Towards a Modular IoT System Architecture for Rural Aqueducts using Model-Based Systems Engineering

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Contents

What are Rural Aqueducts?

1. Self-managed
2. Rural community-based
3. Small-scale
4. Limited staff
5. Commonly resource-constrained
6. Manual monitoring, inspection, and control methods
7. Vulnerable to water loss and unreliable service

Figure: Aerial view of the water tank facility of ASADA Paso Ancho, Costa Rica.

IoT Systems in Rural Aqueducts Context

Previous Work on IoT Technology Transfer to Rural Aqueducts at Laboratorio Delta

Figure: IoT system developed by [1] for ASADA Paso Ancho, Cartago.

Figure: IoT system developed by [2] for ASADA Playa Sámara, Nicoya.

Research Questions

- **RQ1:** Are there existing systems engineering-based (including ARCADIA MBSE) architectures for the design of IoT systems for rural aqueducts?
- **RQ2:** If they exist, are the architectures generic and modular?
- **RQ3:** What are the needs and desires of rural aqueducts that can be addressed by IoT systems?
- **Contribution:** A generic system architecture for rural aqueducts, developed using the ARCADIA method

The ARCADIA MBSE Methodology

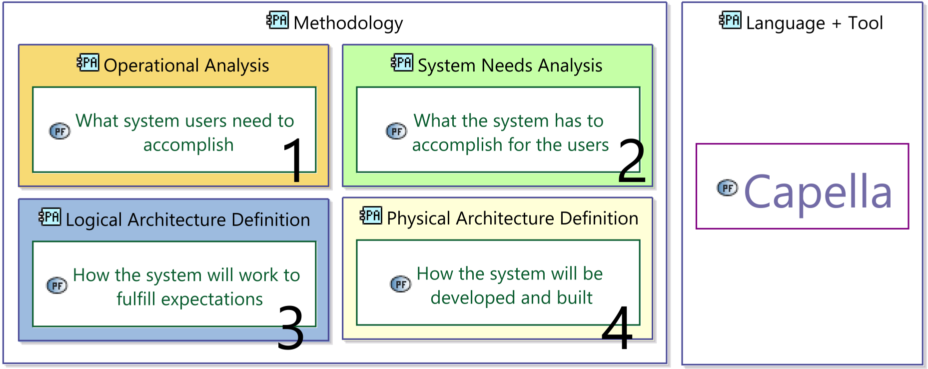

Figure: Phases of the ARCADIA Model-Based Systems Engineering Methodology and its associated Language and Tool Capella.

Operational Need Analysis

Extracting Generic Needs and Desires about IoT Systems in Rural Aqueducts using NLP

Table: Needs and desires extracted from paper full text embeddings using BERTopic.

Code	Need or desire
ND1.1	Identify sources of water pollution
ND1.2	Monitor water pollution
ND2	Monitor water pH
...	...
ND52	MQTT node communication
ND53	Mobile network connectivity
ND54	WiFi connectivity
ND55	LoRaWAN connectivity

Operational Need Analysis: Operational Capabilities

1: Provide high-quality water, 2: Comply with water quality standards and 4: Share data with external entities

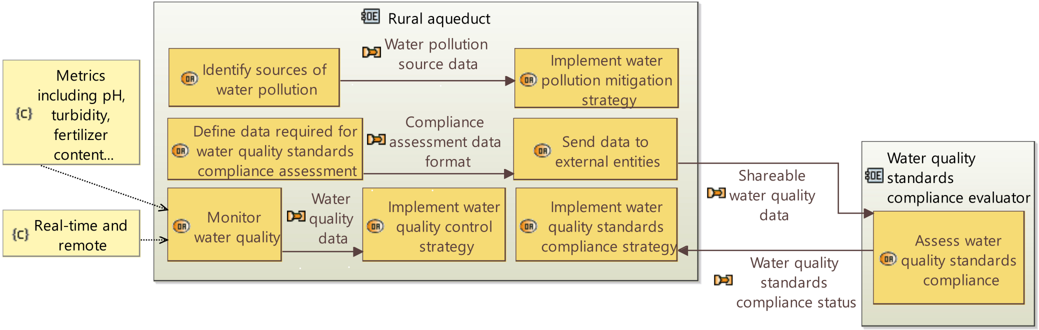

Figure: Operational Need Analysis for rural aqueducts, reduced to the activities involved in Capabilities 1, 2 and 4.

