HAN Master Major Project

Major Project Plan

Using FANUC R-2000iC/210F (6-axis robot) for improved efficiency in FRC parts formation

Student Number: 617931

Name: Karl Wallkum

Track: Master Control Systems Engineering

Company: HAN Smart Production Cell (IPKW)

Supervisors: Nguyen Trung, (Company Supervisor)
Wesselingh Ellen, (HAN Supervisor)

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HAN Smart Production Cell (IPKW)

Nguyen Trung

Wesselingh Ellen

Contents

Background

Fiber-reinforced composite materials (FRC) are seeing a widespread use in a large number of applications ranging from aerospace systems over renewable energy production to automotive parts [5] [2]. These composite materials generally provide high specific strength and improved stiffness compared to other materials [3]. Through the combination of different materials, desirable mechanical properties like low weight with high stiffness can be achieved that would be hard or near impossible to recreate with single compound materials [7]. The attributes of an FRC can generally be described as the combination of three components [6]:

- The matrix, made of a polymer. This polymer can either be applied as a resin that hardens irreversible or a thermoplastic is used, that needs to be heated for application.
- The reinforcement component which consists of fibres with high strength and modulus. These days preferred materials are glass, carbon or polyethylene fibres.
- The fine interphase region. It's the interface between the matrix and the reinforcement that transfers the load between these.

FRCs can look back to a long history since the beginning of the 20th century with phenolic sheet Bakelite being the first fibre-reinforced plastic. Bakelite, a thermoset being the matrix was combined with different fibre materials like paper, cotton fabrics, or synthetic fabrics to create parts that can meet diverse mechanical, electrical and thermal requirements. [4]

In this project, a thermoplastic matrix will be used together with carbon or glass fibres. Besides the use of more modern polymers and fiber materials, new production techniques are incooperated. The mixed reinforced thermoplastic being supplied as pellets in various sizes for different properties is dried and then melted in an extruder through a continuous process. The material is then portioned into pieces by a guillotine and combined and stacked into assemblies by a delta robot. These assemblies are then brought to temperature again before being loaded into a hydraulic press with a mould by a FANUC R-2000iC/210F 1.1 industrial robot arm. [1]

Problem Definition

Assemblies of hot, formable Thermoplastic are delivered on a conveyor belt in varying positions after being reheated in an oven. Then they are kept in a warming area with an automatic hatch, that opens when material is needed. The assemblies then need to be picked up with a FANUC R-2000iC/210F 6-axis Industrial robot arm from the conveyor belt through a small window in a heat shield that keeps the assemblies warm. The Industrial robot then swings over to the press when it is open and the mould is free. The assemblies are then placed inside the mould at desired spots while making sure, the robot arm does not collide with any part of the press. After all parts are placed, and the robot arm has pulled back in a safe position, the press is activated and forms the parts with heat and pressure. When the forming process is finished, the press opens, the product is picked by the robot arm and placed on another conveyor belt for further processing. As the press is free, the cycle can repeat. [1] The overall goal of the Smart Production Cell is to drive down cycle time for these composite parts from ca. three minutes to one minute. Also the robot needs to cooperate with different parts of the process like the oven and the press and it plays a major role in synchronization between the subprocesses.

Figure 1.1: FANUC R-2000iC/210F 6-axis industrial robot arm

Project Objectives

The robot needs to be set up to work in cooperation with other subprocesses. Also a control strategy for the robotic arm with efficient movements guided by information from previous subprocesses needs to be implemented in Software.

Requirement Analysis

To deem the project a full success following requirements need to be fulfilled:

Software requirements

As the robot will be digitally twinned, certain goals in software need to be achieved:

Program Transfer The program transfer from Visual components to the R-30iA controller needs to be optimized and work seamlessly
LS or TP programs need to be exported from VC to the R-30iA controller without additional edits

Functional requirements:

The robot needs to be capable of fulfilling following functions:

Movements The robot needs to be able to execute all desired movements within its working range
The Robot needs to make a picking and placing movement for the press from and to conveyor belts

Communication The Robot needs to communicate to the PLC via Profinet.
The PLC and the robot need to have a handshake via Profinet

Position tracking The Robot needs to send its position via the PLC to Visual components
Position of the tool-head in XYZ need to be transmitted to VC

