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Specialty: **Industrial Computing and Automation**

Firmware Development For Industrial Robots

Elaborated by
Mariam BEJI

Host Company: **Synapticon GmbH**

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Dedication

I would like to dedicate this piece of work to the people who made it possible.
First and foremost, I wish to offer this first humble success,
to my parents,
to whom I am deeply indebted on so many levels. It is through your early nurturing of success that I have come this far.

I extend my recognition
to my grandparents,
your pride-filled eyes and joyous voices have been a constant motivation and source of inspiration throughout my academic journey.

I would also like to mention
the family that held my hand along this path,
with special appreciation
to my sister,
your faith in me has consistently fueled my achievements. I promise to persistently strive for excellence, continuously making you proud.

Not forgetting **Rabeb, Darsoufa's family, Uma and Marwen, Tata Saloua's family and Rim's family**,
you've been great hosts abroad.

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the friends who turned into family,
I appreciate your existence, you are adding glitter to my life.

Shortly, you all brought a significant difference to my life through your presence and support and I am obliged to each and every one of you.

Acknowledgement

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Abstract

This document encompasses a range of activities crucial to successfully make the servo drives connected to robotic joints, master-independent. Firstly, the CiA 402 profile (Device Profile for Drives and Motion Control), was studied to gain in-depth knowledge of its specifications and requirements. Additionally, the SOMANET firmware was analyzed since it represented the base that we were building on. As challenges arise, difficulties were addressed and overcame by finding their sources and required solutions. To further advance the development, MicroPython modules and APIs, were build with careful examination of the various dictionary objects and their types relevant to the CiA 402 profile. Furthermore, usable script samples that effectively showcase the capabilities of the solution, were developed to provide users with practical examples to interact with. Finally, evaluating the performance of this implementation and identifying areas for enhancement was an integral part of this project. By accomplishing these tasks, the project aims to achieve its objectives and deliver a robust control of an industrial robot's axis through script without fieldbus connection.

Key words : Motion Control, Servo Drive, CANopen over EtherCAT, CiA 402, Object Dictionary, XMOS xCORE, xC, C, MicroPython, Script

Résumé

Ce document englobe une série d'activités cruciales pour rendre les servomoteurs connectés aux articulations robotiques, indépendants du maître. Tout d'abord, le profil CiA 402 (Device Profile for Drives and Motion Control) a fait l'objet d'une étude approfondie afin d'obtenir une expertise de ses spécifications et de ses exigences. En outre, le firmware SOMANET a été analysé car il représentait la base sur laquelle nous construisions. Au fur et à mesure que les défis se présentaient, les difficultés ont été abordées et surmontées en trouvant leurs sources et les solutions requises. Pour faire avancer le développement, des modules et des API MicroPython ont été créés après un examen minutieux des différents objets du dictionnaire et leurs types pertinents pour le profil CiA 402. De plus, des échantillons de scripts utilisables qui présentent efficacement les capacités de la solution ont été développés pour fournir aux utilisateurs des exemples pratiques avec lesquels interagir. Enfin, l'évaluation des performances de cette mise en œuvre et l'identification des domaines à améliorer faisaient partie intégrante de ce projet. En accomplissant ces tâches, le projet vise à atteindre ses objectifs et à fournir un contrôle robuste des axes d'un robot industriel par le biais d'un script sans connexion de bus de terrain.

Mots clés : Motion Control, Servo Drive, CANopen over EtherCAT, CiA 402, Object Dictionary, XMOS xCORE, xC, C, MicroPython, Script

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List of Acronyms and definitions

List of Acronyms

- **API.** Application Programming Interfaces
- **CAN.** Controller area network
- **CAN-ID.** CAN identifier
- **CiA.** CAN in AUTOMATION
- **CNM.** Connector Module
- **CoE.** CAN over ETHERCAT
- **CRC.** Cyclic Redundancy Check
- **CSDO.** Client-SDO
- **CTM.** Control Module
- **DRM.** Drive Module
- **DSP.** Digital Signal Processing
- **ETHERCAT.** Ethernet for Control Automation Technology
- **ESI.** EtherCAT Slave Information
- **FSA.** Finite state automaton
- **FoE.** File access over EtherCAT
- **LSB.** Least significant bit/byte

- **MAC.** Multiply-Accumulate
- **MSB.** Most significant bit/byte
- **NMT.** Network management
- **Node-ID.** Node identifier
- **OD.** Object Dictionary
- **PDO.** Process data object
- **PDS.** Power Drive System
- **RO.** Read Only
- **RxPDO.** Receive-PDO
- **RW.** Read Write
- **SDO.** Service data object
- **SSDO.** Server-SDO
- **TxPDO.** Transmit-PDO
- **uPy.** MicroPython

General Introduction

The human body is a remarkable organism, characterized by its flawless design. The seamless coordination between our body movements and the brain is a topic of immense fascination. This is what we aim to achieve at Synapticon, unparalleled perfection in our creations to revolutionize the field of motion control for robotics and machinery.