Operational Need Analysis

Operational Capability 3: Mitigate water loss

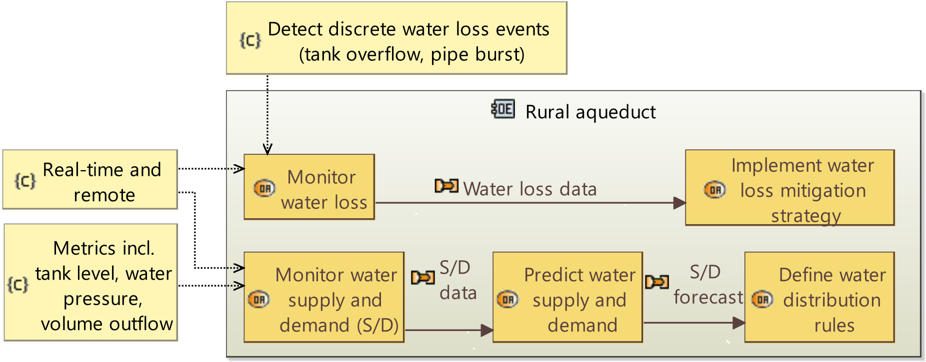

Figure: Operational Need Analysis for rural aqueducts, reduced to the activities involved in Capability 3.

System Need Analysis: System Capabilities

1: Provide water quality data, 5: Share data with external entities

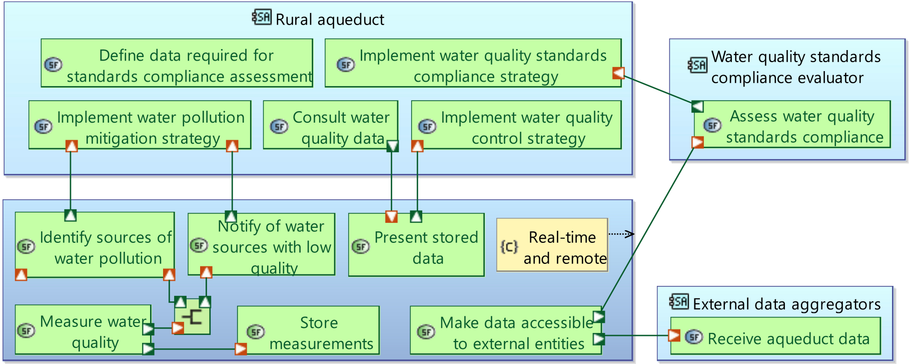

Figure: System Need Analysis for IoT systems in rural aqueducts, reduced to the activities involved in Capabilities 1 and 5.

System Need Analysis: System Capabilities

2: Provide water loss data, 3: Provide water supply and demand data, 4: Control water distribution

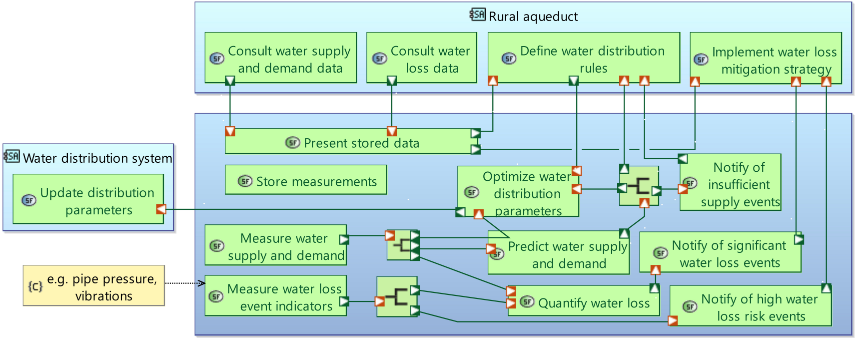

Figure: System Need Analysis for IoT systems in rural aqueducts, reduced to the activities involved in Capabilities 2, 3 and 4.