Movement authority The robot needs to receive movement authority from the PLC and apply the right action based on the given movement authority
The Robot should be started automatically in auto mode via the PLC with no manual pressing of the cycle start button and run a program chosen or given by the PLC

Safety requirements:

As the robot is used in a laboratory environment special precautions that differ from a standard production cell need to be set in place:

Safety manual A short and precise safety manual needs to be created for the robot in this specific laboratory environment
The safety manual needs to contain specific information for Programmers, Operators and other people working in the vicinty of the robot

Acoustic or visual feedback As the robot is used in a laboratory environment, where it cannot be guaranteed at any time that a person cannot get close to its working range, feedback needs to be given shortly before movements are executed.
A warning light or other feedback equipement needs to be activated when the robot starts moving

Security requirements:

All machinery in the production line will be connected to other systems via the internet. This throws up several security questions:

Risks Risks regarding external connectivity and the resulting threats need to be outlined
An Evalutaion of potential intrusion strategies needs to be worked out

Firewall If the machines are connected to the local network at SPC, a firewall solution needs to be set in place
A firewall needs to be set in place between the company network and the Perimeter Network + Fieldbus

Performance requirements:

The goal of the Production line is to minimize cycle time for FRC parts. This puts certain demands on the robot:

Robot cycle time Every minute one part has to be produced. The robot needs to fulfill all movements within that cycle time
An Control strategy with a maximum cycle time of 45 seconds needs to be found

Documentation requirements:

As the SPC is a flexible working environment with changing teams, good documentation is key for a good handover to following teams

Programmer manual Many configurations and Programs were tested on the robot. Following teams should have an easy start.
A Programmer manual with wiring, configuration and a quickstart guide needs to be made

Maintenance requirements:

As the robot is used in a laboratory setting, some parts are used more excessively than in a normal production setting

Brake inspection As the E-stop is used relatively often, they will need to be replaced earlier than usueal
An annual inspection with FANUC needs to be scheduled.

Activities and Products

With regard to the goals, following activities need to be carried out which produce below mentioned Products.

Activities:

Mounting and Floorplan All parts involved in the process except from the press are not yet bolted to the ground. A floorplan needs to be developed based on simulations in Visual Components. Together with the SPC team and consultants from Quing this floorplan will be developed. Then the FANUC R-2000iC/210F together with all other components can be moved to their final position and bolted to the ground.

Wiring The FANUC R-2000iC/210F is not connected to power and to its accompanying R-30iB controller. Cables need to be connected to the robot and the controller.

Commissioning The FANUC R-2000iC/210F although being a second hand robot has never been put into operation at the SPC. The robot and its R-30iB controller need to be placed into operation step by step with several function tests.

Fieldbus - Hardware A Profinet fieldbus network needs to be designed and installed to connect all components with each other for exchange of data and commands. For this, an Industrial Ethernet network needs to be set up with a Profinet Stack. Twisted-Pair-Cables need to be cut in the right length and equipped with RJ45 connectors. Also additional network components like an industry grade switch for routing and Ethernet hubs as well as USB network adapters for package sniffing need to be selected and procured.

Fieldbus - Software To use Profinet, all involved network interfaces, input and output of data as well as global commands and flags need to be configured to make all devices communicate with each other.

Modelling To develop and test a controller for the FANUC R-2000iC/210F, a simulation in software will be made with the help of Visual Components. To get a deeper understanding of the robot arm, a kinematic modelling will be done.

Sensors All virtual and physical sensors necessary to guide the FANUC R-2000iC/210F will be identified, and connected to a Profinet member.

Control Scheme A control scheme for the FANUC R-2000iC/210F will be developed with the help of an iPendant connected to a R-30iB Plus controller and Karel Programming language in the software ROBOGUIDE to fulfill the desired tasks.

Programming Parts of the program for integration of the FANUC R-2000iC/210F robotic arm into the overall production line will run on a Siemens Simatic S7-1500 Programmable Logic Controller (PLC). This PLC is the brain of the plant where all information from different subprocesses comes together and is processed.

Testing After developing a program to control the robot, extensive testing is needed to verify safety and assure 24/7 operation.

Report A report will be made, and drafts will be sent to the supervisors for feedback.

Fine Tuning When all subprocesses work properly together, fine tuning can be applied based on observations to drive down the cycle time or reduce energy consumption.

