing technology could be accomplished by uniform sensing of all active spaces at any give time. However, operationalizing the purpose for which sensing is undertaken can allow for economic deployment strategies and could provide smaller and higher quality datasets.

The features, state, and characteristics of workspaces uniquely identify the sensing and sensor management requirements for a jobsite. A decision maker can easily classify spaces based on operational similarity and identify changes in sensing requirements (sensor density, timing, frequency, granularity of data, etc.) across groups. Parameters such as precision and recall can be used to ascertain reliability of individual sensing technologies and can also inform the decision makers developing different deployment strategies.

MANAGEMENT FRAMEWORK FOR SENSED JOBSITES

Although sensors can be randomly deployed to collect data in a specific location for a specific set of tasks, wider sensor layout planning requires additional formalisms for proper management of sensor and the collected data. Some sensors generate large format data and real-time analysis is sometime not possible. The sensor layout becomes more complex when more than one sensing technology is to be deployed on a jobsite. In addition to problem with data granularity, post-hoc analysis can reveal that one of more deployed technologies sometimes do not provide data for the area under investigation. Two key formalisms are presented here to alleviate such problems.

Coverage. A space is considered covered only if the sensing technology under consideration provides reliable data within the extents of the space. A fully sensed jobsite with even a single sensing technology can be costly. Full coverage of all spaces with multiple sensing technologies is neither possible nor desirable. The cost and benefits typically guide practitioners to instrument only **active** spaces and even instrumenting all active spaces can be a cost prohibitive proposition.

Given that full coverage is not a practical objective, each sensing technology can cover certain areas on a jobsite in which the data collected is representative of the sensor. The absolute area depends on the physical placement of the sensor and the sensor parameters. The physical location of a sensor can be fixed, mobile (continuously moving), or transient in nature (moving between a set of predetermined fixed locations occupying each station for some period of time). In an open setting, the coverage area for line of sight based sensors can be computed by using their effective range and field of view (FOV). However, occlusions limit the range for these sensors in occupied spaces. For communication based technologies in an open unobstructed setting, the coverage area can be computed based on the radio power and antenna patterns. However, coverage is susceptible to ambient radio noise and signal interference due to characteristics of the jobsite. Determination of effective range of communication based sensors is a difficult task and practically, multiple sensors are often needed to cover areas that are theoretically in the communication range of a single sensor.

Line of sight sensors typically have a very long range and a single sensor (or sensing setup) can be used to provide coverage for multiple spaces identified in the aforementioned section. Most deployments of line of sight sensors are fixed or transient in nature. Fixed reference points are often needed in order for fusion with other sensing technologies. The unit cost of line of sight sensors is typically very high and is a prohibitive factor when it comes to building redundancy in a system to improve coverage.

The range of communication based sensors is often limiting and multiple sensors can be needed to provide necessary coverage of a given space. However, the cost of these sensors is ever reducing and supports redundant deployment to improve coverage. Theoretical range of communication based sensors is not a suitable parameter for deployment planning as even the more conservative estimates of communication range can sometimes prove impractical due to ambient signal noise and radio interference.

For each space identified in the previous section, at any given instance in time a sensing technology either provides full coverage of the space or the space bounds need to be adjusted and new spaces created to reflect the covered and uncovered areas. If the space is physical in nature, a logical space needs to be created with bounds to represent the portion of the physical space under sensing coverage.

Connectivity. A space is fully connected if two way communications can take place in the bounds of the space between: (a) the sensors and a central server, and (b) the decision makers and the workmen on ground. A space is partially connected if either of these is missing or the communication is one way in nature.

