Technische Universität Wien

Master Thesis Proposal

Implementation of a distributed Robot Control

Student:

Sejdefa Ibisevic
e11913116@student.tuwien.ac.at

Supervisors:

Univ.-Prof. Dipl.-Ing. Dr.sc.techn.
Dipl.NDS ETHZ
Georg Schitter
Projektass. Dipl.-Ing.
Martin Melik-Merkumians
Dipl.-Ing. BSc.
Christoph Zech

January 17, 2022

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1 Motivation and Problem Statement

The motivation for implementing distributed robotic control lies in providing an adaptive and resilient collaborative control in the face of dynamic changes during movement execution. Most industrial robots today actually have a separate control box that implements the control. But lightweight robot designs often have an integrated motor control. Separate control boxes not only require additional area but also is less flexible for current automation systems comparing to distributed control. Performing all necessary computations, such as kinematics and dynamics, in the distributed manner is becoming more popular in robotics.

Distributed robotic control is beneficial for a variety of reasons. For instance, robotic applications could be distributed in the field, which leads towards the need for a distributed solution. By dividing robotic functionality among the several units, efficiency of many applications might be significantly increased. Distributed approach offers possibility for functionality replication, hence increasing resilience and dependability through redundancy. In many cases, it may be considerably cheaper and more practical to develop a number of robotic units that can work together on a task, rather than attempting to build a centralized robotic control that can accomplish the full work with enough dependability. [1] A modular control concept such as a distributed control also makes the overall control program modular and flexible. The addition of another joint does not require a completely new program, but only one added software module.

The increased demand for smaller products leads to requirement for fast *reconfigurable manufacturing systems* (RMS) in order to increase the flexibility of the manufacturing system. The aim of modularization is to divide the rigid structure of current manufacturing systems into smaller independent subsystems which can then be combined in order to assemble the manufacturing system for producing the desired product. [2]

However, achieving fully functional distributed robotic control brings many challenges including action selection, coherence, conflict resolution, and inter-unit communication, which must be correctly addressed in order to build a functional system.

2 Aim of this Work

The goal of the master thesis is to develop functional and distributed robotic control units for the robotic arm joints, which conducts its own kinematic and dynamic computations in accordance with other modules. Microcontrollers STM32 [3] will be employed to distribute control tasks based on an existing control paradigm. The initial task is to establish robotic control on a single slave, followed by the series connection of multiple EtherCAT [4] slaves to achieve complete distributed control. After achieving this, the next step is benchmarking performance of the distributed control against existing simulation. Finally, the implementation is compared against a centralized approach on a Techservo TB6R5 test robot.

The thesis aims to answer the following research questions:

- Q1: How to design and implement distributed robotic control, and which available technologies fit best the needs?
- Q2: What are the results of comparison of developed solution against existing simulation?
- Q3: How to verify the distributed control implementation performance and how to compare it to a real unit control system?

3 Methods

The methodical approach for writing the thesis and developing proof-of-concept is divided into several steps, which are discussed below.

1. **Literature review:** Before focusing on implementation itself, an extensive review of state of the art and relevant literature related to the topic is required. The literature study provides a wider picture in the various concepts, techniques, and state of the art solutions for distributed robot control. It is also possible to derive a suitable set of requirements for the implementation of a distributed robot control system, which provide a firm foundation for the theoretical basis.

2. **Implementation:** The implementation of the control system is broken down into several independent modules that are performing its own kinematic and dynamic computations. Based on an existing control concept, STM32 microcontrollers shall be used to distribute the control task. The main issue is calculating the inverse kinematics and required joint torques in a modular manner. Every module computes all necessary parameters by itself, while EtherCAT [4] ensures correct data propagation in the forward and backward phase. On the Figures 1 and 2 forward and backward phases are illustrated. Therefore, the first step would be commissioning the EasyCAT [5] Shield and ARM based microcontroller STM32 [3]. A modular approach for computing inverse kinematics and the desired joint torque is based on [2]. After establishing successfully connection, follows the implementation of an algorithm for parameters calculation on microcontroller. This is performed on a single slave module, followed by connecting all six EtherCAT [4] slaves in series for a complete modular design of robotic control. Finally, the solution is used on a real robotic arm, Techservo TB6R5.

3. **Testing, evaluation and results:** In order to test the proposed distributed solution, the results for different joint positions will be compared against the existing Matlab simulation model. As already mentioned before, the solution will also be used for robotic control of a real robotic arm. In both cases, the manipulator will be requested to reach a desired point or to follow a linear trajectory in Cartesian space. The obtained results will be used to determine the performance of modular implementation against centralized robot control.