Logical Architecture Definition

Implementing modularity with end-user and environmental interactions

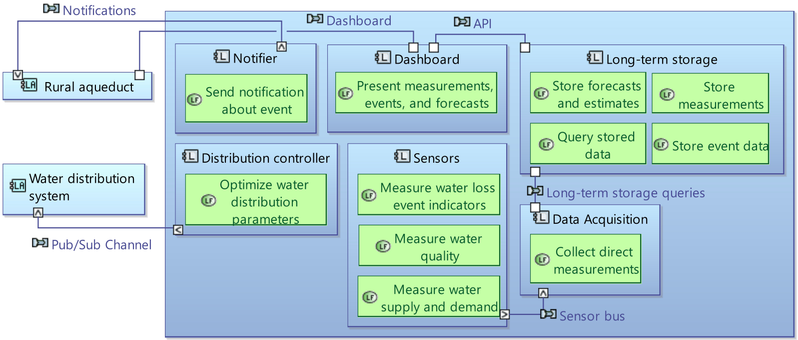

Figure: Logical architecture for IoT systems in rural aqueducts, reduced to the logical componentes that interact with end-users and the environment.

Logical Architecture Definition

Implementing modularity with buses, queues, and pub/sub channels

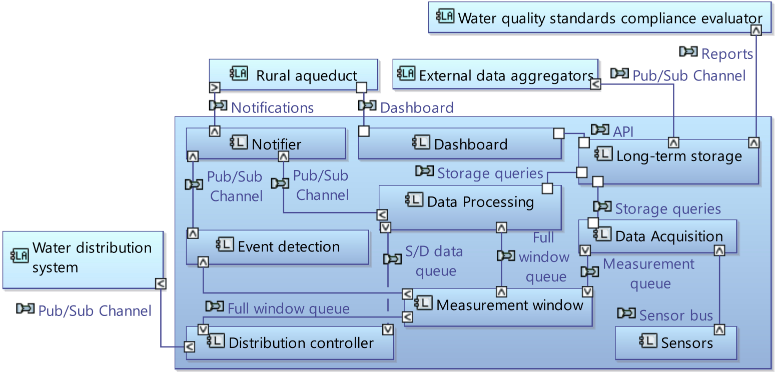

Figure: Logical architecture for IoT systems in rural aqueducts, reduced to logical components and their component exchanges.

Physical Architecture Definition

Implementing Logical Components

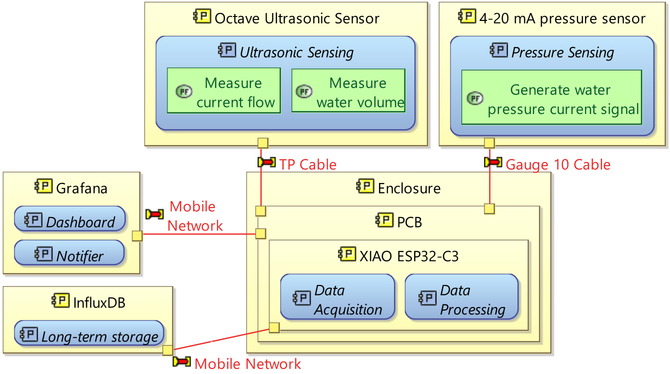

Figure: Physical architecture for IoT systems in rural aqueducts, reduced to the Physical Components implementing the Logical Architecture.