Products:

Floorplan Floorplan including all major relevant components

Model and Simulation Model and simulation of the robot arm

Control Scheme Control scheme implemented in software

Presentation and Report Major project report and a real-life presentation of the movements of the Fanuc R-2000iC/210F

Safety plan A basic summary of procedures for safe operation of the robot

Organization

HAN Automotive has founded a Smart Production Center(SPC) in order to research the possibilities for improvement in mass production of lightweight automotive parts using Fibre Reinforced Thermoplastics (FRT). The SPC is located in the Mobility Innovation Center (MIC) in Industriepark Kleefse Waard (IPKW) in Arnhem.

The SPC provides a room for companies to collaborate with the HAN. Some of these companies interested in the project and inclined to help are located in the direct surroundings of the MIC building such as Quing who are involved with the simulations.

Peter Verschut, the Program Manager of Automated Composites and Didier Polling, researcher in lightweight structures, keep an overview over the activities of all students involved. Suzanne Ezendam is Project coordinator and head of the building and labs.

Master Level

This Thesis project demands creating a model of the robotic arm. The modelling of the 6 axis FANUC R-2000iC/210F will require knowledge from Systems Modelling. If parameters cannot be determined, they can be found with techniques from Systems Identification. Based on this model, a controller can be developed and a range of paths can be found through inverse kinematics. This controller is an extension of the subjects taught in the module Advanced Controller Design. The number of resulting paths can then be narrowed down further, for example based on safety restrictions or the desired working area of the robot. This will be a further development of the knowledge conveyed in Applied Control Strategy from the module Applied Control. This results in a control scheme that can be implemented in Matlab and simulated numerically, and probably also graphically. The basics of implementation were shown in Controller Implementation from the module Applied Control

I will demonstrate my master level by understanding and simulating the dynamics of a 6 axis Robot arm.

Restrictions

Surrounding subprocesses To fully demonstrate all abilities of the FANUC R-2000iC/210F, all sub-processes (extruder with supply hopper, conveyors, delta robot with gripper, press with mould, robot gripper, oven with heat-shield) need to be in place and running on their own. Also test material will be needed that can be picked up and placed.

Gripper The robot arm currently does not have a gripper. To demonstrate the picking abilities in real life with test material, this gripper will need to be designed in time by another student at the SPC.

Temperature range of material For the Process to operate correctly, the material taken out of the oven needs to be hot enough to stay formable. This will also be a core point of the overall research to find an ideal oven-temperature in the range between $230 - 330°C$.

Fieldbus An Ethernet network needs to be set up to host the communication via Profinet between the subprocesses.

Software For simulation Visual Components and for control ROBOGUIDE with Karol Programming Language as well as TIA Portal need to be made available, installed and configured.

Robot Placement The final placement of the robot is not yet determined and the robot needs to be bolted to the ground in its final position before it can be used.

References

[1] Jens and Timo Jacobs Lubbers. *Smart X-Cell Production SYSTEM RQUIREMENTS DOCUMENT*. Tech. rep. HAN automotive Research, Jan. 2015.

[2] C.A. Lawrence. *High Performance Textiles and Their Applications*. Jan. 2014, pp. 1–437.