As a 5th year engineering student at the National Institute of Applied Sciences and Technology, Tunisia, I joined Synapticon, a German company active in Drive Control Manufacturing, as an intern for 6 months starting from February 2023. Being a student in Industrial Computing and Automation and an active member in a university club specializing in robotics and embedded systems, I looked for an internship that could help me put theory into practice. I have therefore joined Synapticon as a firmware engineering intern to improve their motion control device: Integro.

A fairly complete overview of this end of studies project will be included in this report. The topic being «Firmware Development For Industrial Robots», our main goal is how to successfully control one robotic axis using a MicroPython script on the XMOS processor. I have detailed all the stages of my internship in this report composed of four main chapters:

- In the first chapter, the host company, its activities, products and the project's context were presented.

- In the second chapter, I highlighted the project's main concepts directing the following tasks and deliverables.
- By the third chapter explains and presents the project in details, the different techniques used and configurations.
- Lastly, the fourth chapter evolves around the tasks carried out during the internship period as well as their results and performance.

A general conclusion that summarizes the work completed serves as a reminder to the reader of the concepts covered all along this project. By the end, a number of viewpoints that can either help this effort or help others in the future, will close this present manuscript.

1

The General Context and Project Overview

Introduction

This chapter is dedicated to providing an overview of the general context of our project. We begin by introducing the host company, its different departments as well as the products developed within its scope. Subsequently, we delve into the project's overview, providing a comprehensive understanding of its scope and objectives. Then, we present the detailed specifications and requirements that guided our work throughout the project.

1 The Host Company

1.1 Generalities

Synapticon is a private technology company that bridges the gap between advanced software and electromechanics. The name, derived from "synapse" meaning connecting and "con" meaning together, symbolizes the company's core mission to connect different realms. Through their concept of "Integrated Motion," Synapticon combines electronics, mechanics, and software to create a unified and dynamically regulated entity where various components harmoniously interact to achieve optimal performance and control. They offer a wide range of motion control technologies to robotics and machinery original equipment manufacturer (OEMs), providing comprehensive solutions that cater to the specific needs of its clients and help them propel to new heights.

This Figure 1.1 shows the logo of the company :

Figure 1.1: Company logo
Image Source: www.Synapticon.com

1.2 Mission

Driven by the will to revolutionize the field of motion control, Synapticon is changing the 'point of motion' and redefining it for the digital age. The company is introducing a groundbreaking approach that integrates previously separate components, such as motors, drives, sensors, and gearboxes, into cohesive and streamlined units. This integration enables the digitalization of performance and quality factors that were traditionally reliant on expensive mechanical manufacturing processes. In terms of financial support, Synapticon has attracted investments from a diverse group of nine investors, including notable names like Stabilus, Schneider Electric, ICT Capital, and 7 Industries. These investments further solidify Synapticon's position as a leader in the industry and support its ongoing innovation and growth initiatives.

1.3 The Team

1.3.1 Departments and Distribution

Different departments including 100 employees working for the company are devided between:

- Engineering departments: Software Engineering, Hardware Engineering and Test and Validation department.
- Administrative teams: Marketing, Sales and Administration

A picture of the whole team wearing the company T-shirt is added in the Figure 1.2 below:

Figure 1.2: A picture of the team
Image Source: www.Synapticon.com

From an attic in the German highlands, called the Schwäbische Alb, at first just two, then from 2012, three friends joined forces and pooled their knowledge and expertise to assess the current state of affairs in robot development. From

2016, the team relocated to the gates of Stuttgart and also established its US subsidiary in Silicon Valley. In 2018, a Chinese subsidiary in Shanghai was opened up. Synapticon is now a multicultural company with employees from different nationalities and teams around the globe: Stuttgart, Belgrade, California and Shanghai.

1.3.2 Subteam

This project was conducted under the software development department, under the supervision of Mr. Fizul Rahman Jamal Mohamed, Firmware engineer along with Mr. Aatif Shaikh a master's student intern.

