HAN Master Major Project

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

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Figure 0.1: FANUC R-2000iC/210F 6-axis industrial robot arm

Contents

1. Abstract

This work aims to integrate a FANUC 210F 6 axis industrial robot arm into an experimental production line. As this production line is set in a research environment, gaining a deeper understanding of all involved systems is desired.

The dynamic behaviour of a physical system is best expressed with an analytical model. In order to control a robot arm, a kinematic model needs to be created. With this model, a control algorithm can be derived.

The objective of this thesis is to derive the complete inverse kinematic model of a 6 degrees of freedom (DOF) robotic arm analytically. For an exact numerical simulation of the device most steps are laid out theoretically and difficulties in the practical implementation are described. Additionally for follow up projects this work also contains a quick start guide and a safety manual for the robot in this setting . Finally to contribute to current research, twinning specifications will be defined.

2. Preface

Robots can be defined as programmable movement automatons that can perform tasks without human supervision and can be taught at least repetitive tasks. Increasingly, also ways to sense their surroundings are added and improve their movements according to their surroundings. These additionally to the sensors like pulse encoders at their axes to feedback control their endpoint position accuracy.

I have started working with robots and robotic systems in my bachelor studies. As a starting engineer, I was exploring the possibilities of automated manufacturing with CNC mills and 3D printers. These were very simplistic robotic systems based on a feedforward control with stepper motors for position accuracy. For starting a production process, these devices had to be half automatically calibrated and the position and orientation needed to be taught automatically by pointing the drill/printing head to the markerpoints.

3. Summary

4. Acronyms

HAN Hogeschool van Arnhem en Nijmegen

SPC Smart Production Cell

DOF degrees of freedom

FRC Fibre Reinforced Composites

DH Denavit-Hartenberg

IOT Internet Of Things

FHEM Freundliche Hausautomation und Energie-Messung [6]

NFC Near-field communication

IPKW Industrial Park Kleevse Waard

NFC Near Field Communication

ROS Robot Operating System

GUI Graphical User Interface

5. Problem Definition

For Fibre Reinforced Composites (FRC) part production, a robot arm can be used to load the press with raw material, as it allows for more flexibility in the production line. As the robot arm has many degrees of freedom, there are different strategies for a control cycle. Main constraint is to achieve this movement of materials as fast as possible to minimize the cool-down of the molten FRC. Additionally, the accelerations and forces on the material should be minimized while transferring, to make sure no material is lost in the process. This makes hit hard to find an ideal, fast control strategy to place the raw material into the press.

6. Denavit-Hartenberg-Convention

TheDenavit-Hartenberg (DH)-Convention is a commonly used and simplifies the forward and backward transformation. It was named after Jaques Denavit and Richard Hartenberg who developed a general theory to describe a serial link mechanism. [12]
It consists of following parts:

- DH-Convention for establishing the coordinate systems
- DH-Transformation for generation of the coordinate systems
- DH-Parameters as a result form the transformations

Determining the coordinate systems is done according to set rules. Nevertheless, the choices of coordinate frames are also not uniqe, so different peole will derive different, but correct frame assignments. This freedom of choice should be used to bring as many DH-Parameters as possible to zero. This simplifies subsequent equations and calculations. [31]
Each joint of the robot is described by four parameters.

7. Literature survey

In my project plan I stated that "I will demonstrate my master level by understanding and simulating the dynamics of a 6 axis Robot arm."[27] This should be done by creating a model of the robot arm. To create the model of the robot arm, a literature review is necessary to lay out the best approach.

7.1 Mapping of the field of study

To start the literature review, a set of first keywords was needed. Through an expert interview with my company supervisor Trung Nguyen [16] , who had already supervised other thesis projects in the domain of robotics, a list of keywords to start with was found in a quick discussion. Not all of these keywords were immediately clear, so it was necessary to find definitions for these. With the help of scientific databases and search engines, sources for these definitions could be found.

6 axis robot serial 6 degree of freedom robots ([26] with HANQuest)

industrial robot arm some form of jointed structure achieved by the linking of a number of rotary and/or linear motions or joints([30] with Science Direct)

inverse kinematics mathematical process of recovering the movements of an object with kinematic equations to determine the joint parameters that provide a desired position for each of the robot's end effectors ([7] with Wikipedia)

Peter Corke robotics toolbox Matlab toolbox for the study and simulation of classical arm-type robotics, for example such things as kinematics, dynamics, and trajectory generation ([21] with Google search)

motion planning find a sequence of valid configurations that moves the robot from the source to destination ([14] with Google search)

robot dynamics relationship between the forces acting on a robot mechanism and the accelerations they produce ([5], with Scholarpedia)

