Viewpoints for Sensor based Environmental Information Systems

Ruthbetha Kateule, Andreas Winter
{kateule, winter}@se.uni-oldenburg.de

Abstract: Sensor based environmental information systems are in use worldwide such as road traffic control systems, air pollution detection systems and others. However, development and maintenance of these systems are difficult and time-consuming. Despite the great diversity in their application domains, technically these systems possess similar components that could be unified and presented in a single standardized architecture i.e. reference architecture. This reference architecture will facilitate the rapid development and maintenance of concrete system architectures of sensor based environmental information systems. Hence, this paper proposes a need for designing a reference architecture for sensor based environmental information systems and defines a set of required viewpoints that will serve as a construction kit in which concrete system architectures could be derived.

1. Introduction

Environmental information systems manage data about the soil, water, air, and other things such as vehicles in the world around us [1]. Environmental information systems collect, store, share, analyze, manipulate and display environmental data from various locations. As far as the reduction or prevention of environmental disastrous consequences is concerned, the environmental information systems need to access up-to-date information. This is possible through the emergence of sensing techniques. Sensor based environmental information systems resulted from the integration of sensing techniques and environmental information systems.

A desired large-scale sensor based environmental information systems consist of various devices that are physically distributed but integrated functionally. These devices accessibility, analysis and processing of environmental phenomena data is complicated and difficult to maintain. Hence an approach that allows easy development and maintenance of these systems is required. Several researchers recommend a design of software architecture as a viable approach. Software architecture is defined as “the structure or structures of the system, which comprise software components, the externally visible properties of those components and the relationship among them” [2]. They guarantee the prosperity of software (systems) by defining sets of concepts and principles that guide the analysis of specifications, designs, implementation, maintenance and evolution of software systems.

A number of sensor based environmental information systems architectures have been designed by researchers. For instance, in [8], P. S. Jadhav et al. designed an architecture for precision forest fire detection system based on a wireless sensor network. In [9], S. Shukla et al. proposed an architecture for flood monitoring using wireless sensor network system. In [10], K. K. Khedo et al. proposed an architecture for wireless sensor network air pollution monitoring system (WAMPS). In [11], D. Curiac et al. proposed an architecture for urban traffic control system based on wireless sensor-actuator networks to optimize the movements of vehicles and pedestrians. The diversity of these systems architectures is observed on the dimension of the application domain and fulfillment of a particular set of systems attributes mainly scalability, heterogeneity and energy efficiency. However, on the technical perspective, these systems possess similar subsystems that could be generalized into three subsystems mainly *Sensors and Actuators Subsystem* which refers to the devices that measure physical environment events i.e., temperature, humidity etc., pre-processing the collected data and alter the state of environmental phenomena to satisfy intended objectives of a system. *Information Control Centre Subsystem* which integrates, analyzes, processes, stores and visualizes the information as received from the sensors and generates alarms and events via actuators based on the objectives of particular system. *Communication Subsystem* that facilitates the interactions between the subsystems mentioned above.

Therefore, a general abstraction representation namely a Reference Architecture is highly recommended to represent such systems' common denominator [3] to make the development and maintenance of concrete architectures to be more effective and efficient. Reference architecture is a generic template software architecture that preserves the established solutions or knowledge to assist the design, description, and analysis of concrete architectures by reusing architecture knowledge [4, 13]. Reference architecture is an inspiration or standardization technique that facilitates the design of concrete system architectures while guaranteeing various systems quality attributes [6]. As most of the matured domains, the designs of concrete system architectures are deduced from the defined abstractions instead of re-inventing the wheel from scratch [5]. Well-designed reference architectures do not request much work to be adapted to concrete issues as there are existing usages of reference architecture [12].

This work discusses the initial stages towards the design of reference architecture for sensor based environmental information systems by proposing the required set of viewpoints to standardize the description of sensor based environmental information systems. The remainder of the paper is organized as follows; Section 2 describes the description of the reference architecture based on IEEE 42010-2007 standard. Section 3 explains the proposed set of viewpoints. Section 4 describes a software architecture instance as presented by one of the views. The paper is concluded in Section 5.

2. Architecture Description

The description of the reference architecture for sensor based environmental information systems adopts the format of IEEE 42010-2007 Recommenced Practice for Architectural Description of Software-Intensive Systems [15] as shown in Figure 1. The standard elaborates the main sections of designing the software architecture; stakeholders and concerns are specified explicitly, then the architecture description will consist of the architectural viewpoints and views. The selected viewpoints address the identified concerns. Viewpoints describe the conventions that enable the creation, illustrations and analysis of views. Views are the actual representation of one or more structural aspects of a particular system.

