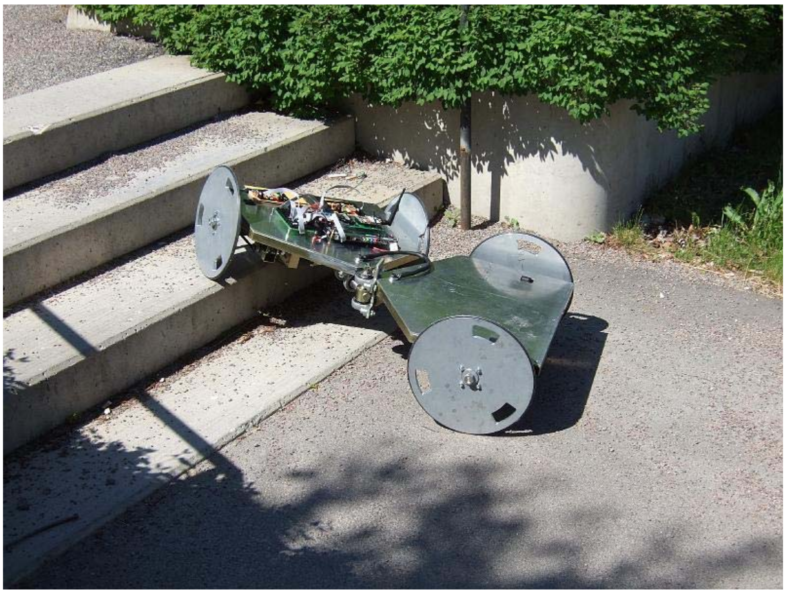
Team MinMyra



Introduction

The MinMyra project has been developed by 4 students as a final project during the spring before doing their master thesis. The project is at the division of Fluid and Mechanical Engineering Systems (FluMeS) at Linköpings University, Linköping Sweden.

The MinMyra is a prototype platform that focuses on mechanical stability to ensure the safety of the platform and its cargo. The platform is made as a welded frame, powered by step engines and controlled by a FPGA (Field Programmable Gate Array). The parts are manufactured from standard parts, easy obtainable and low in cost. The platform shall in future studies carry sensor systems to learn to navigate and detect the surrounding environment.

The purpose of the robot is to build a stable autonomic platform that can safely travel from A to B. It shall be stable enough to carry expensive sensors and electronics. The usage of this sort of robot is in environments where it’s dangerous for humans to be, i.e. minefields, mines and contaminated environments as accidents and nuclear facilities. With the right sensors it’s a cheap way to solve problems in those areas.

Mechanical design

A mechanical model was developed to describe the movement of the robot. From this model was a robot built. Al the mechanics was drawn in pro/ENGINEER wildfire and produced locally at the university. The mechanics is described in teknisk_dokumentation.pdf. Much care was focused on getting a stable and durable platform.

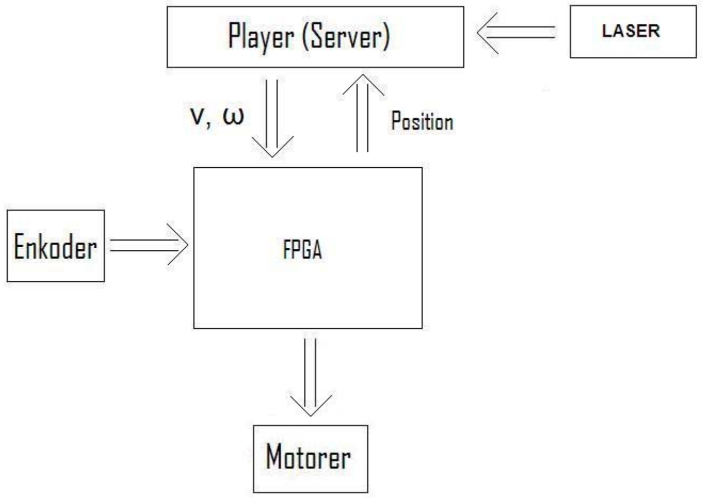
Electronic and software design

The FPGA have a number of support systems, i.e. amplifying the motor control signals or transforming the signals from the wheel encoders. The circuit boards were designed by us.

The FPGA had multiple responsibilities.

- Sending and receiving information with a computer according to player standard interface.
- Calculate wheel velocities according to the received information.
- Transform the velocities to control signals for the stepper motors. This is made by a VHDL block.
- Calculating the distance travelled by each wheel according to encoder data. This is also made by a VHDL block.
- Calculating the position of the robot depending on how long the wheels have travelled and sends it to the player computer.