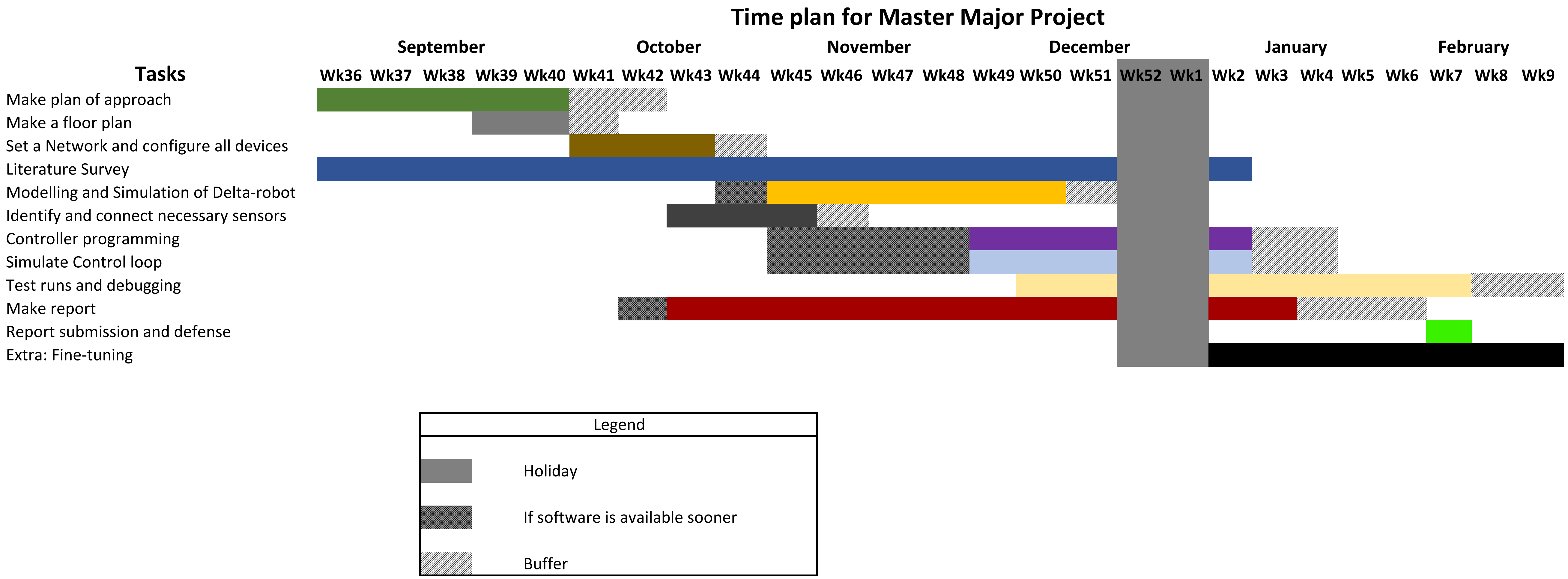
[3] Angela Madeo. *Generalized Continuum Mechanics and Engineering Applications*. Elsevier Science, Sept. 2015. ISBN: 9781785480324.

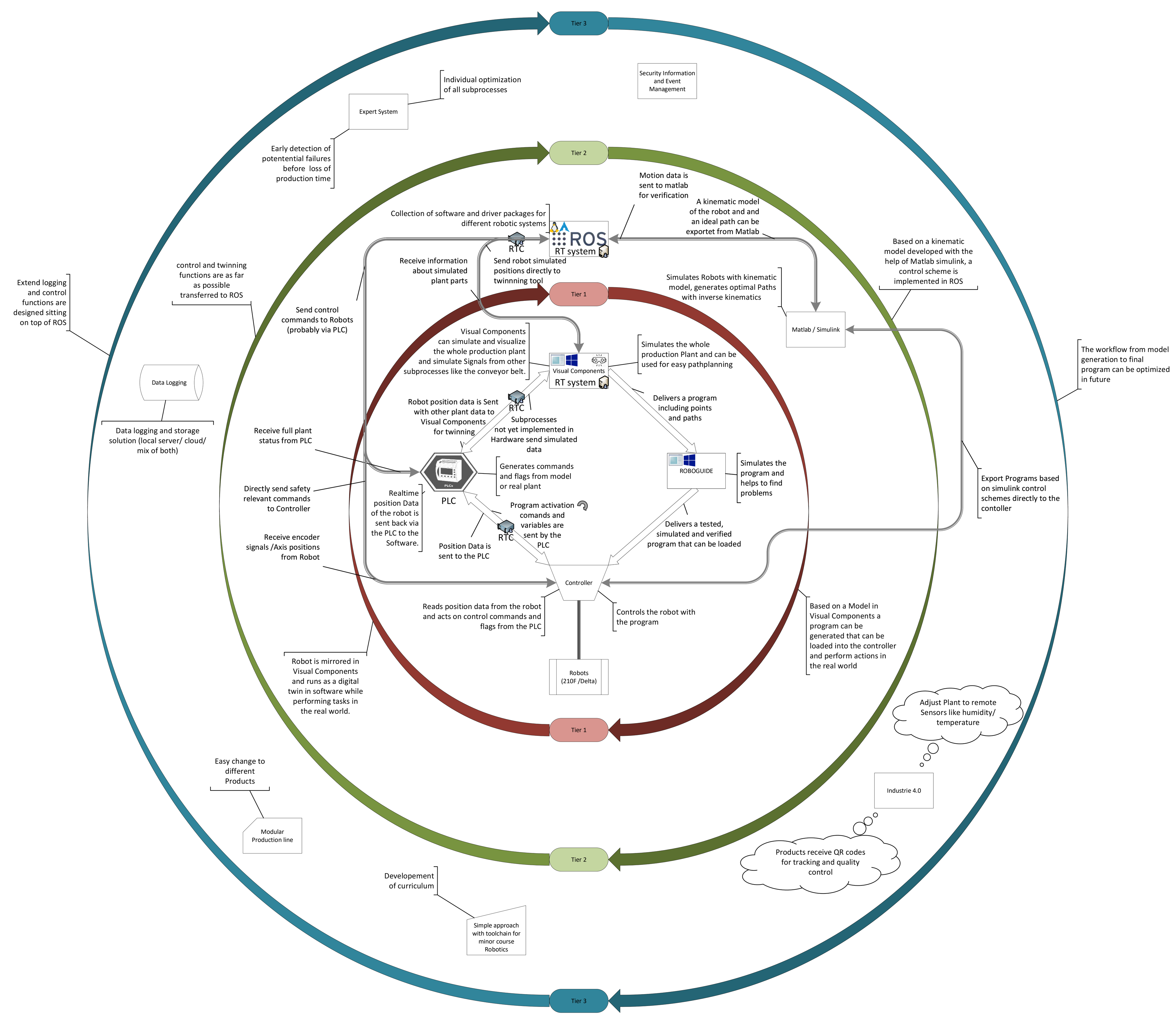
[4] nimrodplastics. *Bakelite*. URL: `http://www.nimrodplastics.com.au/product-bakelite.htm`.