ROS Robot Operating System - framework for writing robot software. It is a collection of tools, libraries, and conventions that aim to simplify the task of creating complex and robust robot behaviour across a wide variety of robotic platforms. ([20] with Google search)

As seen in "Implementation of Robot Systems" [30], the FANUC 210F is an articulated robot arm, also called a jointed arm. It is a 6 axis robot that has six rotational joints, each mounted on the previous joint. This type of robot has the ability to reach a point within the working envelope in more than one configuration or position. As there are multiple configurations possible to reach the same position, path planning would become an important topic. This means through inverse kinematics the motion of the joints needs to be determined without considering the local forces that cause them to move. The robotics toolbox by Peter Corke was seen as a good tool for simulating these kinematics in MATLAB. When attaching the dynamics to this model, further simulations could be made to simulate the dynamic bahaviour of the robot arm and create a controller. ROS, while being an advanced tool for robot control would not fall in the scope of this thesis, as it would rather be a tool for later in the process of integrating the robot into the production line.

7.2 In depth literature

As stated in the online manual of MathWorks, "Kinematics is the study of motion without considering the cause of the motion, such as forces and torques." [17] Inverse Kinematics, also called backward kinematics is the logical opposite to forward kinematics also called direct kinematics (See figure 7.1).

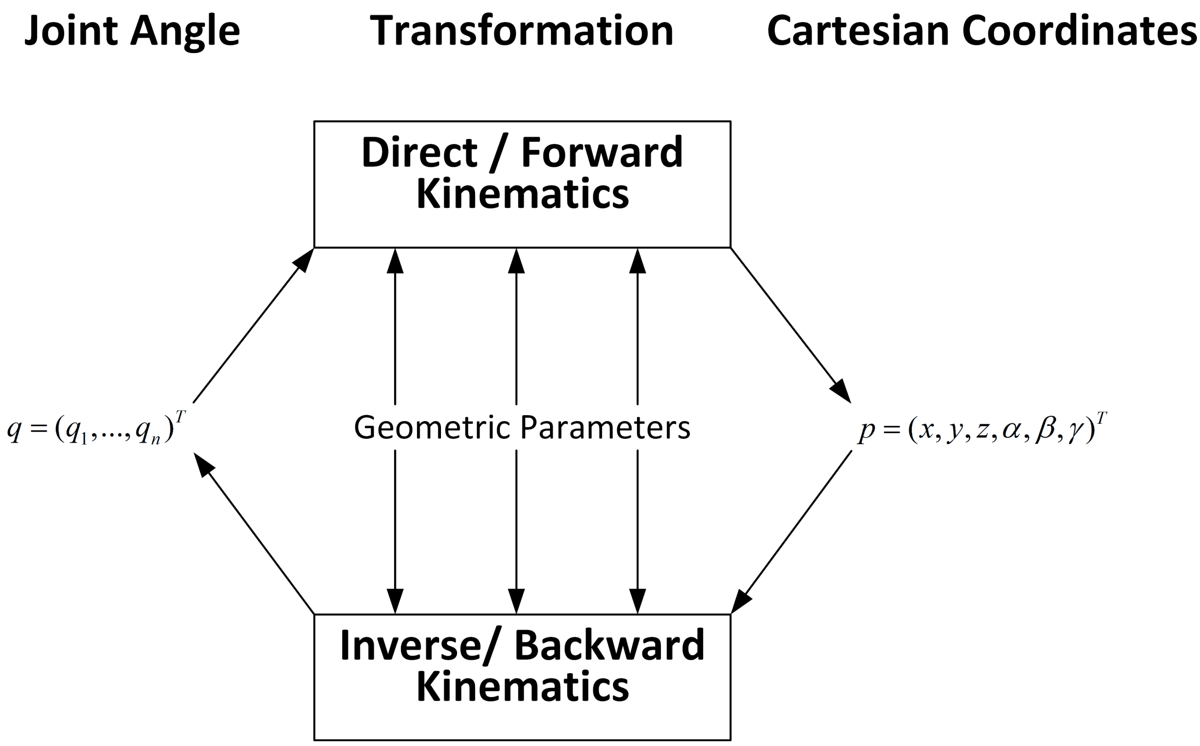

Figure 7.1: Relation between inverse and forward kinematics translated from German Wikipedia site on inverse inematics [19]

In the german wikipedia article on inverse kinematics [8], the thesis "Verallgemeinerte inverse Kinematik für Anwendungen in der Robotersimulation und der virtuellen Realität" [22] is given as one of the main sources. This thesis work gives a good overview on the topic of inverse kinematics. As stated in this thesis work, the