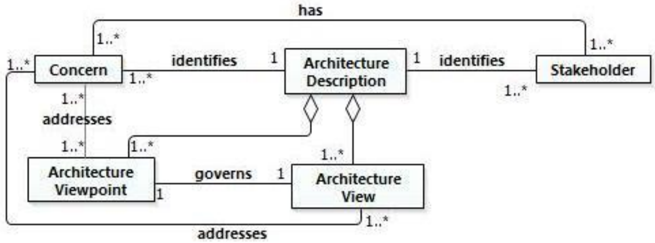

Figure 1: The relationship between stakeholder, concerns, viewpoints and views [15]

The Siemens four-view model [2] is adopted and customized. As they possess certain essential viewpoints that should be contained in the architecture description. The class diagrams from Unified Modeling Language (UML), a de facto standard in the software industry are utilized to design the architectural viewpoints and views.

2.1 Architectural Design Goals

The concerns originated from several stakeholders mainly sensor/actuators builders, analysts, designers, maintainers, architects, institutes and users were considered. The architectural design goals are formulated based on the integration and analysis of these stakeholders concerns. The identified architectural design goals (denoted AD) are:

AD1: The reference architecture is required to support a collection of data and execution of control actions from both single and multiple sensors and actuators respectively. Sensor based environmental information Systems employ one or more sensors and actuators or combination of both.

AD2: The reference architecture is required to support networks of homogeneous and heterogeneous sensors and actuators. The utilization of different types of sensors in networks requires the systems to be modularly and adaptable.

AD3: The reference architecture is required to configure, coordinate, monitor and manage sensors and actuators that are spread over the environment (field of interest). The sensing or actuating devices do not possess user interfaces. The systems should manage such devices remotely.

AD4: The reference architecture should be able to accommodate the sensor or actuator network dynamics and rapid topological changes. Sensor based environmental information systems need to support scaling of devices deployment from small to large in volume.

AD5: The reference architecture is required to describe how the lifetime of a sensor network could be sustained to fulfill the intended objectives of the systems. The radio transceiver consumes a massive energy for data transmission. The networks design should consider energy consumption.

AD6: The reference architecture is required to define activities or functionalities that the sensor based environmental information systems should offer.

AD7: The reference architecture must define the computational elements of sensor based environmental information systems.

AD8: The reference architecture is required to support interactions among subsystems of the systems. Normally, the sensor and actuator subsystem is located in the field of interest in the remote area far away from the information control centre. The support of communication transport and protocols is highly recommended.

AD9: The reference architecture should support various visualization approaches to present the environmental phenomena. Sensor based environmental information systems need to present the information to the user of the system, for instance, all the information required by flood or fire departments could be presented via GUI interface [7].

AD10: The reference architecture should describe how the systems will be deployed.

These architectural design goals will be achieved through a suitable and well-designed set of architectural viewpoints as described in the following section.

3. Proposed set of Viewpoints

The following are required viewpoints of a reference architecture for sensor based environmental information systems. However, a conceptual viewpoint of information control centre is described in brief:

Conceptual Viewpoint: The conceptual viewpoint addresses AD1, AD2, AD3 AD4, and AD5. This viewpoint describes the main components of the systems and their functionalities. The conceptual viewpoint of information control centre is depicted in Figure 2. A Node (a Sensor or Actuator), Server, Database, and UserInterface are identified as the main components in sensor based environmental information systems which interact with each other through Connector. A Node sense and manipulate the environmental phenomena. The Server processes collected data and manages nodes. Database stores collected data originated from nodes and *UserInterface* enables the users to access the system.

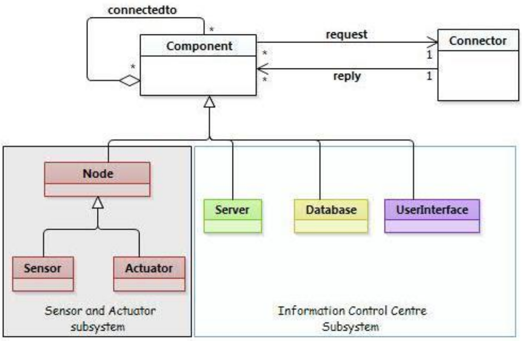

Figure 2: Conceptual Viewpoint of Information Control Centre

Logical Viewpoint: This viewpoint will address AD7 by describing the essential computational elements and their interfaces to support the behavior requirements of sensor based environmental information. This viewpoint is designed to support the actual systems development process.

