Requirements specification
Modeling and control of an industrial robot

Version 1.2

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Document History

Version	Date	Changes made	Sign	Reviewer
0.1	2011-09-14	First draft.	AP	Patrik Axelsson
0.2	2011-09-15	First revision.	AP	Patrik Axelsson
0.3	2011-09-16	Second revision.	AP	Mikael Norrlöf
0.4	2011-09-20	Third revision.	AP	Mikael Norrlöf
0.5	2011-09-21	Fourth revision.	AP	Patrik Axelsson
1.0	2011-09-22	First version.	AP	Patrik Axelsson
1.1	2011-11-04	Second version.	AP	Mikael Norrlöf
1.2	2011-11-23	Third version.	AP	Patrik Axelsson

Contents

1 Introduction

This document is a summary of the requirements of the system that is to be implemented, a model and a control system for an industrial robot. A picture of the robot and the control electronics can be seen in figure 1.

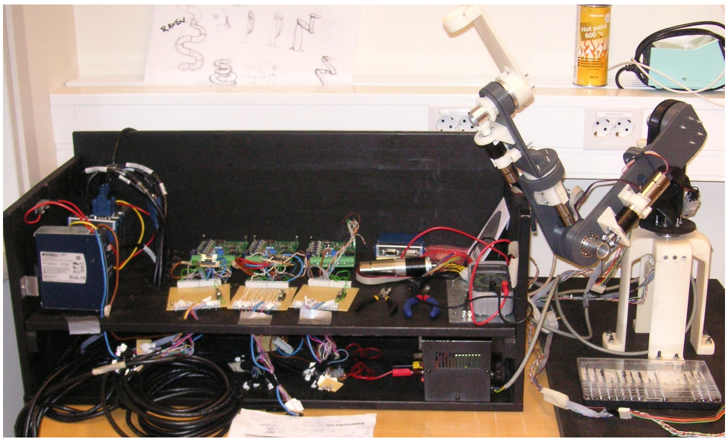

Figure 1: A picture of the robot and the control electronics.

The robot is supposed to go from one set of arm angles to another, and go linearly from point A to point B. This will be achieved by modeling the robot dynamics and implement a control system.

1.1 Parties

The customers for this system is Mikael Norrlöf, ABB Robotics and Johan Sjöberg, ABB Corporate research. Orderer of the project is Patrik Axelsson, Department of Electrical Engineering (ISY) at Linköping University. Advisor for the project is André Carvalho Bittencourt, ISY. The project members are students at Linköping University in the course TSRT10, Control project laboratory.

1.2 Purpose and objectives

The purpose of this course is to learn how to work in a project using a project model. The objectives of the project are to model and control a miniature industrial robot and to write technical documents for it. The results of this work can hopefully be used in future student projects. The requirements in this document are developed from the project directives [1].

1.3 Appliance

If the outcome of this project is particularly good, the system can be used in future projects in this course, e.g. by placing the robot on a moving platform.

1.4 Background

The robot used in this project was constructed by mechanical engineering students in a previous project course. A very simple control system was implemented and the objective for this year's project is to improve it. This project is divided into two parts: first modeling of the robot dynamics and control system, then implementing this on the real robot. The project group consists of students from the mechanical engineering and electrical engineering programs, thus the competence in the group includes mechanics, automatic control, signal processing, programming, modeling and simulation etc.

1.5 Definitions

The system requirements will be presented in tables similar to the one below. Priorities are numbered as 1, 2 or 3. Priority 1 means that this requirement is mandatory and must be included in the delivery. Priorities 2 and 3 are optional, and will be performed if time allows it.

Requirement nr x	**Changes**	Description	Priority

2 Overview of the system

In figure 2 an overview of the system is presented. The system consists of a miniature industrial robot connected to a computer via control electronics.

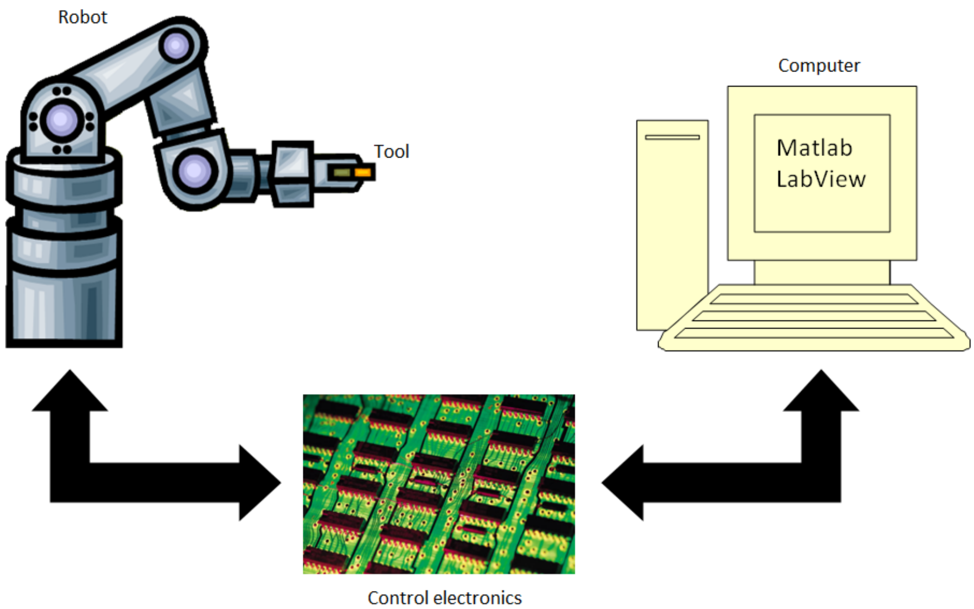

Figure 2: An overview of the system.

