Project Report*

*As a fulfilment to the course: "Project course name", D7039E & E7032E. Lecturer: Jan van Deventer.

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***Abstract*—**

I. Introduction

Background and motivation

Self explanatory.

Contributions

How does this report contribute. Are there any novel solutions?

Structure

The overall structure of the report [?]

II. Arrowhead

Arrowhead

What is it?

Extras

More in depth about the strucutre of the Arrowhead implementation. Flow diagrams etc.

III. Concept Design

Mechanical structure

The final design of the robot. Include CAD renderings etc.

Electrical components

Electrical components such as motors, MCUs etc. Why were they chosen

Requirements

IV. Communication

Communication

TTL, ROS, Arrow-¿Robot

V. Modeling

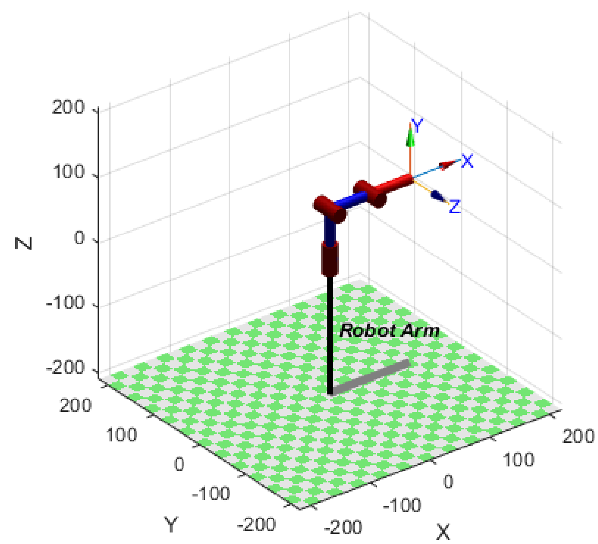

Fig. 1. Placeholder image for the robotic arm?.

Manipulator Kinematics

Kinematics is what describes the motion of rigid bodies and points in space.

Backgroud

Rigid body transformation

In general any position can be described by translation along three axes and rotation along these same axes. These translations/rotations can be described by a matrix

$$T = \begin{bmatrix} R & d \\ \mathbf{0} & 1 \end{bmatrix} \tag{1}$$

where R is a 3 x 3 rotation matrix and d a 3 x 1 translation matrix. This implies that any transformation could be characterized by six parameters, three for the translation and three for the rotation. [?]

Denavit-Hartenberg Convention

A common approach for selecting the coordinate frames of reference for each joint in a robotic arm is the Denavit-Hartenberg convention. This allows the transformation matrix for each joint to be expressed as

$$A_i = Rot_z(\theta_i) \cdot Trans_z(d_i) \cdot Trans_x(a_i) \cdot Rot_z(\alpha_i) \quad (2)$$

that consists of the four basic transformations

$$Rot_z(\theta_i) = \begin{bmatrix} cos(\theta_i) & -sin(\theta_i) & 0 & 0 \\ sin(\theta_i) & cos(\theta_i) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$Trans_z(d_i) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$Trans_x(\alpha_i) = \begin{bmatrix} 1 & 0 & 0 & \alpha_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

$$Rot_z(\theta_i) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos(\alpha_i) & -sin(\alpha_i) & 0 \\ 0 & sin(\alpha_i) & cos(\alpha_i) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (6)$$

Where the parameters θ_i, a_i, d_i and α_i, known as DH-parameters, characterize each joint. To allow the transformation for each joint to be represented by only four parameters, compared to the six parameters that is required in general, there are some restrictions on how the coordinate frames can be chosen. To comply with the DH-convention, the following must be satisfied.

- The axis x_1 is perpendicular to the axis z_0
- The axis x_1 intersects the axis z_0

where it is assumed that two frames are given, frame 0 and frame 1, and the transformation from equation **??** transforms a coordinate from frame 1 into a coordinate in frame 0. [**?**]

Kinematic Chain

A robotic manipulator can be described by a set of joints with links between them where a homogeneous transformation matrix A_i that describes the transformation with respect to the previous joint exists for each joint. This means that a transformation that describes the position and orientation of joint j with respect to a joint i to a can be found by a transformation matrix [**?**]

$$\begin{cases} T_j^i = A_{i+1}A_{i+2}...A_{j-1}A_j, \text{ if } i < j \\ T_j^i = I, \text{ if } i = j \\ T_j^i = (T_i^j)^{-1}, \text{ if } i > j \end{cases} \quad (7)$$

Forward Kinematics

Forward kinematics is the problem of finding the position and orientation of the end effector.