Denavit-Hartenberg notation is a robotic convention to map the local coordinate systems within a kinematic chain as found in robot arms.
As seen in "A Mathematical Introduction to Robotic Manipulation" [18] (obtained through Semantic Scholar, search phrase: robotic convention), there are several other conventions besides the "Denavit-Hartenberg notation" used in the robotics research field like the the "product of exponentials formulation". As most literature prefers a Denavit-Hartenberg fomulation of the kinematics (see [18]), this convention will be chosen in this work as well.
Solutions for forward kinematics are simple to obtain but solving inverse kinematics has been one of the main concerns in robot kinematics research. With more DOF, solutions get more complex as non-linear equations with transcendental functions need to be solved. For this set of equations, no general algorithms are available. Often algebraic, geometric and iterative methods for complex manipulators are used to find a solution to the inverse kinematic problem as stated by Tarun Pratap Singh et al. [23].
To find a suitable method for solving the inverse kinematic problem, a definition for the solution is needed:

"A manipulator will be considered solvable if the joint variables can be determined by an algorithm that allows one to determine all sets of joint variables associated with a given position and orientation. [...] The algorithm should find all possible solutions" -Dr.-Ing. John Nassou[15]

With this definition of solvability, all systems with revolute and prismatic joints with 6 DOF in a single series chain are solvable with the current available research. [15] As a quick search on HAN Quest with the search term "7 DOF inverse kinematics" suggests, there is currently onging research for the inverse kinematics problem in higher DOF manipulators with fuzzy logic as multiple articles following this approach can be found.

As the goal is to find a suitable solution strategy for the inverse kinematic problem, it helps to map out the different types of methods. Solution strategies can be split into two classes as stated by Dr.-Ing. John Nassou [15]:

Closed-form solutions	**Numerical solutions**
faster because analytical method	slower because of iterative nature
will find all solutions	not always find all solutions
Two approaches:	
algebraic approach **geometric approach**	

As numerical methods solve within an unknown number of operations, cannot always deliver all solutions and depend on the users decision for accuracy, [15] a closed-form solution will be preferred.
On HAN Quest, with the keywords "6DOF inverse kinematics" the article "Inverse Kinematics Solution and Optimization of 6DOF Handling Robot" [28] can be found. This offers an algebraic method to solve the inverse kinematic problem for 6 axis robots. A similar approach is shown in "Forward and Inverse Kinematic Analysis of Robotic Manipulators" [23]

As an alternative, a geometric modeling can be done as seen in "Workspace analysis and geometric modeling of 6 DOF Fanuc 200IC " [2]. A completely different approach is given in "A inverse kinematic solution of a 6-DOF industrial robot using ANN" by using artificial neural networks [1].
With one of these methods, a solution can be found for the inverse kinematic problem. This solution can then be verified with the robotics toolbox (Corke)
With this solution, a dynamic model of the robot can be created by attaching dynamics to the model as seen in "Control and Safety Mechanisms for a 3 DOF Manipulator with Human Interaction" [29] and "A mathematical introduction to Robotic Manipulation" [18]. A complete example of a dynamic simulation of a 6 DOF robot arm can be found in "Dynamic Multibody Simulation of a 6-DOF Robotic Arm" [13]
A controller for trajectory tracking can then be created with the model as seen in "Experimental Evaluation of Nonlinear Feedback and Feedforward Control Schemes for Manipulators" [10]
This controller could then be plugged into the real robot as stated in the "Control of a FANUC Robotic arm using MATLAB manual" [24] An example of this can be found in "Modeling and analysis of a 6 DOF robotic arm manipulator" [9]

7.3 Robot configurations

As mentioned before, a 6 DOF manipulator can reach the same position in multiple configurations. The different configurations in the solutions can be seen in the example of the FANUC robot arms (see figure 7.2)