2.1 General description of the product

The product consists of a control system for the robot and a model of the robot mechanics. The model will be used to test the control system, and can also be used to implement more advanced control strategies, such as LQ, IMC, MPC etc. The control system should be able to control the robot according to the requirements given later in this document.

2.2 Components

The following components will be included in the *product*.

- Kinematic model
- Flexible dynamic model
- Control system
- User interface
- User guide

Apart from these components, the *project* will result in the following things.

- Technical report
- Poster
- Web page
- Film presentation on YouTube
- Oral presentation

2.3 Dependency of other systems

The product is dependent on the hardware developed in a previous student project. A part of this project is to suggest improvements of the current hardware.

2.4 Subsystems

The system is divided into the following subsystems.

- Subsystem 1 - Robot connected to a computer with a Labview interface.
- Subsystem 2 - Models.
- Subsystem 3 - Control system.

2.5 Limitations

The robot has three degrees of freedoms.

2.6 General requirements

In this section, the general requirements for the project will be listed.

Requirement nr 1	**Original**	The project shall follow the LIPS model [2].	1
Requirement nr 2	**Original**	The following roles in the project group shall be appointed: project manager, document manager, design manager (mechanical and control), test manager and information manager.	1
Requirement nr 3	**Original**	A model of the robot shall be designed.	1
Requirement nr 4	**Original**	A control system for the robot shall be designed.	1
Requirement nr 5	**Original**	Potential deficiencies found in the current construction shall be reported in the technical report.	1
Requirement nr 6	**Original**	Suggestions of improvements to the deficiencies shall be reported in the technical report.	2

3 Subsystem 1 - Robot connected to a computer with a Labview interface

The robot and Labview interface are already implemented, but is considered to be a subsystem in this project by obvious reasons.

Requirement nr 7	**Original**	The robot shall be connected to a computer with a Labview interface for control of the motors.	1
Requirement nr 8	**Original**	The control system, model and plot tools will be implemented in Matlab/Simulink and linked with Labview if possible, otherwise they will be implemented directly in Labview.	1

4 Subsystem 2 - Models

In this section the requirements for the kinematic and dynamic models are presented. The models will be used to test the control system before it is implemented on the real robot. Furthermore, if model based control strategies are to be used, the models will be included in the control system.

Requirement nr 9	**Original**	A kinematic model with three degrees of freedom shall be developed, according to equations (1) and (2).	1
Requirement nr 10	**Original**	The kinematic model shall consist of the forward (1) and inverse (2) kinematics.	1
Requirement nr 11	**Original**	A flexible dynamic model shall be developed, according to (3).	1
Requirement nr 12	**Original**	The robot arms shall be modeled as rigid bodies.	1
Requirement nr 13	**Original**	The flexibilities of the gear boxes shall be linearly modeled.	1
~~**Requirement nr 14**~~	**Removed in version 1.2**	~~The parameters for the flexibilities shall be determined by performing experiments.~~	~~1~~
Requirement nr 15	**Original**	The friction in the joints shall be linearly modeled.	1
Requirement nr 16	**Original**	The friction parameters for the joints shall be determined by performing experiments.	1
Requirement nr 17	**Original**	The models shall be implemented in Matlab/Simulink.	1
Requirement nr 18	**Original**	The models shall be validated according to the test plan.	1
Requirement nr 19	**Original**	The flexibilities of the gear boxes shall be nonlinearly modeled.	2
Requirement nr 20	**Original**	The friction in the joints shall be nonlinearly modeled.	2
Requirement nr 21	**Original**	The backlashes in the gearboxes shall be modeled.	3

The forward kinematics is a model that calculates the tool position from the arm angles

$$X = \psi(q), \tag{1}$$

where q are the arm angles and X the tool coordinates. The inverse kinematics is a model that calculates the arm angles from the tool position,

$$q = \psi^{-1}(X). \tag{2}$$

The flexible dynamic model is on the form

$$M(q)\ddot{q} + C(q,\dot{q}) + G(q) + D(\dot{q}) + K(q) + F(\dot{q}) = \tau, \tag{3}$$

where q are the arm and the motor angles, M is the joint-space inertia matrix, C includes Coriolis and centrifugal forces, G includes external forces (gravity), D includes damping, K includes spring forces and F includes friction. τ is the applied torque [3].

5 Subsystem 3 - Control system

The requirements for the control system are listed below. The control system shall be able to move the robot from one set of arm angles to another, and to move the tool from point A to point B in fixed room coordinates.