1.4 Technologies

Synapticon is at the forefront of industrial motion control, offering a comprehensive and cutting-edge portfolio of technologies and products. As the sole software-first servo drive company, Synapticon recognizes the pivotal role of servo drives in the integration of analog and virtual worlds. These drives, along with sensors, and a very capable software are what transform a machine into a fully functioning robot.

1.4.1 SOMANET Servo Drives

Leveraging its proprietary technologies, Synapticon delivers highly compact, self-contained, efficient, and user-friendly performance servo drives.

The SOMANET Servo Drives are designed for decentralized system architectures and provide unmatched solutions for seamlessly integrating drives within motion axes.

Synapticon's offerings ensure optimal performance and facilitate seamless integration, setting new standards in the field of industrial motion control. These drives are equipped with an EtherCAT interface that adheres to the CiA 402 (Device Profile for Drives and Motion Control) profile.

1.4.1.1 SOMANET Nodes

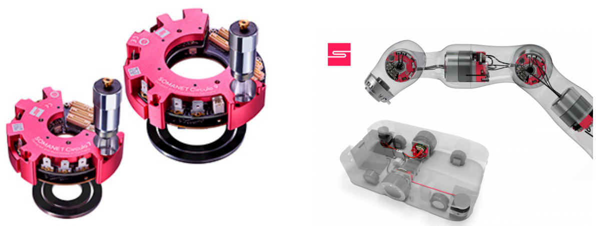
SOMANET Node is a versatile embedded EtherCAT servo drive that effectively controls and drives a single permanent magnet synchronous motors with a peak power capability of up to 2080 Watts. It stands out as the most compact and flexible solution in its category as it can be assembled like in the Figure 1.3b .

(a) Somanet Node (b) Somanet Node in an assembly

Figure 1.3: Somanet Node Servo Drive (a) and how it is assembled (b)
Images Source: www.Synapticon.com

1.4.1.2 SOMANET Circulo

SOMANET Circulo is an Integrated Motion Device: a servo solution playing the role of a robot axis controller that combines a high-performance servo drive, position sensors, IO capabilities, brake control, functional certified safety features, and seamless mechanical integration. They can be assembled to a variety of systems, including robotic arms as shown in F igure 1.4 .



(a) Somanet Circulo (b) Somanet Circulo in an assembly

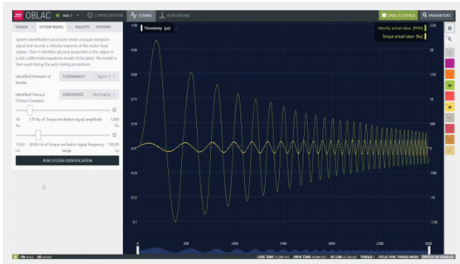
Figure 1.4: Somanet Circulo Servo Drive (a) and how it is assembled (b)
Images Source: www.Synapticon.com

1.4.2 Motion Software

1.4.2.1 OBLAC Drives Box

The OBLAC Drives Box, displayed in Figure 1.5a, is a preconfigured physical machine equipped with Linux OS, specifically designed to run OBLAC Drives and its associated services. It offers tuning and simulation possibilities through user friendly interfaces as in the Figure 1.5b.

(a) OBLAC Drives Box as an accessory to the Servo Drives



(b) OBLAC Software allowing auto tuning

Figure 1.5: OBLAC Box (a) and its Software (b)
Images Source: www.Synapticon.com

1.4.2.2 MOTORCORTEX Motion Suite

The MOTORCORTEX Motion Control Suite, visible in Figure 1.6, represents a hard-real-time Linux-based Control System for high-end industrial applications. It offers a wide range of features including a dedicated solution for controlling and programming robot arms. While the MOTORCORTEX Robot User Interface specifically caters to collaborative robotics, it can also be utilized for multi-axis kinematics in various applications.

Figure 1.6: MOTORCORTEX Motion Control Suite
Image Source: www.Synapticon.com

1.4.3 SOMANET Motion Cores

The SOMANET Motion Cores, that are viewed in th Figure 1.7, are robust industrial motion control and IO processors built on the xCORE architecture, offering extensive configurability and high performance.

Figure 1.7: SOMANET Motion Cores
Image Source: www.Synapticon.com

2 Project's Overview

2.1 General Context

Synapticon boasts an extensive and diverse global customer base, including renowned companies such as Schneider Electric, KUKA, and ABB. The company is committed to addressing the evolving needs of their existing and potential clients. As it continues to pursue excellence, anticipating the market demands is crucial to uphold its reputation as a leading partner in the industry. Synapticon is therefore willing to enhance its Integrated Motors axis. Their new-born product is the Integro, an integrated servo drive. As it appears in Figures 1.8a and1.8b it enables the combination of motor + cabinet servo drive directly attached to it.