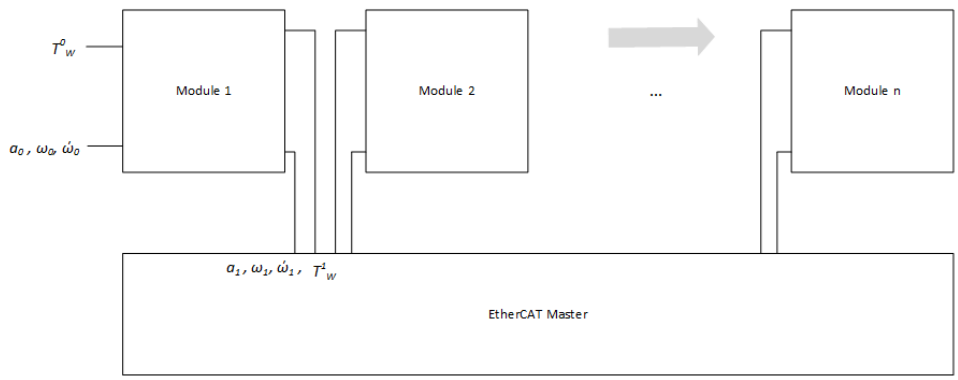

Figure 1: Forward propagation

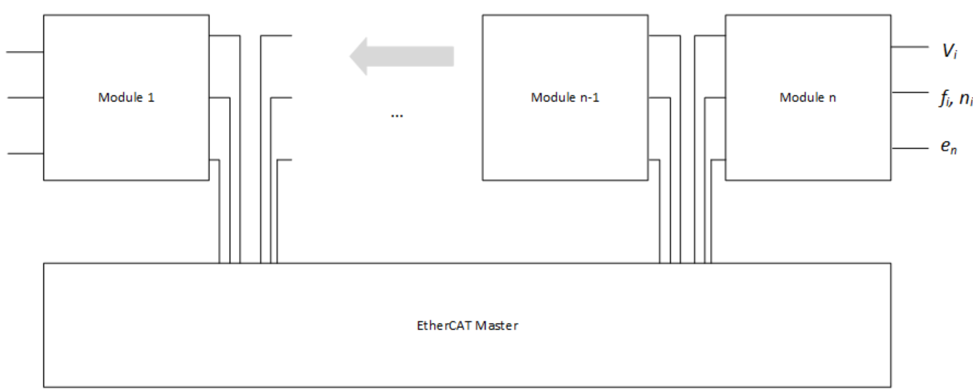

Figure 2: Backward propagation

4 State of the Art

The modularization of the robotic system for industrial manufacturing becoming subject of interest recently due to many positive impacts and has been a topic for several research papers. Some research publications related to the distributed robot control have been analyzed. The most significant remarks are discussed below.

A distributed control approach for reconfigurable robotic systems is presented in [2].The described approach relies on dynamic programming to address the inverse kinematics issue in a distributed manner. Using the recursive Newton-Euler algorithm, it provides the computations for the Cartesian trajectory of the manipulator. Finally, the approach is evaluated using a simulation of a manipulator with four degrees of motion.

In the "The Design of Distributed Robot Control System" [6] paper, the design of a distributed robot control system which consists of the host computer, the controller for each joint and the communication network is described. However, the host computer is still in charge of the entire system scheduling management, online motion planning, fault diagnosis. The joint controller receives the commands of the host computer, and controls the movement, but it does not calculate the movements on its own.

Furthermore, in the "Distributed Control of Multi-Robot Teams: Cooperative Baton Passing Task" [1], Lynne E. Parker describe a novel behavior-based, fully distributed architecture, called ALLIANCE, that utilizes adaptive action selection to achieve fault-tolerant cooperative control. The ALLIANCE architecture, which provides fault-tolerant, adaptive multi-robot action selection, serves as the foundation for the cooperative control mechanism addressed in the paper [1]. The ALLIANCE approach to communication is by broadcasting messages from individual units to announce their current activities and to obtain multi-robot cooperation that gracefully degrades and/or adapts to real-world problems, such as robot failures, changes in the team mission, changes in the robot team, or failures or noise in the communication system.

In the research publication "Distributed Control Architecture for Self-reconfigurable Manipulators" [7], an effective, computationally distributed, algorithm for controlling self-reconfigurable modular tree-structured chains has been presented. This technique proves that the motion of the end-effectors could be controlled in the operational space by solely exploiting the control capabilities of the processing units embedded inside the modules.

5 Relevance to the Curriculum of Computer Engineering

The Thesis combines knowledge and the practice from various domains provided within Automation and Cyber-Physical-Systems (CPS) course modules which are one of the representatives of 066 938 Computer Engineering Master Program at TU Vienna. For the purpose of the Thesis implementation knowledge in embedded technologies, mostly microcontrollers, its architecture, operation and programming is required.

In order to understand the relation between the Thesis topic and the Computer Engineering curriculum, the most closely related courses are listed below.

- 191.104 VU Information Technology in Automation
- 182.763 VU Stochastic Foundations of Cyber-Physical Systems
- 182.753 VU Internet of Things
- 183.660 VU Mobile Robotic
- 376.047 VO Automation and Control Systems

References

[1] L. E. Parker, “Distributed control of multi-robot teams: Cooperative baton passing task,” *4th International Conference on Information Systems Analysis and Synthesis (ISAS ’98)*, pp. 89–94, 2008.

[2] M. M.-M. G. S. Michael Steinegger, Nikolaus Plaschka, “A framework for modular and distributable control of reconfigurable robotic system,” *2016 IEEE International Conference on Industrial Technology (ICIT)*, pp. 848–853, March 2016.

[3] “Stm32 nucleo-64,” https://www.st.com/en/microcontrollers-microprocessors/stm32-32-bit-arm-cortex-mcus.html, 2022.

[4] “Ethercat,” https://www.ethercat.org, 2022.

[5] “Easycat,” https://www.easycatshield.com, 2022.

[6] X. G.-Z. W. Zunyi Deng, Yi Ning, “The design of distributed robot control system,” *International Conference on Electronic Mechanical Engineering and Information Technology*, pp. 4524–4526, August 2011.

[7] C. G. S. A. Turetta, A., “Distributed control architecture for self-reconfigurable manipulators,” *The International Journal of Robotics Research*, pp. 481–504, March/April 2008.