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| **Título del Trabajo** *Lanaren izenburua* Project Topic |
| **RUNTIME VERIFICATION FOR SPATIO-TEMPORAL PROPERTIES OVER IOT NETWORKS** |

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Abstract

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Laburpena

(Laburpen amaieran ipini dokumentuaren amaierarantz informazio gehiago dagoela euskaraz \*Erreferentzia bat sartu atal horretara)

Resumen

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# Introduction

This chapter is the introduction to the Bachelor’s Degree Final Project “Runtime verification for spatio-temporal properties overt IoT networks”. In this section, the concepts involved in the project are defined. Additionally, the project definition, scope of the project, planification and the product specification and requirements are explained.

## Problem definition

IoT (**Internet of Things**) is the area of computer science that collects the challenges of connecting millions of smart devices and sensors and making them accessible via the internet. This field is growing fast. The forecast is that the connected devices by 2030 will be 25.44 billion worldwide [1]. These devices are already part of several fields (e.g., e-health services, smart cities, e-farm, and intelligent transportation systems (ITS)), being a big part of the digitalization of society to build a smart world.

Among the systems that can exploit an IoT infrastructure, a noteworthy category is **Cyber Physical Systems** (CPS), where physical systems are monitored and/or controlled by a computational core. They interact with physical processes through sensors and actuators. The increasing numbers of IoT devices and intelligent systems made CPS influence society. They can be found in different sectors such as self-driving cars, home equipment and medical devices [2] [3]. The following definition is the most famous one for the term “Cyber Physical Systems”:

“Cyber-Physical Systems are engineering, physical and biological systems whose operations are integrated, monitored, and/or controlled by a computational core. Components are networked at every scale. Computing is deeply embedded into every physical component, possibly even into materials. The computational core is an embedded system, usually demands real-time response, and is most often distributed. The behaviour of a cyber-physical system is a fully-integrated hybridisation of computational (logical) and physical action."

(Helen Gill, US National Science Foundation) [4]

Monitoring is an activity related to the wider category of **Runtime Verification** (RV), which purpose is to observe information from a system while it is operating and analyse the behaviour to detect if it satisfies or violates certain properties. Monitoring the status of a CPS at runtime can give precise information to ensure reliability, safety, robustness and security [5] [6].

This project focuses precisely on the challenges when doing monitoring on CPS over IoT and provides an implementation of a service to monitor data collected by sensors at runtime. It is closely related to some aspects of Helen Gill’s definition. The IoT devices are in the physical part where they are spatially distributed and networked. The data will be collected, both across space and time. One main task of the project is to connect the sensors with the monitor so they can share information (i.e., networking). Finally, this data will be sent to MoonLight to monitor everything in real-time.

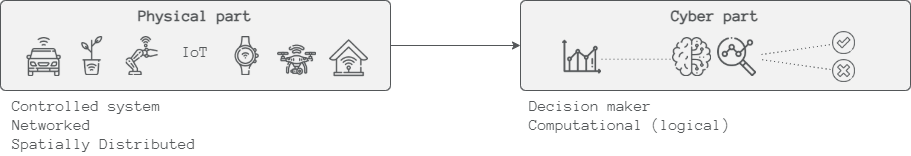


Figure 1‑A Project outline

## Objectives

The objective of this project is to implement a middleware.

Essentially functioning as hidden translation layer, middleware enables communication and data management for distributed applications.

<https://www.ibm.com/cloud/learn/middleware>

## Project phases

## Product specifications and requirements

For this project, IoT sensors (Thingy52) and a monitor (MoonLight) are already provided. The resources will be studied and manipulated and, for the communication of these components, a middleware will be implemented. This monitor will be capable of monitoring at runtime. For the monitoring of spatio-temporal properties, logicbased specification languages such as STREL will be used. STREL permits to specify the requirements and to monitor them over a spatio-temporal trace.

# State of the art

# Product specifications and requirements

//TODO: Change the tests to another apartado

The scope of the work is monitoring spatio-temporal properties using logic-based specification languages. The goal of the student work is to evaluate existing technologies for Runtime Verification of Spatio-Temporal properties over smart cities such as SaSTL. Further, to identify best practices and implement a demonstration methodology based on one of the use-cases defined in the project. Lastly, the method will be tested in order to establish a grade of improvement compared to earlier and state-of-the-art techniques. Writing a technical report on the work performed and the achieved results.

