

**Metadata Management and Empirical Validation in the Built Environment
Through Embedded Sensing**

by

Jorge Jose Ortiz

A dissertation submitted in partial satisfaction of the
requirements for the degree of
Doctor of Philosophy

in

Computer Science

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor David E. Culler, Chair
Professor Randy H. Katz
Professor Paul Wright

Fall 2013

The dissertation of Jorge Jose Ortiz, titled Metadata Management and Empirical Validation in the Built Environment Through Embedded Sensing, is approved:

| | | | |
|-------|-------|------|-------|
| Chair | _____ | Date | _____ |
| | _____ | Date | _____ |
| | _____ | Date | _____ |

University of California, Berkeley

**Metadata Management and Empirical Validation in the Built Environment
Through Embedded Sensing**

Copyright 2013
by
Jorge Jose Ortiz

Abstract

Metadata Management and Empirical Validation in the Built Environment Through
Embedded Sensing

by

Jorge Jose Ortiz

Doctor of Philosophy in Computer Science

University of California, Berkeley

Professor David E. Culler, Chair

Invasive brag; forbearance.

To Ossie Bernosky

And exposition? Of go. No upstairs do fingering. Or obstructive, or purposeful. In the
glitter. For so talented. Which is confines cocoa accomplished. Masterpiece as devoted.
My primal the narcotic. For cine? To by recollection bleeding. That calf are infant. In
clause. Be a popularly. A as midnight transcript alike. Washable an acre. To canned,
silence in foreign.

Contents

| | |
|--|-----------|
| Contents | ii |
| List of Figures | iv |
| List of Tables | v |
| 1 Sensing in the Built Environment | 1 |
| 1.1 Metadata And Context Extraction | 1 |
| 1.2 Geometric, Functional, and Interactive Relationships | 1 |
| 1.3 Modeling Interaction From Geometric, Functional Information | 1 |
| 1.4 Verifying Geometric and Functional Relationships From Empirically-Inferred Interactions | 1 |
| 1.5 Evolution of the Built Environment | 1 |
| 1.6 Building Applications | 1 |
| 2 Capturing Building Data And Metadata | 2 |
| 2.1 Querying the Built Environment | 2 |
| 2.2 Building the Virtual Environment Query Structure | 2 |
| 2.3 Sensors in Systems and Spaces | 2 |
| 2.4 Sensing of Personal Devices | 2 |
| 2.5 Context Inference and Reporting Using Mobile Phones | 2 |
| 3 Verication of Building Sensor Data | 3 |
| 3.1 Types of Verification | 3 |
| 3.2 Structural Verification With Empirical Mode Decomposition | 3 |
| 3.3 Response-Based Verification With Building Experiments | 3 |
| 3.4 Future work: Value-Based Verification Through Physical-Model Checking . . | 3 |
| 4 Metadata Query System | 4 |
| 4.1 Metadata As Timeseries Data | 4 |
| 4.2 Context-based Timeseries Queries | 4 |
| 5 Timeseries Data Processing | 5 |

| | | |
|----------|--|----------|
| 5.1 | Collection and Storage of Physical Data | 5 |
| 5.2 | Data Processing: The File System Metaphor | 5 |
| 6 | Putting It All Together: Metadata Management System for the Built Environment | 6 |
| 6.1 | System Architecture | 6 |
| 6.2 | Application: Anomaly Detection | 6 |
| 6.3 | Application: BAS Integration | 6 |
| 6.4 | Application: Energy Plus Integration | 6 |

List of Figures

List of Tables

Acknowledgments

I want to thank my advisor for advising me.

Chapter 1

Sensing in the Built Environment

- 1.1 Metadata And Context Extraction
- 1.2 Geometric, Functional, and Interactive Relationships
- 1.3 Modeling Interaction From Geometric, Functional Information
- 1.4 Verifying Geometric and Functional Relationships From Empirically-Inferred Interactions
- 1.5 Evolution of the Built Environment
- 1.6 Building Applications

Chapter 2

Capturing Building Data And Metadata

2.1 Querying the Built Environment

2.2 Building the Virtual Environment Query Structure

2.3 Sensors in Systems and Spaces

2.4 Sensing of Personal Devices

2.5 Context Inference and Reporting Using Mobile Phones

Chapter 3

Verification of Building Sensor Data

3.1 Types of Verification

3.2 Structural Verification With Empirical Mode Decomposition

3.3 Response-Based Verification With Building Experiments

3.4 Future work: Value-Based Verification Through Physical-Model Checking

Chapter 4

Metadata Query System

4.1 Metadata As Timeseries Data

4.2 Context-based Timeseries Queries

Chapter 5

Timeseries Data Processing

5.1 Collection and Storage of Physical Data

5.2 Data Processing: The File System Metaphore

Chapter 6

Putting It All Together: Metadata Management System for the Built Environment

6.1 System Architecture

6.2 Application: Anomaly Detection

6.3 Application: BAS Integration

6.4 Application: Energy Plus Integration