Requirement nr 22	**Changed in version 1.1**	The robot joints can be controlled manually from the graphical user interface with a reduced speed (25 % of automatic).	1
Requirement nr 23	**Original**	A graphical user interface for the manual and automatic control shall be implemented.	1
Requirement nr 24	**Original**	A controller and a model for converting the desired torque to the corresponding voltage/current for the motors shall be implemented.	1
Requirement nr 25	**Original**	The control system shall be able to move the robot from one set of arm angles to another set of arm angles.	1
Requirement nr 26	**Original**	The control system shall be able to move the tool linearly from point A to point B in room coordinates.	1
Requirement nr 27	**Original**	A limitation for the applied torque on the motors shall be implemented in the control system.	1
Requirement nr 28	**Original**	The control system shall be implemented in Matlab/Simulink.	1
Requirement nr 29	**Original**	The overshoot for a step in desired joint angle shall not exceed 10 % when using maximum speed.	1
Requirement nr 30	**Original**	The stationary error for the joint angles shall not exceed 10 %.	1
Requirement nr 31	**Original**	For steps in the desired joint angles, the user shall be able to choose the maximum rotational speed for the joints, up to 1 rad/s.	1
Requirement nr 32	**Original**	The overshoot for a movement from A to B shall not exceed 10 % of the distance moved when using maximum speed.	1
Requirement nr 33	**Original**	The stationary error for the position shall not exceed 10 %.	1
Requirement nr 34	**Original**	The user shall be able to choose the maximum speed from point A to B, up to at least 10 cm/s.	1
Requirement nr 35	**Original**	The control system shall be tested according to the test plan.	1

Requirement nr 36	**Original**	The overshoot for a step in desired joint angle shall not exceed 5 % when using maximum speed.	2
Requirement nr 37	**Original**	The stationary error for the joint angles shall not exceed 5 %.	2
Requirement nr 38	**Original**	The overshoot for a movement from A to B shall not exceed 5 % of the distance moved when using maximum speed.	2
Requirement nr 39	**Original**	The stationary error for the position shall not exceed 5 %.	2
Requirement nr 40	**Original**	The robot shall be able to be controlled manually with a joystick with a reduced speed (25 % of automatic).	2
Requirement nr 41	**Original**	More than one control strategy shall be implemented and evaluated.	2
Requirement nr 42	**Original**	The control system shall be able to move the tool from point A to point B in a given nonlinear trajectory.	2
Requirement nr 43	**Original**	The robot shall be controlled by voice control.	3

6 Economy

Apart from the requirements below, the project will have a part in a room at ISY with two computers, a part in a laboratory at IEI where the robot is located, guidance of hardware at IEI and two laptop computers.

Requirement nr 44	**Original**	Every project member shall work a maximum of 240 hours in this project.	1
Requirement nr 45	**Original**	The group has 30 hours of advising time available.	1

7 Deliveries

The project consists of the following deliveries. Dates for the deliveries are specified after agreement with the orderer.

Requirement nr 46	**Original**	The requirements specification, project plan with time plan and system sketch shall be delivered at BP2, 2011-09-22.	1
Requirement nr 47	**Original**	Design specification and test plan shall be delivered at BP3, 2011-10-10.	1
Requirement nr 48	**Original**	Product, user guide and test protocols shall be delivered at BP5, 2011-11-25.	1
Requirement nr 49	**Original**	Technical report, after study, poster, website and film presentation shall be delivered at BP6, week 49.	1

8 Documents

In the table below, all documents in the project are listed.

Document	Language	Description	Target group	Format
Requirements specification	English	Defines the requirements on the system.	Project group, customer and orderer.	PDF
System sketch	English	Gives a brief description of the system.	Project group, advisor and orderer.	PDF
Project plan with activity list	English	A plan for how the project will be executed.	Project group and orderer.	PDF
Time plan	Swedish	A plan for the time disposal in the project.	Project group and orderer.	Excel
Test plan	English	A plan for how the tests will be executed.	Project group, advisor and orderer.	PDF
Design specification	English	Describes the design of the system in more detail.	Project group, advisor and orderer.	PDF
Test protocols	English	The results from the tests.	Project group, advisor and orderer.	PDF
Meeting protocols	Swedish	Protocols for the weekly meetings.	Project group and orderer.	PDF
User guide	English	Describes how to use the system.	User (customer).	PDF
Technical report	English	Describes how the system is designed and implemented.	Customer.	PDF
After study	Swedish	An evaluation of the project.	Examiner and future students.	PDF

Requirement nr 50	**Original**	All documents shall follow the LIPS standard [2].	1
Requirement nr 51	**Original**	All documents (except the time plan) shall be written in LaTeX.	1
Requirement nr 52	**Original**	All documents shall be handed in before deadline.	1

References

[1] Axelsson, Patrik, *Projektdirektiv*. Division of automatic control at LiTH, Linköping, 2011.

[2] Svensson, Tomas & Krysander, Christian, *Projektmodellen LIPS, Version 1.3*. LiTH, Linköping, 2007.

[3] Craig, John J., *Introduction to robotics: Mechanics and control*. Pearson Education, 3rd Edition, 2005.