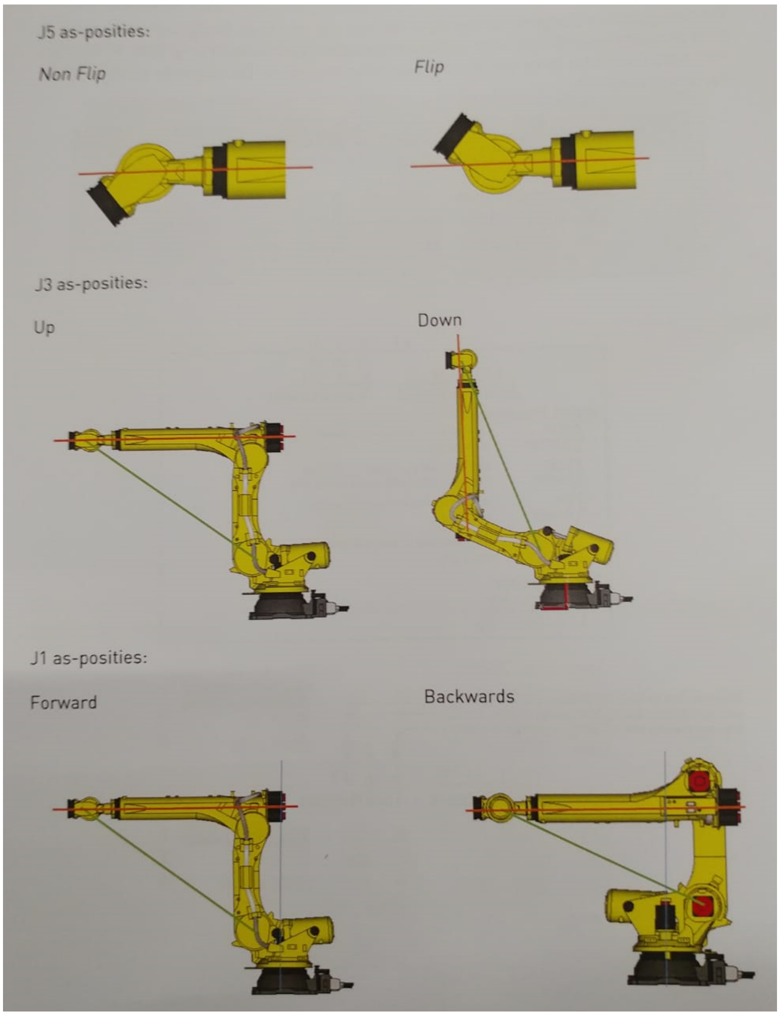

Figure 7.2: 6 axis robot configurations on the example of a FANUC Robot [3]

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Appendices

A. Appendix 1

B. Appendix 2

C. Robot Quick start guide

A big part of this was derived from [25].

3.0.1 Parts of the robot

A quick overview over the visible parts.

FANUC R-2000iC/210F 6 axis robotic arm

The robot has 6 movable joints with a possible payload attached to the end. Its features include a wide reach (2655 mm), sturdy but flexible arm design, a spring loaded counterbalance, relatively high payload capacity (210Kg) and fast moving axes. The joints also have hashes to indicate the zero positions which help with the calibration of the robot.

R30iA Robot Controller

The Robot is controlled using an original equipment manufacturer controller called the FANUC R30iA controller. Its features include faster sustained speed and superior position accuracies. It also has the I/O ports that are used to connect grippers and other payloads. (It also houses the camera circuits which are required to access the data from the SONY camera provided with the robot. - Delta only) The controller is also provided with a data card slot in which the special SD cards manufactured can be inserted and used as external memory. On the outside of the controller (side of iPendant at Delta) a USB port can be found. With these, programs, firmware files and other files can easily be transferred. Additionally, there is extended connectivity via its Ethernet port e.g. for FTP available.

iPendant

The teaching pendant is the primary user interface to the robot. It is used to move the joints of the robot manually, to program specific trajectories, to control the gripper, and various other actions. It also is an interface that can be used for input and output of the robot controller parameters. The user can access the system variables and position variables. (It is provided with a USB port that can be used to connect to a USB drive for external storage. - Delta only) It can also be used to setup an FTP server and client in order to communicate with the PC.

Gripper

The robot as handed over does not have an active gripper system. It has been tested though with a pneumatic gripper controlled via the DO ports and pneumatic valves. A 2-way pneumatic valve, some piping and a pressure regulator are still available. (Delta Equipment varies here a lot).

3.0.2 iPendant Navigation Manual:

The teaching pendant is the primary user interface to the robot. This section deals with the important buttons on the TP.

Figure 3.1: Most important iPendant buttons numbered: This image from another iPendant than the ones available was chosen because of its labelling of buttons. Some buttons of the available iPendants are not labelled, so this picture can be used as a reference. Source: [25]

Emergency stop:

Makes the robot stop immediately by applying brakes. Use it only when necessary as the brakes wear down. There is also an E-stop on the controller. Press down on the button to activate it. Twist it to the right to release. If a slow and gradual halt is required, press HOLD on the iPendant. TP on/off Below the E-stop button. It should be ON to access any function in the Teach Pendant (Set-ups, calibration, programs etc) and OFF when running in AUTO mode. Deadman switch The 2 yellow bars behind the iPendant. 3 modes are available: Fully released, halfway pressed, fully pressed. Only the middle mode activates control.