Since a manipulator can be seen as a kinematic chain the problem of finding the position and orientation of the end effector can be solved by finding the transformation matrices in equation **??**.

Inverse Kinematics

The problem of finding the joint states required for achieving a desired pose is called inverse kinematics. For some simple kinematic chains an analytical solution exists, but in general a numerical approach might be required.

Workspace

A robotic manipulator will not be able to reach all points in space since it has a fixed size. It will not even be able to reach all mathematically reachable points since each joint (usually) have some restrictions on how it can rotate/translate. The physically reachable space is defined as the workspace of the manipulator.

Implementation

Denavit-Hartenberg Convention

In table **??** the DH-parameters that was used for the robotic manipulator, seen in figure **??**, are listed.

TABLE I
THE DENAVIT-HARTENBERG PARAMETERS USED FOR THE ROBOTIC MANIPULATOR.

i	θ_i [rad]	d_i [mm]	a_i [mm]	α_i [rad]
1	θ_1	75	0	$\pi/2$
2	θ_2	0	67.5	0
3	θ_3	0	67.5	0
4	θ_4	0	65	0

Forward Kinematics

The transformation matrices from equation **??** for each joint can be multiplied together

$$T_{end} = A_1 \cdot A_2 \cdot A_3 \cdot A_4 \quad (8)$$

where A_1 - A_4 are calculated from equation **??** to find the pose T_{end} of the end effector and thereby solving the forward kinematic problem.

Inverse Kinematics

To solve the inverse kinematics for the position of a three joint manipulator a geometric method can be used to find an analytical solution. The required angles to achieve a desired position (x_d, y_d, z_d) in an elbow-up configuration are [**?**]

$$\begin{cases} \theta_1 = Atan(x, y) \\ \theta_3 = Atan(D, +\sqrt{1-D^2}) \\ \theta_2 = Atan(\sqrt{x_d^2 + y_d^2}, z_d - d_1) \\ -Atan(a_2 + a_3 \cdot D, a_3 \cdot \sqrt{1-D^2}) \end{cases} \quad (9)$$

where $Atan(x, y)$ is the two argument arctangent function [**?**] and

$$D = \frac{x_d^2 + y_d^2 + (z_d - d_1)^2 - a_2^2 - a_3^2}{2a_2a_3} \tag{10}$$

and a_2, a_3, and d_1 are the corresponding DH-parameters.

Workspace

The robotic manipulator seen in figure **??** has the following limitations for the first three joints

$$\begin{cases} -100° < \theta_1 < 100° \\ -100° < \theta_2 < 100° \\ -100° < \theta_3 < 100° \end{cases} \tag{11}$$

and a simulated 2D slice of the workspace can be seen in figure **??**. The full workspace can be formed by rotating this 2D slice around the z-axis according to the limitations on θ_1 from equation **??**.

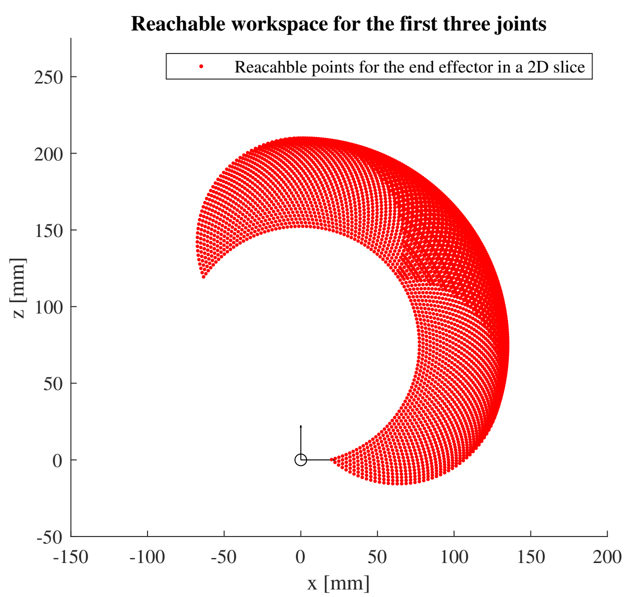

Fig. 2. A simulated 2D slice of the workspace for the three jointed manipulator.

