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MASTER'S DEGREE IN
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Master Thesis

DECONSTRUCTING THE UNKNOWN: A BLACK BOX APPROACH TO REVERSE ENGINEERING ICS USING GRAPHS AND INVARIANTS

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"Gallina vecchia fa buon brodo"

(Valentino Rossi)

Abstract

Bla bla bla

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Chapter 1

Introduction

LOREM ipsum dolor bla bla bla. Ma dove metto l'abstract? Prova di interlinea che direi posso anche andare bene, ma bisogna poi vedere il tutto come si incastra alla fine, in modo da ottenere un bel risultato alla vista.

1.1 Contibution

Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s, when an unknown printer took a galley of type and scrambled it to make a type specimen book. It has survived not only five centuries, but also the leap into electronic typesetting, remaining essentially unchanged. It was popularised in the 1960s with the release of Letraset sheets containing Lorem Ipsum passages, and more recently with desktop publishing software like Aldus PageMaker including versions of Lorem Ipsum.

1.2 Outline

Why do we use it? It is a long established fact that a reader will be distracted by the readable content of a page when looking at its layout.

The point of using Lorem Ipsum is that it has a more-or-less normal distribution of letters, as opposed to using 'Content here, content here', making it look like readable English. Many desktop publishing packages and web page editors now use Lorem Ipsum as their default model text, and a search for 'lorem ipsum' will uncover many web sites still in their infancy. Various versions have evolved over the years, sometimes by accident, sometimes on purpose (injected humour and the like).

Where does it come from? Contrary to popular belief, Lorem Ipsum is not simply random text. It has roots in a piece of classical Latin literature from 45 BC, making it over 2000 years old. Richard McClintock, a Latin professor at Hampden-Sydney College in Virginia, looked up one of the more obscure Latin words, consectetur, from a Lorem Ipsum passage, and going through the cites of the word in classical literature, discovered the undoubtable source. Lorem Ipsum comes from sections 1.10.32 and 1.10.33 of "de Finibus Bonorum et Malorum" (The Extremes of Good and Evil) by Cicero, written in 45 BC. This book is a treatise on the theory of ethics, very popular during the Renaissance. The first line of Lorem Ipsum, "Lorem ipsum dolor sit amet..", comes from a line in section 1.10.32.

The standard chunk of Lorem Ipsum used since the 1500s is reproduced below for those interested. Sections 1.10.32 and 1.10.33 from "de Finibus Bonorum et Malorum" by Cicero are also reproduced in their exact original form, accompanied by English versions from the 1914 translation by H. Rackham.

Chapter 2

Background

2.1 What ICSs are

INDUSTRIAL CONTROL SYSTEMS (ICSs) are information systems used to control industrial processes such as manufacturing, product handling, production, and distribution [1].

ICSs are often found in critical infrastructure facilities such as power plants, oil and gas refineries, and chemical plants.

ICSs are different from traditional IT systems in several key ways. Firstly, ICSs are designed to control physical processes, whereas IT systems are designed to process and store data. This means that ICSs have different requirements for availability, reliability, and performance. Secondly, ICSs are typically deployed in environments that are harsh and have limited resources, such as extreme temperatures and limited power. Thirdly, the protocols and hardware used in ICSs are often proprietary and not widely used outside of the industrial sector.

ICSs are becoming increasingly connected to the internet and other networks, which has led to increased concerns about their security. Industrial systems were not originally designed with security in mind, and many of them have known vulnerabilities that could be exploited by attackers. Additionally, the use of legacy systems and equipment can make it difficult to implement security measures. As a result, ICSs are increasingly seen as a potential target for cyber attacks, which could have serious consequences for the safe and reliable operation of critical infrastructure.

The increasing connectivity of ICSs and the associated security risks have led to a growing interest in the field of ICS security. Researchers and practitioners are working to develop new security technologies, standards, and best practices to protect ICSs from cyber attacks. This includes efforts to improve the security of ICS networks and devices, as well as the development of new monitoring and detection techniques to identify and respond to cyber attacks.

2.2 ICS components

Industrial control systems (ICSs) are composed of several different components that work together to monitor and control industrial processes.

2.2.1 SCADA systems

Supervisory control and data acquisition (**SCADA**) is a system of software and hardware elements that allows industrial organizations to [2]:

- Control industrial processes locally or at remote locations
- Monitor, gather, and process real-time data
- Directly interact with devices such as sensors, valves, pumps, motors, and more through human-machine interface (HMI) software
- Record events into a log file

The SCADA software processes, distributes, and displays the data, helping operators and other employees analyze the data and make important decisions.

