Virtual Sensors: A Demonstration

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***Abstract*—This paper describes an application demonstration of a new abstraction that supports heterogeneous in-network aggregation over networks of resource-constrained devices. For the purposes of our demonstration, we draw upon an intelligent job site application for the construction domain. The demonstration is carefully constructed to highlight the ability of our approach to provide on-demand access to local data, aggregation of data across dynamically defined regions, and fusion of heterogeneous sensor data. The paper briefly describes the abstraction and the details of the demonstration.**

I. Introduction

Sensor networks are an integral component of pervasive computing environments. Currently, existing deployments of sensor networks are application-specific, where the nodes are statically deployed for a particular task. We target pervasive environments in which the applications that will be deployed are not known *a priori* and may include varying sensing needs and adaptive behaviors. Examples of such domains include aware homes [1], intelligent construction sites [2], battlefield scenarios [3], and first-responder deployments [4]. Existing applications commonly assume that sensor data is collected at a central location to be processed and used in the future and/or accessed via the Internet. Applications from the domains described above, however, involve users immersed in the sensor network who access locally-sensed information on-demand. This is exactly the vision of future pervasive computing environments [5], in which sensor networks must play an integral role [6].

We have developed virtual sensors, which enable collecting low-level sensed data and transforming it to a more abstract measurement to relay to the user. Our virtual sensors abstraction connects users (e.g., construction workers in a dynamic and unsafe environment, responders in an emergency) directly to sensors in the local environment. Virtual sensors can be deployed on small devices, operate independently of heavyweight infrastructure, and provide on-demand, real-time connection to information that enables users to complete their tasks quickly, safely, and with the best possible information.

The remainder of this paper is organized as follows. Section II describes the application domain we use for our demonstration. Section III overviews the capabilities of virtual sensors, while Section IV describes the demonstration itself. Section V concludes.

II. An Application Domain

The intelligent job site [7] as envisioned for construction environments presents considerable challenges to pervasive computing, requiring both context-awareness and the ability to support multiple applications on networks of physically distributed (and mobile) devices. The intelligent job site consists of users, mobile devices, and sensors connected by a wireless network.

In the construction industry, the complex and dynamic nature of the work and the site is an important reason for the high rates of injuries and fatalities. As a central component of many construction sites, cranes are the cause of a large fraction of construction deaths (estimated to be about one-third of all construction fatalities) [8]. Avoiding such accidents requires using various types of data from different types of sources and transforming this data to a form that is comprehensible for a worker.

III. Virtual Sensors

To support the heterogeneous in-network aggregation necessary for ubiquitous computing environments such as the one given in the previous section, we have created a unique abstraction that enables domain experts to create customizable applications for dynamic networks involving resource-constrained sensing devices.

Specifically, our approach highlights the following three capabilities not found in today's sensor network coordination frameworks:

- *On-demand local data access:* Contrary to existing applications, the users in our targeted scenarios are immersed in the sensor network. As such, we target new communication and query protocols that allow users to opportunistically interact with locally available sensors.
- *Regional aggregation:* Emerging applications must intelligently aggregate data from a particular (dynamically changing) region. This requires novel algorithms for group communication and aggregation.
- *Expressive sensor fusion:* Sensor network aggregation commonly operates on single data types and generates measures like average, minimum, etc. When users are immersed in a network, their data needs include requests for abstracted information, and we have developed novel

ways to place some of this abstraction burden in the sensor network using lightweight sensor fusion.

IV. The Demonstration

To demonstrate the novel features of our approach, we use an application example from the domain of the intelligent construction site. In our scenario, the user requests information about the region around the base of a crane where it is unsafe to walk or drive. In this case, a virtual sensor is constructed that dynamically discovers physical sensors attached to components of a nearby tower crane (e.g., the base of the crane, the trolley along the boom, the counterweight of a crane). The virtual sensor combines the information collected from these distributed physical sensors to calculate the requested abstract data type (i.e., a danger circle calculated using location estimates from sensors attached to the crane). Once these sensors are discovered, the virtual sensor registers persistent queries on these particular sensors and remains connected to them. As the sensors generate and send updates, the virtual sensor automatically refreshes the presentation of the abstract data type and displays the changes to the application, so the worker receives a warning when entering a potentially dangerous area. This example performs on-the-fly heterogeneous data fusion from multiple sensor streams in the field, which has not been performed in existing solutions.

Specifically, our application demonstration connects a set of Cricket Motes [9] (a location-aware version of MICA2 Motes [10]) attached to the crane to another Cricket Mote that represents a worker on the site. Clearly, we do not plan to demonstrate these applications at the conference on a full-blown construction site. Instead, we simulate the situation using a Lego crane [11] (as shown in Fig. 1). Changes in the worker's position and crane movement occur in real time in the demonstration to show different situations. Since the middleware instead of the application is the real contribution of the work, our demonstrations highlight specific middleware functions at different points. The application example is a virtual sensor that calculates a "danger circle" using readings from three different physical sensors, so that a worker walking on the site does not get hit by a moving crane load.

Fig. 1. The virtual sensor on a tower crane

V. Conclusion

This paper details a demonstration of a new approach to heterogeneous in-network aggregation for sensor networks in which sensor nodes cooperate locally to perform complicated application-directed tasks. In-network processing transforms raw data into high-level abstract information fundamental to application requirements. We have developed a virtual sensor that embodies a novel abstraction designed to simplify programming of such applications. This paper briefly introduced the virtual sensors abstraction and then focused on an application demonstration designed for an intelligent construction site. This demonstration emphasizes the novel characteristics of our approach which include on-demand access to local data, the ability to aggregate sensor readings based on regions, and fusion capabilities defined on-the-fly in an application-dependent manner. The virtual sensor has the potential to enable domain programmers to rapidly create expressive applications without having to directly handle the complexities associated with distributed programming.

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