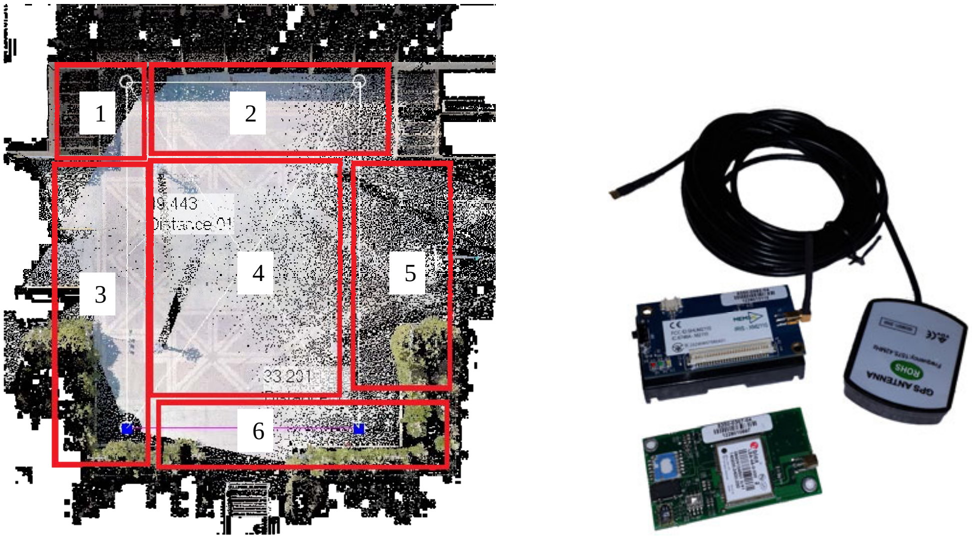
Computing devices are ubiquitous on jobsites and there is an increasing appetite for more bandwidth to deliver content and service to mobile devices. Although fully sensed jobsites are unfeasible and uneconomical, a fully connected jobsite can, in many cases, be achieved with minimal expenses. Size of the jobsite, its geographical location, and mobile radio coverage determine the absolute connected area on a jobsite. Connectivity is applicable to both the communication based and vision based sensors. Connectivity becomes important if the sensed environment is being deployed to support decision making in real-time. For such deployments, providing sensing coverage for a space is practical only if the space is connected as well. However, some line of sight based sensors (e.g. most terrestrial 3D Laser Scanners) are not intended for real-time use. Post-hoc processing and analyses are required in such cases and connectivity would only be partial where the sensor would transfer data to a central server for post processing.

Table 1 provides a snapshot of a sensor management plan (state and characteristics only) for a jobsite (Figure 1) being sensed using Wireless Sensor Network nodes. Each node (Figure 2) is equipped with a sensor board that collects (among other things) temperature, humidity, and ambient light data. The heat index (Rothfusz 1990) can be computed at each point where the data is collected and gives a localized assessment of heat stress conditions prevailing at that location.

Table 1. Sensor Management Plan for Heat Stress Management

	State				Characteristics					
Space ID	Mobile	Sensed	Connected	Active	Shaded	Elevated	Crowded	Occupied	Open	Confined
1		X	X	X	X		X			
2			X		X			X	X	
3			X						X	
4		X	X						X	
5		X	X	X					X	
6			X					X	X	

Each X represented in Table 1 can be replaced with descriptive information about the space and its parameters. For example, an open space and be fully open (space 4) or partially open (space 2). A minimalist deployment protocol would only deploy sensing capability during the peak heat load in active spaces. A more aggressive approach would require additional sensors and would pre-emptively sense in-active spaces that are scheduled for activity later in day. By doing so, work would not be scheduled if the conditions are not favorable in the next locations as opposed to the earlier sensing scenario which would result in deploying crews only to discover unfavorable work conditions. The density of sensors deployed in either scenario would determine the quality of the dataset generated and would ultimately impact the operational decisions taken by project managers. The entire jobsite in this deployment is fully connected allowing real-time data transfer between the WSN nodes and a central server. As the characteristics of the spaces change, additional sensors may be required to improve coverage. Some spaces by nature demand a higher sensor density (e.g. a confined occupied active space) while others can be reliably sensed using fewer sensors (e.g. open unoccupied space). The spaces in this particular setup were determined based on the characteristics of each of these spaces as shown in Table 1. For example, Space 1 was expected to be a crowded space and hence had to be separated from spaces 2 and 3.



(a) (b)

Figure 1. (a) Jobsite layout showing different spaces (b) A WSN node with a GPS equipped Environmental Sensor

CONCLUSIONS

Purpose driven sensing relies on systematic deployment of sensing technologies on a jobsite to provide adequate data for reasoning and analysis. This paper presents formal definitions of concepts of coverage and connectivity that can be used to plan sensor deployments. The features and state of spaces introduced in this manuscript can help jobsite managers to plan and manage their deployed sensing assets. Domain application specific characteristics identify unique sensing requirements that prevail on a particular jobsite and provide the necessary knowledge for developing effective sensor management strategies. Future research in this area will focus on developing automated tools that would enable simulation based assessment of coverage using BIM models and project schedule data. This manuscript presents only the heat index related components of the sensed environment. Associate research documents fusion with other data sources to generate information otherwise unavailable to decision makers.

ACKNOWLEDGEMENT

The author would like to acknowledge the support provided by King Abdulaziz City for Science and Technology (KACST) through the Science & Technology Unit at King Fahd University of Petroleum & Minerals (KFUPM) for funding this work through project No 11-ELE1652-04 as part of the National Science, Technology and Innovation Plan.

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