A schematic picture of the system is shown below.



LASER

A LASER sensor was mounted on top of the robot which gave the robot a possibility to detect and avoid the environment. The LASER was connected to the player computer and the host program sent information to the FPGA to control the robot.

Result

The robot was made and it works very well, it is able to detect and avoid obstacles in a non static environment. Today the robot can not detect mines but with right added sensors it can help with the detection of those. The robot shows that it’s possible to build a platform with limited budget, small means and an ordinary workshop.

The robot is 1000x600x300 mm and weighs approximately 25 kg. The travelling speed of the robot is 4 km per hour. The work was presented and a demonstration was made of the robot at “hydraulikdagarna”, a conference at the university held by FluMeS.

Technical Documentation

Johan Vestman

Version 1.0

Status

Granskad		
Godkänd		

PROJEKTIDENTITET

MinMyra 07
Linköpings tekniska högskola, IEI

Namn	Ansvar	Telefon	E-post
Patrik Stener	Projektanansvarig	0702-268039	patst577@student.liu.se
Johan Vestman	dokumentansvarig	0707-518125	Johve944@student.liu.se
Patrik Sjöberg	designansvarig	0733-263676	patsj733@student.liu.se
Erik Moqvist	testansvarig	0702-775832	erimo144@student.liu.se

E-postlista för hela gruppen tmms06_minmyra@listserv.ikp.liu.se

Kund: FOI, Linköping
Kontaktperson hos kund: Jonas Nygårds
Kursansvarig: Karl-Erik Rydberg, 013-281187, karry@ikp.liu.se
Handledare: : Magnus Sethson, 013-282733, magnus.sethson@liu.se