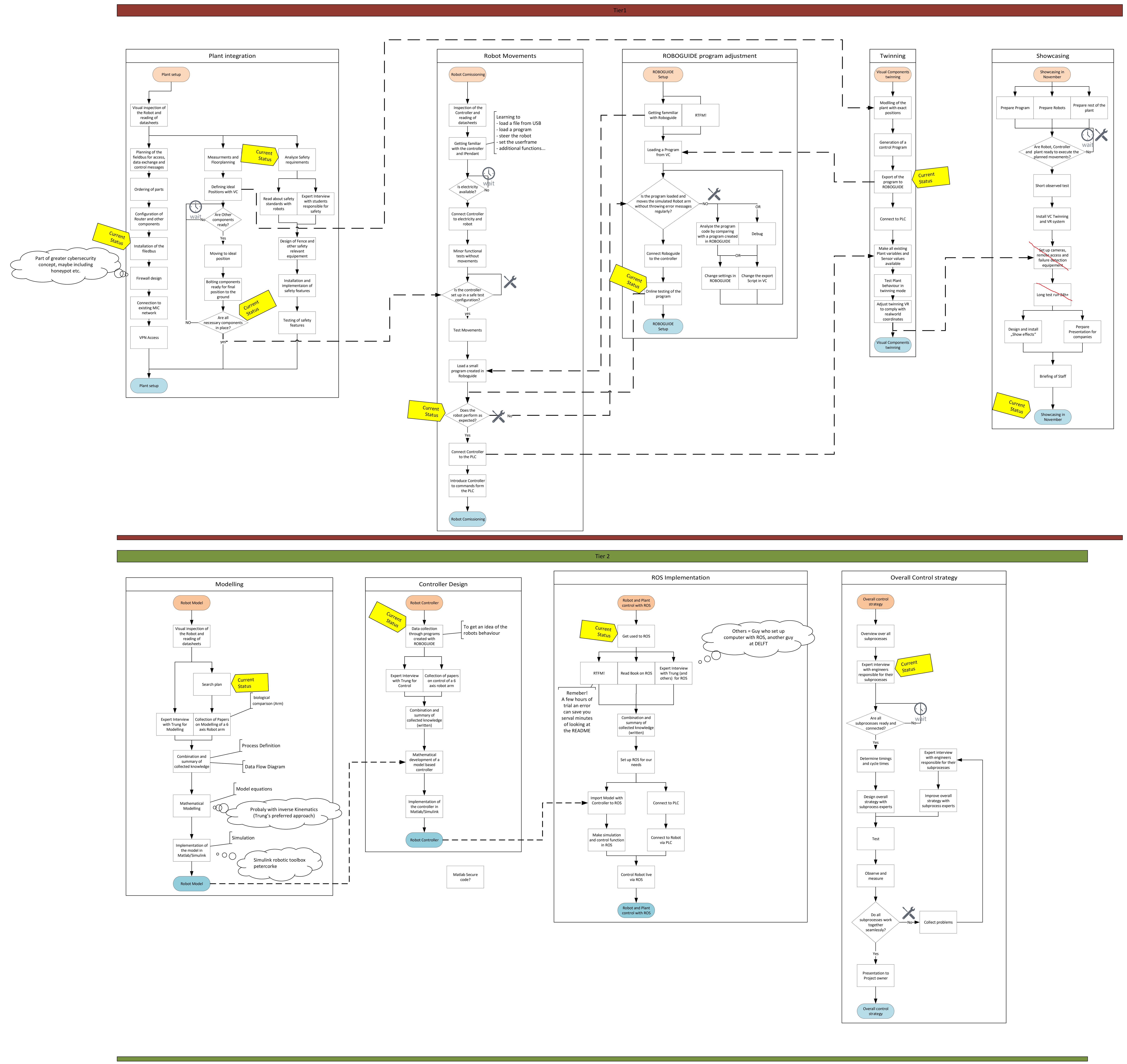
[5] S.J. Park and M.K. Seo. *Interface Science and Composites*. Interface Science and Technology. Elsevier Science, 2011. ISBN: 9780123750495. URL: `https://books.google.nl/books?id=DewhZ53WgLwC`.