SCADA systems are known for their ability to monitor and control large-scale industrial processes, and for their ability to operate over long distances. This makes them well-suited for use in remote locations or for controlling processes that are spread out over a wide area. However, the same features that make SCADA systems so useful also make them vulnerable to cyber attacks.

SCADA systems were not originally designed with security in mind, and many of them have known vulnerabilities that could be exploited by attackers. Additionally, the use of legacy systems and equipment can make it difficult to implement security measures. As a result, SCADA systems are increasingly seen as a potential target for cyber attacks, which could have serious consequences for the safe and reliable operation of critical infrastructure.

To secure SCADA systems, it is important to implement security measures such as network segmentation, secure communication protocols, and access control. Additionally, it is important to monitor SCADA systems for unusual activity and to implement incident response procedures to quickly detect and respond to any security breaches.

2.2.1.1 Scada architecture

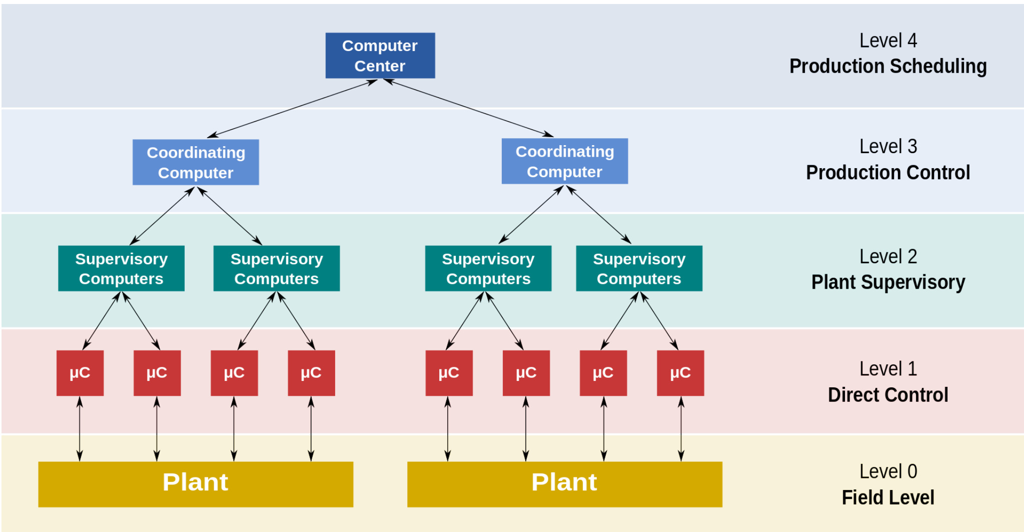

Figure 2.1: SCADA architecture schema

SCADA architecture consists in **five layers** (Figure 2.1):

- Level 0 (**Field Level**): contains **field devices** (2.2.2), or *sensors*.
- Level 1 (**Direct Control**): includes **local or remote controllers** such as **PLCs** (2.2.3) and **RTUs** (2.2.4). Controllers interface directly to the field devices reading data from sensors and sending commands to actuators.
- Level 2 (**Plant Supervisory**): contains computer systems that **collate and store informations** from the previous level and provide a **Human-Machine Interface** (*HMI*, 2.2.6) for operator control.
- Level 3 (**Production Control**): collect and aggregates data from the Plant Supervisory level to generate **reporting** to the Production Scheduling layer.
- Level 4 (**Production Scheduling**): includes business systems (such as ERP systems) used to **manage ongoing processes**.

Production Control level and Production Scheduling level are not directly connected to the process control, but concerned with monitoring production and targets and production scheduling level.

2.2.2 Field devices

Field devices are the **sensors** and **actuators** that are used to collect data from the process and control it. Examples of field devices include temperature sensors, pressure sensors, valves and pumps.

2.2.3 PLC

A *Programmable Logic Controller* (PLC) is a **small and specialized industrial computer** having the capability of controlling complex industrial and manifacturing processes [3].

Compared to relay systems and personal computers, PLCs are optimized for control tasks and industrial environments: they are rugged and designed to withdraw harsh conditions such as dust, vibrations, humidity and temperature: they have more reliability than personal computers, which are more prone to crash, and they are more compact a require less maintenance than a relay system. Furthermore, I/O interfaces are already on the controller, so PLCs are easier to expand with additional I/O modules (if in a rack format) to manage more inputs and ouputs, without reconfiguring hardware as in relay systems when a reconfiguration occours.