Contents

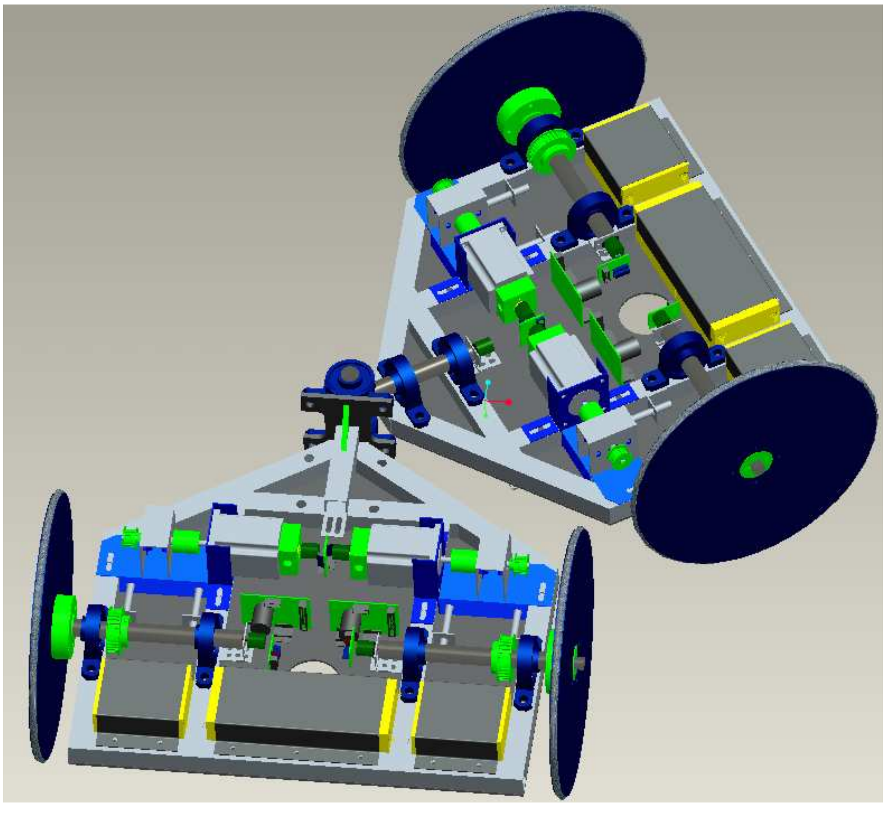
Document history

version	date	Changes	made by	reviewed
1.0	2004-05-07	First version	JV	

1. System overview

1.1. Mechanics

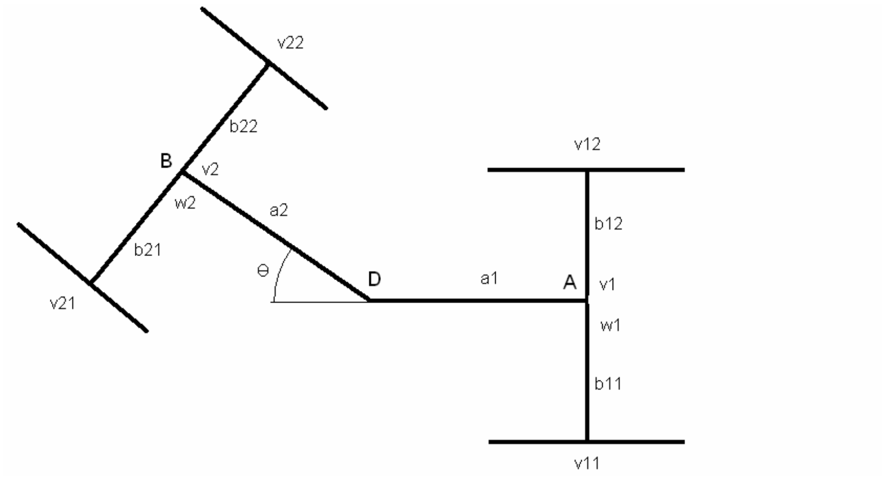
In figure 1 below you can se an overview of the underside of the robot. It shows the cargo bay for the batteries, the wheel axis, the motor block and the mid joint. You can also se the aluminium surface that will be used to attach electronics and our high precision wheels.



Figur 1, overview of the robot

1.2. Mechanical model

We have assumed that the robot is moving on a non slippery surface. The control parameters are V_1 and ω_1 and they will be set by the main program. With this we calculate the speed of the front wheels, v_{11} and $v_{12,}$ see figure 2. The mid joint centre of rotation D will decide what speed the rear wheels, v_{21} and $v_{22,}$ have to be. The v_{21} and v_{22} is a slave system to v_{11} and v_{12}.



Figur 2, Geometric description

In figure 2 above:

Name	Description	SI-Unit
V_1, V_2	Speed of the axis centers.	m/s
ω_1, ω_2	Angle velocity of the axis mid points.	rad/s
b_{11}, b_{12}, b_{21}, b_{22}	Distance from the wheels to the centre of the axis.	m
a_1, a_2	Distance from the mid joint centre of rotation to the front and rear axis.	m
v_{11}, v_{12}, v_{21}, v_{22}	Speeds on the wheels.	m/s
θ	Angle of the mid joint.	rad

The mean speed and the angular velocity at point A (Figure 2) is calculated as:

$$v_1 = \frac{v_{11}b_{12} + v_{12}b_{11}}{b_{11} + b_{12}} \quad \omega_1 = \frac{v_{11} - v_{12}}{b_{11} + b_{12}}$$

$$\begin{bmatrix} v_1 \\ \omega_1 \end{bmatrix} = \frac{1}{b_{12} + b_{11}} \begin{bmatrix} b_{12} & b_{11} \\ 1 & -1 \end{bmatrix} \begin{bmatrix} v_{11}) \\ v_{12} \end{bmatrix} \Rightarrow \begin{bmatrix} v_{11} \\ v_{12} \end{bmatrix} = \begin{bmatrix} v_1 \\ \omega_1 \end{bmatrix} \begin{bmatrix} 1 & b_{11} \\ 1 & -b_{12} \end{bmatrix}$$

The velocity of the midpoint D must be the same for both the front part and the rear.

$$V_{D1} = R(\theta) \begin{bmatrix} 1 & 0 \\ 0 & -a_1 \end{bmatrix} \begin{bmatrix} v_1 \\ \omega_1 \end{bmatrix} \qquad V_{D2} = \begin{bmatrix} 1 & 0 \\ 0 & a_2 \end{bmatrix} \begin{bmatrix} v_2 \\ \omega_2 \end{bmatrix}$$

$$R(\theta) = \begin{bmatrix} \cos(\theta) & \cos(90-\theta) \\ -\cos(90-\theta) & \cos(\theta) \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}$$

$$V_{D2} = V_{D1}$$

$$\begin{bmatrix} 1 & 0 \\ 0 & a_2 \end{bmatrix} \begin{bmatrix} v_2 \\ \omega_2 \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & -a_1 \end{bmatrix} \begin{bmatrix} v_1 \\ \omega_1 \end{bmatrix}$$

$$\begin{bmatrix} v_2 \\ \omega_2 \end{bmatrix} = \frac{1}{a_2}\begin{bmatrix} a_2 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}\begin{bmatrix} 1 & 0 \\ 0 & -a_1 \end{bmatrix}\begin{bmatrix} v_1 \\ \omega_1 \end{bmatrix}$$