Physical Architecture Definition

Introducing Implementation-Specific Functions

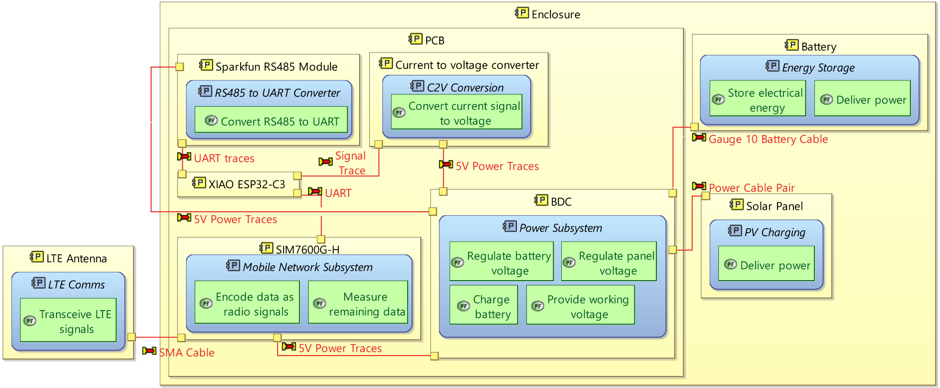

Figure: Physical architecture for IoT systems in rural aqueducts, reduced to implementation-specific functions not found in the Logical Architecture.

Conclusions and Future Work

- Generality was introduced by extracting needs and desires from a wide range of literature using data mining techniques.
- The application of the ARCADIA MBSE method enabled traceability from needs to logical and even physical architecture, and technology-agnostic design.
- Modularity was achieved by separating end-user and environmental interactions, and by using buses, queues, and pub/sub channels for component exchanges.
- The presented architecture can be adapted to a practical implementation, for example by technology transfer initiatives.
- Future work should strengthen the data mining pipeline by including more sources of information, and further developing the physical architecture with more case studies.

References

[1] A. Oviedo Muñoz, "Desarrollo de un prototipo para recopilación y monitoreo remoto de datos hídricos de los tanques, basado en dispositivos IoT, en la ASADA paso ancho y boquerón," Specialization Practice Report to qualify for the title of Industrial Maintenance Engineer, with the academic degree of Licentiate, Tecnológico de Costa Rica, Escuela de Ingeniería Electromecánica, March 2024.

[2] S. Solórzano Alfaro, "Sistema de control y monitoreo hídrico, basado en LoRaWAN™, para el acueducto principal de la asociación administradora del acueducto rural de playa sámara de nicoya," Specialization Practice Report to qualify for the title of Industrial Maintenance Engineer, with the academic degree of Licentiate, Tecnológico de Costa Rica, Escuela de Ingeniería Electromecánica, June 2021.

Backup Slide

NLP Pipeline for Generic Needs and Desires Extraction

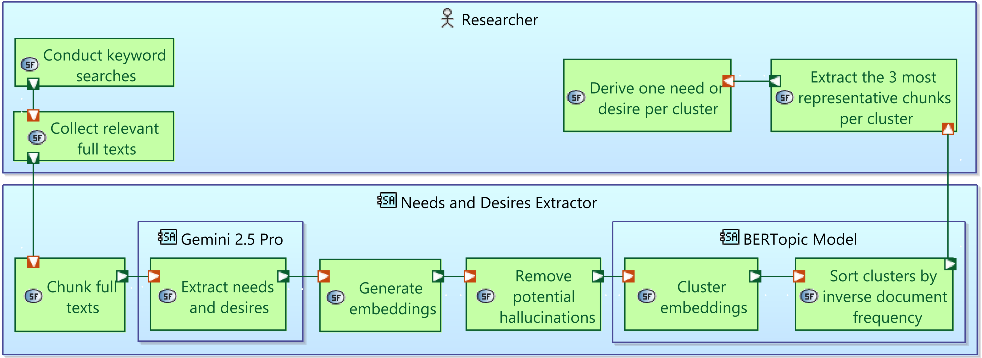

Figure: Process of extracting generic needs and desires about IoT systems in rural aqueducts from published literature.