[6] Zohaib Sultan et al. *Advanced Dental Biomaterials*. June 2019. ISBN: 9780081024768.

[7] George Voyiadjis and Peter Kattan. *Advances in Damage Mechanics: Metals and Metal Matrix Composites With an Introduction to Fabric Tensors*. Jan. 2006. DOI: `10.1016/B978-0-08-044688-2.X5000-0`.


Time plan for Master Major Project
September
October
November
December
January
February
Tasks
Wk36 Wk37 Wk38 Wk39 Wk40 Wk41 Wk42 Wk43 Wk44 Wk45 Wk46 Wk47 Wk48 Wk49 Wk50 Wk51 Wk52 Wk1 Wk2 Wk3 Wk4 Wk5 Wk6 Wk7 Wk8 Wk9
Make plan of approach
Make a floor plan
Set a Network and configure all devices
Literature Survey
Modelling and Simulation of Delta-robot
Identify and connect necessary sensors
Controller programming
Simulate Control loop
Test runs and debugging
Make report
Report submission and defense
Extra: Fine-tuning
Legend
Holiday
If software is available sooner
Buffer


Tier 3
Tier 2
Tier 1
Security Information and Event Management
Expert System
Individual optimization of all subprocesses
Early detection of potentential failures before loss of production time
Motion data is sent to matlab for verification
A kinematic model of the robot and and an ideal path can be exportet from Matlab
Collection of software and driver packages for different robotic systems
ROS
RT system
RTC
Receive information about simulated plant parts
Send robot simulated positions directly to twinnning tool
Based on a kinematic model developed with the help of Matlab simulink, a control scheme is implemented in ROS
Simulates Robots with kinematic model, generates optimal Paths with inverse kinematics
Matlab / Simulink
control and twinning functions are as far as possible transferred to ROS
Extend logging and control functions are designed sitting on top of ROS
Send control commands to Robots (probably via PLC)
Visual Components can simulate and visualize the whole production plant and simulate Signals from other subprocesses like the conveyor belt.
Visual Components
Simulates the whole production Plant and can be used for easy pathplanning
The workflow from model generation to final program can be optimized in future
Data Logging
Data logging and storage solution (local server/ cloud/ mix of both)
Robot position data is Sent with other plant data to Visual Components for twinning
Subprocesses not yet implemented in Hardware send simulated data
Delivers a program including points and paths
Receive full plant status from PLC
PLC
Generates commands and flags from model or real plant
ROBOGUIDE
Simulates the program and helps to find problems
Export Programs based on simulink control schemes directly to the contoller
Directly send safety relevant commands to Controller
Realtime position Data of the robot is sent back via the PLC to the Software.
Program activation comands and variables are sent by the PLC
Position Data is sent to the PLC
Delivers a tested, simulated and verified program that can be loaded
Receive encoder signals /Axis positions from Robot
Controller
Reads position data from the robot and acts on control commands and flags from the PLC
Controls the robot with the program
Based on a Model in Visual Components a program can be generated that can be loaded into the controller and perform actions in the real world
Robot is mirrored in Visual Components and runs as a digital twin in software while performing tasks in the real world.
Robots (210F /Delta)
Adjust Plant to remote Sensors like humidity/ temperature
Industrie 4.0
Easy change to different Products
Modular Production line
Products receive QR codes for tracking and quality control
Developement of curriculum
Simple approach with toolchain for minor course Robotics