(a) Somanet Integro

(b) Somanet Integro in an assembly

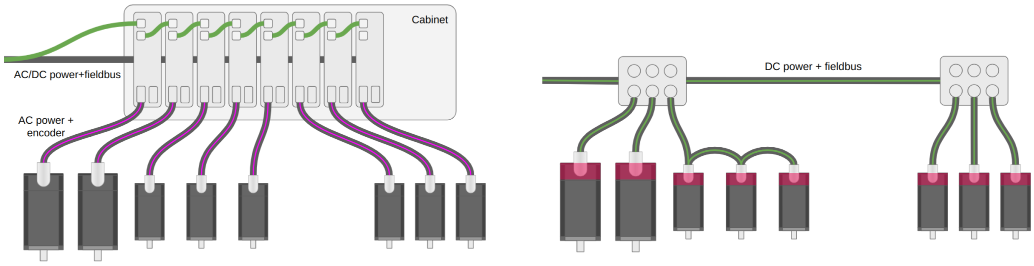
Figure 1.8: Somanet Integro Servo Drive (a) and how it is assembled (b)
Images Source: Syapticon's internal drive

To advance their technologies and add more value to this servo drive, Synapticon is working on adding new features that were not implemented on their previous products. It is therefore studying the possible implementation of features that will revolutionize the servo drives market and make the company stand out from its competitors.

2.2 Overview of Integro

The SOMANET Integro is a combination of servo drive with a position feedback sensor (encoder) and a mechanical integration solution that makes it an exact fit for robot actuators without any cable mess. Their shape and hollow shaft are ideal for direct motor mounting on fully integrated hollow-shaft actuators that are mainly used in robotic arms.

The revolutionary feature of this product is that it will help users to save space in their applications. First, thanks to its cable management, all we need is a hybrid Cable (EtherCAT + STO/SBC) and a single power supply cable (48V). An illustration in the Figure 1.9will show the amount of mess cabling 1.9a that we will reduce with using Integro 1.9b.



(a) Cabling mess without Somanet Integro (b) Mess solved with Somanet Integro

Figure 1.9: The advantage of Somanet Integro Servo Drive in an assembly
Images Source: Syapticon's internal drive

Second, its mechanical integration consisting of compact dual encoder arrangement, thermal management and hollow shaft support will make more space for the batteries for example and hence more runtime for the AGV robots. The result is obvious in the accompanying Figure 1.10: we can see the difference between the amount of components a normal AGV needs before using a Somanet Software 1.10a and after 1.10b. .

(a) An AVG without Somanet Integro (b) An AVG with Somanet Integro

Figure 1.10: The advantage of Somanet Integro Servo Drive in an assembly
Image Source: www.Synapticon.com

3 Project's Scope

3.1 Current Situation

The SOMANET Servo Drives are to be attached to industrial motors. The high performance of these integrated motion control systems allow for their use in different types of complex applications starting from Robotic Arms, Mobile Robots & Automated Guided Vehicles (AGV) to Packaging, 2D & 3D Printing, Textile, Food & Beverage, Electronic Assembly and Semiconductors. For this wide range of applications, the motors have to be compatible with as many EtherCAT masters that support CiA 402 as possible, It can now be run by Beckhoff TwinCAT, CODESYS, Matlab Simulink, Omron, Nexcobot or MOTORCORTEX, Synapticon's product. Commissioning and tuning can be done with OBLAC Drive Tools by Synapticon, installed on PC or available in the physical OBLAC Drives Box.

The Figure 1.11 below shows the various industrial applications the servo drive can be part of.

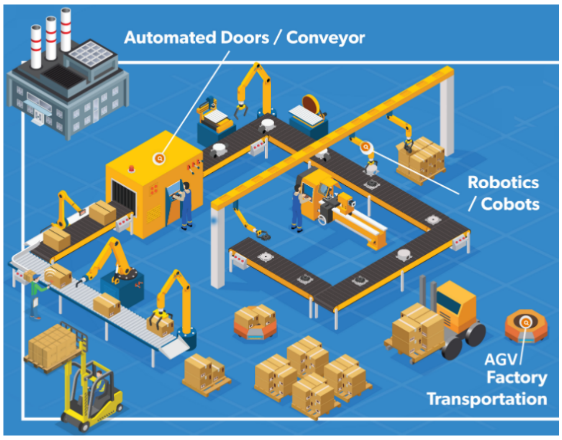


Figure 1.11: The servo drive applications in industry
Image Source: https://www.allegromicro.com/en/applications/industrial/building-and-factory/robotics-and-manufacturing-automation

3.2 Problematic

Similar to the other SOMANET servo drives, the Integro drive also adheres to various industry communication standards: EtherCAT®, CANopen and CANopen over EtherCAT®. A previous research project focused on adding more standards like PROFINET. This would allow for seamless interchangeability of drives across various systems.