BASE

CAMERA VISION AND CALIBRATION

In this section it is outlined the theory behind the camera vision system. How points in a 3D-space are projected on a 2D-plane, calibration and distortion correction.

Camera model

Distortion

VI. MACHINE VISION

LINE FOLLOWING

QR-CODES READING

DEEP LEARNING?

VII. MOTION

ROBOT ARM

BASE

VIII. EXPERIMENT

PROTOTYPE COMPONENTS

Overview of what is being used in the evaluation

MOVABLE BASE EVAUATION

ARM EVALUATION

GRIPPING EVALUATION

SENSOR EVALUATION

ARROWHEAD EVALUATION

IX. CONCLUSIONS

Conclusions of the robot and the course (?) Is our design good? Is Arrowhead good?

CONCEPTUAL DESIGN

APPENDIX

MARTIN BLASZCZYK

Martin is a 5th year Y-student with interest in Control och Mechatronics. In this course he'll take the role of the Project Leader where the main objectives are to keep focus on the goal, hold meetings and an overall oversight of the project. As for the technical part the main interest will be in machine vision together with Edward K. to use cameras or other sensors to localize external objects for the robot to grip, avoid or approach.

EDWARD CEDGÅRD

Master in electronic systems and control engineering. Edward's main task is to design the robotic arm and gripper mechanism together with Niklas. Tasks as deriving the kinematic equations, and implementation using forward and inverse kinematics. Choise of motors, armdesign, communication with motors using serial communication.

NIKLAS DAHLQUIST

Niklas is studying his fifth year at the Engineering physics and electrical engineering student program.

His main focus will be to work with Edward Cedgård to evaluate the gripping mechanism and if necessary design new components and model the corresponding control system to be able to lift up and hold the target object.

EDWARD KÄLLSTEDT

Currently studying his fourth year in the Master Programme in Computer Science and Engineering. A fan of making things secure, fast, scalable, and well-documented. Primarily interested in low level software development. Will initially work on the machine vision implementation together with Martin. In addition to machine vision specifically this work will also consist of robot localization and collision avoidance. As the project progresses he will take on more general software problems that might arise. The first week will be spent researching different computer vision technologies.

ALBIN MARTINSSON

Albin is a 5th year computer science student specializing in industrial computersystem. In this project he will be focusing on the arrowhead integration and bein charge of the Github repository. This will entail connecting all the services toeach other and making sure they are authenticated and secure. Being in chargeof the git repository will entail merging pull requests and sorting out conflicts, making sure that the version control part of this project runs smoothly.

MÅNS NORELL

Studying for a master in electronic systems and control engineering. Måns main task is to design the base and line-following controller for moving the robot along a line. Tasks include designing the base, printing the specialized parts, simulating and testing the base. Communication between controller, motor and camera will be worked on in collaboration with those in charge of these tasks.

PROJECT STRUCTURE

To keep the project going and have an organized structure the project is divided in different parts, or subprojects. Each group member is either alone or in group responsible for each part of the project which coincides with their interests.

- Arrowhead
- Machine vision and localization of external objects
- Gripping tool
- Movable base

MEETINGS

Every week the group will be meeting on Mondays and Tuesdays to catch up and support each other. This scheme may change in the future if needed. The Monday meetings will have the following agenda where the goal is to catch up with the whole project group and discuss the project

- Status of work done the previous week by each member
- Preparation for the seminar
  - Discussion of the previous seminar meeting
  - How the weeks work has been coinciding with the seminar feedback
  - Questions to ask the teachers
  - Questions to ask the other group
  - Who does what during the Tuesday seminar
- Other

The Tuesday meeting will be after the seminar to collect and reflect over the feedback from the teachers and the other group. Also a status on the work planned to be done the coming week will be discussed so that each member has an overview of what the other members are doing. The meetings will have the following agenda

- What feedback did the teachers give
- What feedback did he other group give
- Feedback to each other withing the group
- Work to be done the following week
- Other

As mentioned, this meeting structure may be subject to changes if needed and of course if any member of the group wants to work from home a video call will be organized.