Tier1
Plant integration
Plant setup
Visual inspection of the Robot and reading of datasheets
Planning of the fieldbus for access, data exchange and control messages
Ordering of parts
Configuration of Router and other components
Installation of the filedbus
Firewall design
Connection to existing MIC network
VPN Access
Measurments and Floorplanning
Current Status
Analyze Safety requirements
Defining ideal Positions with VC
Are Other components ready?
wait
No
Yes
Moving to ideal position
Bolting components ready for final position to the ground
Are all necessary components in place?
NO
yes
Read about safety standards with robots
Expert Interview with students responsible for safety
Design of Fence and other safety relevant equipement
Installation and implementaion of safety features
Testing of safety features
Part of greater cybersecurity concept, maybe including honeypot etc.
Robot Movements
Robot Comissioning
Inspection of the Controller and reading of datasheets
Getting familiar with the controller and IPendant
Learning to
- load a file from USB
- load a program
- steer the robot
- set the userframe
- additional functions...
Is electricity available?
Connect Controller to electricity and robot
Minor functional tests without movements
Is the controller set up in a safe test configuration?
Test Movements
Load a small program created in Roboguide
Does the robot perform as expected?
Connect Controller to the PLC
Introduce Controller to commands form the PLC
ROBOGUIDE program adjustment
ROBOGUIDE Setup
Getting fammiliar with Roboguide
RTFM!
Loading a Program from VC
Is the program loaded and moves the simulated Robot arm without throwing error messages regularly?
OR
Analyze the program code by comparing with a program created in ROBOGUIDE
Debug
Change settings in ROBOGUIDE
Change the export Script in VC
Connect Roboguide to the controller
Online testing of the program
Twinning
Visual Components twinning
Modlling of the plant with exact positions
Generation of a control Program
Export of the program to ROBOGUIDE
Connect to PLC
Make all existing Plant variables and Sensor values available
Test Plant behaviour in twinning mode
Adjust twinning VR to comply with realworld coordinates
Showcasing
Showcasing in November
Prepare Program
Prepare Robots
Prepare rest of the plant
Are Robot, Controller and plant ready to execute the planned movements?
Short observed test
Install VC Twinning and VR system
~~Set up cameras, remote access and failure detection equipement~~
~~Long test run 24h+~~
Design and install „Show effects"
Perpare Presentation for companies
Briefing of Staff
Tier 2
Modelling
Robot Model
Search plan
biological comparison (Arm)
Expert Interview with Trung for Modelling
Collection of Papers on Modelling of a 6 axis Robot arm
Combination and summary of collected knowledge
Process Definition
Data Flow Diagram
Mathematical Modelling
Model equations
Probaly with inverse Kinematics (Trung's preferred approach)
Implementation of the model in Matlab/Simulink
Simulation
Simulink robotic toolbox petercorke
Controller Design
Robot Controller
Data collection through programs created with ROBOGUIDE
To get an idea of the robots behaviour
Expert Interview with Trung for Control
Collection of papers on control of a 6 axis robot arm
Combination and summary of collected knowledge (written)
Mathematical development of a model based controller
Implementation of the controller in Matlab/Simulink
Matlab Secure code?
ROS Implementation
Robot and Plant control with ROS
Get used to ROS
Others = Guy who set up computer with ROS, another guy at DELFT
RTFM!
Read Book on ROS
Expert Interview with Trung (and others) for ROS
Remeber! A few hours of trial an error can save you serval minutes of looking at the README
Set up ROS for our needs
Import Model with Controller to ROS
Connect to PLC
Make simulation and control function in ROS
Connect to Robot via PLC
Control Robot live via ROS
Overall Control strategy
Overall control strategy
Overview over all subprocesses
Expert interview with engineers responsible for their subprocesses
Are all subprocesses ready and connected?
Determine timings and cycle times
Design overall strategy with subprocess experts
Improve overall strategy with subprocess experts
Test
Observe and measure
Do all subprocesses work together seamlessly?
Collect problems
Presentation to Project owner