## Description of the service

Real-time systems have computer and memory resources very constrained??

## Resources and materials

### Hardware

sdfghj

### Software

sdfgh

## Tests and trials

Try to do a TDD (Test-driven Development). Not use to do it, sometimes, I wrote production code before the tests. But in general, OK

## Conditions for the implementation of the project

## Legal aspects

General Data Protection Regulation (GDPR):

# Objectives

# Use cases

## Office use case

## Wiener linien use case

# Development (subject to change)

## Middleware



Egin horrelako zerbait nire adibidea erabiliz

<https://docs.oracle.com/cd/E21764_01/core.1111/e10103/intro.htm#ASCON110>

## Services SOA

## Design pattern

Builder 🡪 <https://refactoring.guru/>

## MQTT/REST

DR1 Lightweight communication methods

DR2 Interoperability.

DR3 Non-blocking event propagation. Events may arrive at unknown rates

DR4 Scalability(??)

Edge-based Runtime Verification for the Internet of Things

## Robustness

Error handling

Maintainability

## Buffer

Collecting binary data bits into groups that can then be operated on as a unit,

automatic buffering.

It helps devices to manipulate data before sending or receiving.

## Thingy

Kconfig Json importatu ahal izateko 🡪 zephyrrena

CMakeList

Prj.conf 🡪 sensoreak enable egin ahal izateko

<https://github.com/google/eddystone/blob/master/protocol-specification.md>

# Problems and solutions

# Economic memory

The majority of the cost of a software project is in long-term maintenance. [clean code]

# Conclusions and future lines

This is thechnical

## Conclusions

a. Reflexiones técnicas: relacionadas con los objetivos del proyecto b. Reflexión sobre las implicaciones sociales, de salud y seguridad, medioambientales, económicas e industriales   c. Reflexión sobre la aplicación de conocimientos relativos a cuestiones económicas, organizativos de gestión (gestión del riesgo y del cambio) en el contexto industrial y comercial.

## Future lines

“Smart Home Automation System Using on IoT” dokumentuan rosas dagoenari begirada bat bota /!\

# Personal evaluation of the experience(?) and the project

Proiektua egiten nola sentitu naizen aipatu

Esperientziari dagokionez: A) Unibertsitatea: nola sentitu naizen, IoTko kurtsoak, astero egiten diren hitzaldietara joaten utzi… B) Beste herrialde batera joan: Leku berriak ezagutu, bertoko kulturatik ikasi, bakarrik bizitzea eta independentzia.

# Sarrera, ondorioak eta etorkizuneko ildoak

Atal honetan sarrera, ondorioak eta etorkizuneko ildoak atalen laburpen bat egingo da euskaraz.

## Sarrera

## Ondorioak

## Etorkizuneko ildoak

# Appendix A **STREL**

Titulua aldatzerako orduan kontuz! Formatua galdu gabe/!\ Aurkibidean polit ikusteko

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Tabla A1 …

# Appendix B **MQTT**

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# Appendix C **REST**

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# Appendix D **Data bus**

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# Appendix E **Gantt chart**

# Bibliography

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| --- | --- |
| [1] | T. Insights, «Statista,» December 2020. [En línea]. Available: https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/. |
| [2] | L. Nenzi, E. Bartocci, L. Bortolussi, M. Loreti y E. Visconti, «Monitoring Spatio-Temporal Properties (Invited Tutorial),» de *Runtime Verification*, Springer International Publishing, 2020. |
| [3] | D. Ratasich, F. Khalid, F. Geissler, R. Grosu, M. Shafique y E. Bartocci, «A Roadmap Toward the Resilient Internet of Things for Cyber-Physical Systems,» *IEEE Access,* vol. 7, pp. 13260-13283, 2019. |
| [4] | H. Gill, US National Science Foundation, 2006. |
| [5] | C. Tsigkanos, M. M. Bersani, P. A. Frangoudis y S. Dustdar, «Edge-based Runtime Verification for the Internet of Things,» *IEEE Transactions on Services Computing,* 2021. |
| [6] | M. Illarramendi, L. Etxeberria, X. Elkorobarrutia, J. Perez, F. Larrinaga y G. Sagardui, «MDE based IoT Service to enhance the safety of controllers at runtime,» 2019. |