However, with the immerging industry 4.0 applications, the market's demands got bigger. If SOMANET servo drive is an EtherCAT® slave for example, then an EtherCAT® master is required to operate it. Among the desired future features, there is an imminent requirement for an even more flexible operability in the next generation products. The servo drives have to go masterless! And the integrated motion systems have to become self-controlled.

3.3 Project Goals

Although different masters might support different communication standards, they operate similarly and share the same fundamental data at the same address, according to the same motion drive profile. Hence, SOMANET Servo Drives aim to ensure compatibility and interoperability among different manufacturers.

More flexibility in terms of control is best if the forthcoming products would have the capability to operate without being connected to an external master, independently of the communication protocols.

In this context, Synapticon is willing to integrate the scripting feature in its latest product Integro to improve the functionality of the Integrated Motion Device and pave the way for more complex functionalities related to smart systems and IOT integration.

Achieving master independence necessitates the ability to control industrial motors by running and compiling MicroPython scripts on Synapticon's unique multi-core SoC. Consequently, the scope is to develop a suitable methodology and software setup so that script written in (micro)Python can control an industrial motor.

This would bring many advantages to the industrial applications. For example, small machines would be able to run completely without PLC, the testing on certain sections of a machine would be much easier if testable separately, we will be able to have triggered data logging. On another side, top level PLC can be exchanged easier and we will have more modular systems.

3.4 Main Tasks

The project requirements were analysed and tasks have been split between the two interns who are under the supervision of Mr. JAMAL; and this is the summery of what I would take responsibility of during this project.

Tasks:

- Studying the CiA 402 profile (Device Profile for Drives and Motion Control).

- Studying the Somanet Software system and getting familiarized with it structures.

- Create Python modules/API by studying different objects and their types.

- Solve the emerging errors and difficulties during the MicroPython implementation.

- Build suitable methodology to test the integration into the Somanet Software.

- Evaluate the performance of the implementqtion and improve it.

- Create application samples for the users.

3.5 Project Planning

In order to track the progress of the project and ensure timely completion of tasks, we established a set of actions that were implemented throughout this graduation project.

The following Gantt diagram in Figure 1.12, illustrates the distribution of these actions.

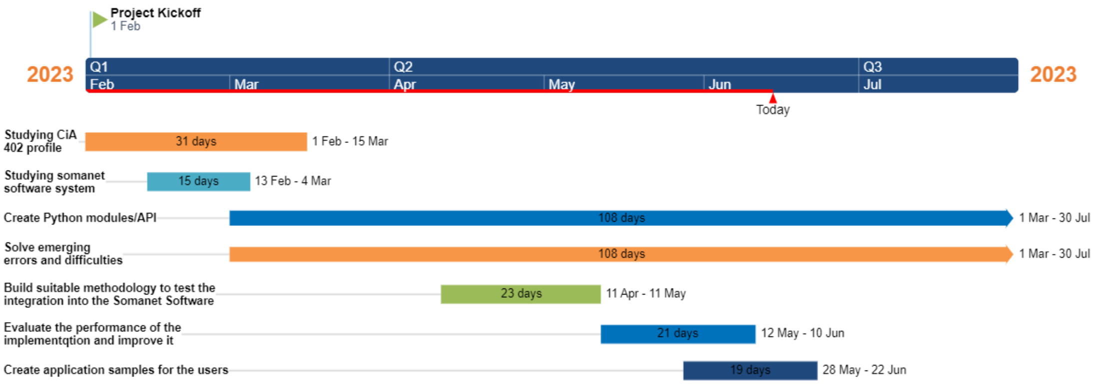


Figure 1.12: Project's Gantt Diagram
Image Source: Created by Mariam Beji

Conclusion

This chapter gives an overview of the host company, its activities, and the specific department where our work was conducted. We also outline the context of our project and the objectives we aim to achieve through a series of defined tasks, which will be discussed in details in a subsequent chapter. In the upcoming chapter, we will delve into essential background information necessary for a comprehensive understanding of our work.