PLCs are more *user-friendly*: they are not intended (only) for computer programmers, but designed for engineers with a limited knowledge in programming languages: control program can be entered with a simple and intuitive language based on logic and switching operations instead of a general-purpose programming language (*i.e.* C, C++, ...).

2.2.3.1 PLC Architecture

The basic hardware architecture of a PLC consists of these elements [4]:

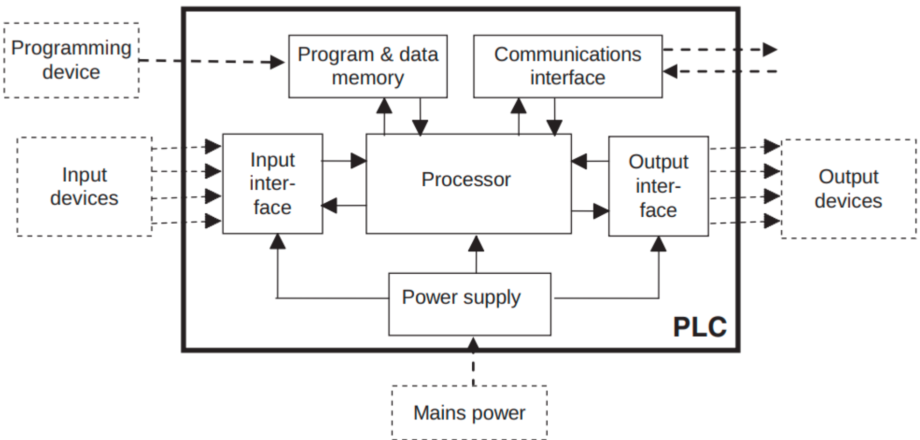

Figure 2.2: PLC architecture

- **Processor unit (CPU)**: contains the microprocessor. This unit interpretes the input signals from I/O modules, executes the control program stored in the Memory Unit and sends the output signals to the

I/O Modules. The processor unit also sends data to the Communication interface, for the communication with additional devices.

- **Power supply unit:** converts AC voltage to low DC voltage.
- **Programming device:** is used to store the required program into the memory unit.
- **Memory Unit:** consists in RAM memory and ROM memory. RAM memory is used for storing data from inputs, ROM memory for storing operating system, firmware and user program to be executed by the CPU.
- **I/O modules:** provide interface between sensors and final control elements (actuators).
- **Communications interface:** used to send and receive data on a network from/to other PLCs.

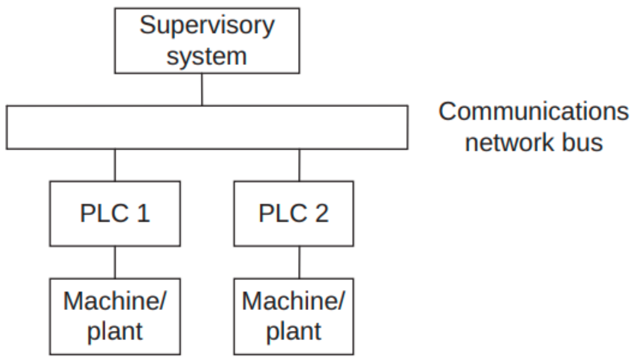

Figure 2.3: PLC communication schema

2.2.3.2 PLC Programming

PLCs are programmed with logic that defines how the process should operate and can be used to make control decisions based on data from the field devices.

2.2.3.3 PLC Security

2.2.4 RTU

Remote Terminal Units (RTUs) are devices that are used to collect data from field devices and send it to the PLCs or the control center. RTUs can also be used to control field devices based on instructions from the PLCs.

2.2.5 IED

todo

2.2.6 HMI

The Human-Machine Interface (HMI) is the interface that operators use to interact with the ICS. HMIs can be used to display process data, make control decisions, and configure the ICS.

2.2.7 Cybersecurity components

Cybersecurity components: This can include firewalls, intrusion detection and prevention systems (IDPS), and security information and event management (SIEM) systems. These are used to protect the ICS from cyber threats and vulnerabilities.

2.2.8 Communication Networks

Communication Networks are the networks that are used to connect the different components of the ICS and allow them to communicate with each other. Communication networks can include wired and wireless networks, such as Ethernet, MODBUS, and DNP3.

2.3 ICS Communication Protocols

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References

[1] *ICS defintion*. URL: https://csrc.nist.gov/glossary/term/industrial_control_system (visited on 04/06/2023).

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