Database Viewpoint: This viewpoint will address AD3. This viewpoint intends to manage the data systematically by mapping the information utilized by components into underlying storage infrastructure. A relational database will maintain the information about the sensors, networks, locations, and actuators. This viewpoint is integrated into the conceptual viewpoint of information control centre.

Physical Viewpoint: This viewpoint will address AD10. This viewpoint comprises the mapping of the identified components of the systems into the software and hardware components.

UserInterface Viewpoint: This viewpoint will address AD9. This viewpoint addresses the needs and supports the deployment of sensor based environmental information systems. This viewpoint will provide the nodes identification, configurations, visual data acquisition as well as events and alerts presentations. This viewpoint is integrated into the conceptual viewpoint of information control centre.

Communication Viewpoint: This viewpoint will address AD8. This viewpoint intends to establish an effective communication between subsystems to promote transportation of collected data and also the execution of control actions in real-time.

Code Viewpoint: This view will facilitate the systems upgrades, integration and testing by defining and organizing all the required system artifacts [14].

Integration Viewpoint: The semantic integrity and consistent of the proposed viewpoints as described in the previous sections is achieved by the integration of those viewpoints into a common viewpoint [19].

4. Views

The reference architecture for sensor based environmental information systems will be established based on the aforementioned viewpoints. Hence the concrete architectures of these systems will be instances of the proposed reference architecture. For instance, the software architecture instance for prototype development of flood detection system requires various views. Conceptual view is one of the views required by the flood detection system, this view is an instance of the proposed conceptual viewpoint (cf. Section 3) as depicted in Figure 3. The *WaterLevel*, *Temperature* and *Rainfall Sensor*s are required to measure the water discharge from the rivers, temperature and rainfall. The collected data are sent directly to the *Server*. The *Server* stores the collected data to the *FloodDB*. The *Flood Detection System* of the *Server,* extracts the required information via *FloodAnalyser*. Afterwards, the *FloodEstimator* runs flood prediction algorithms on the analyzed information to predict the occurrence of the flood, and the result is sent back to the server which monitors vital signs and generates warnings through a *UserInterface*.

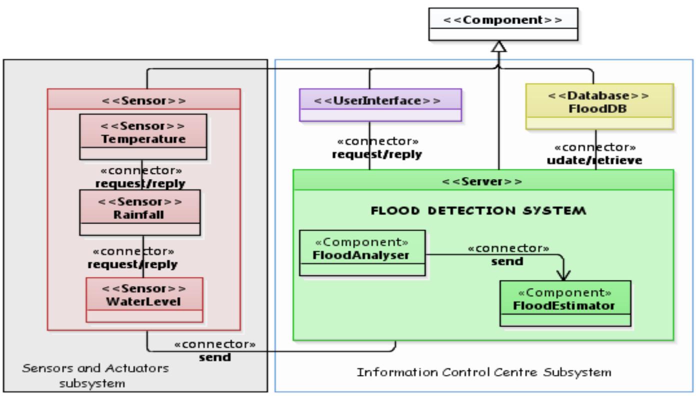

Figure 3: Conceptual View of Information Control Centre for Flood Detection System

5 Conclusion

The sensor based environmental information systems offer tremendous opportunities about environmental events monitoring and control. Despite their existing diversity, technically they consist of similar components that could be presented in a single unified architecture (reference architecture). This paper proposes some crucial viewpoints for a prospective reference architecture of sensor based environmental information systems.

The proposed viewpoints in this work capture all aspects of sensor based environmental information systems, hence a standardized reference architecture description will be established. This standardized architecture description facilitates the design, analysis and evaluation of concrete architectures [18, 20]. The applicability of the proposed viewpoints to serve the purpose in question is demonstrated through existing concrete architectures that are already in use. For instance, the flood detection system using wireless sensor networks employed a conceptual viewpoint of information control centre [17]. The Wi-Fi Cluster-Based Wireless Sensor Network Application [16] was developed for wildfire detection, in which the physical and communication viewpoints were utilized.

In the next stage, all the identified viewpoints of the reference architecture for sensor based environmental information systems will be designed. After that, follows the design and implementation of the instances of a reference architecture to demonstrate more the applicability of the proposed viewpoints in real scenarios.

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