In this case v_{11} and v_{12} is the measured velocities on the front wheel axis, that gives a master slave system.

$$v_2 = \frac{v_{21}b_{22} + v_{22}b_{21}}{b_{21} + b_{22}} \; , \; \omega_2 = \frac{v_{21} - v_{22}}{b_{21} + b_{22}} \; , \; v_1 = \frac{v_{11}b_{12} + v_{12}b_{11}}{b_{11} + b_{12}} \; , \; \omega_1 = \frac{v_{11} - v_{12}}{b_{11} + b_{12}}$$

$$\frac{1}{b_{21} + b_{22}}\begin{bmatrix} b_{22} & b_{21} \\ 1 & -1 \end{bmatrix}\begin{bmatrix} v_{21} \\ v_{22} \end{bmatrix} = \frac{1}{a_2}\begin{bmatrix} a_2 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}\begin{bmatrix} 1 & 0 \\ 0 & -a_1 \end{bmatrix}\frac{1}{b_{11} + b_{12}}\begin{bmatrix} b_{12} & b_{11} \\ 1 & -1 \end{bmatrix}\begin{bmatrix} v_{11} \\ v_{12} \end{bmatrix}$$

$$\begin{bmatrix} v_{21} \\ v_{22} \end{bmatrix} = \frac{b_{21} + b_{22}}{a_2(b_{11} + b_{12})(-b_{22} - b_{21})}\begin{bmatrix} -1 & -b_{21} \\ -1 & b_{22} \end{bmatrix}\begin{bmatrix} a_2 & 0 \\ 0 & 1 \end{bmatrix}\left[\begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}\right]\begin{bmatrix} 1 & 0 \\ 0 & -a_1 \end{bmatrix}\begin{bmatrix} b_{12} & b_{11} \\ 1 & -1 \end{bmatrix}\begin{bmatrix} v_{11} \\ v_{12} \end{bmatrix}$$

$$\begin{bmatrix} v_{21} \\ v_{22} \end{bmatrix} = \frac{1}{a_2(b_{11} + b_{12})}\begin{bmatrix} a_2 & b_{21} \\ a_2 & -b_{22} \end{bmatrix}\left[\begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}\right]\begin{bmatrix} b_{12} & b_{11} \\ -a_1 & a_1 \end{bmatrix}\begin{bmatrix} v_{11} \\ v_{12} \end{bmatrix}$$

Summary:

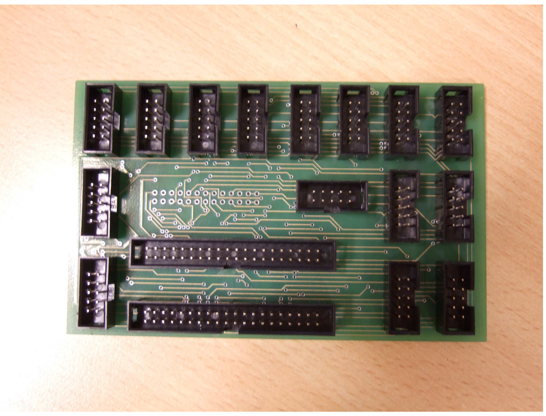
$$\begin{bmatrix} v_{11} \\ v_{12} \end{bmatrix} = \begin{bmatrix} 1 & b_{11} \\ 1 & -b_{12} \end{bmatrix}\begin{bmatrix} v_1 \\ \omega_1 \end{bmatrix}$$

$$\begin{bmatrix} v_{21} \\ v_{22} \end{bmatrix} = \frac{1}{a_2(b_{11} + b_{12})}\begin{bmatrix} a_2 & b_{21} \\ a_2 & -b_{22} \end{bmatrix}\left[\begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}\right]\begin{bmatrix} b_{12} & b_{11} \\ -a_1 & a_1 \end{bmatrix}\begin{bmatrix} v_{11} \\ v_{12} \end{bmatrix}$$

1.3. Electronics

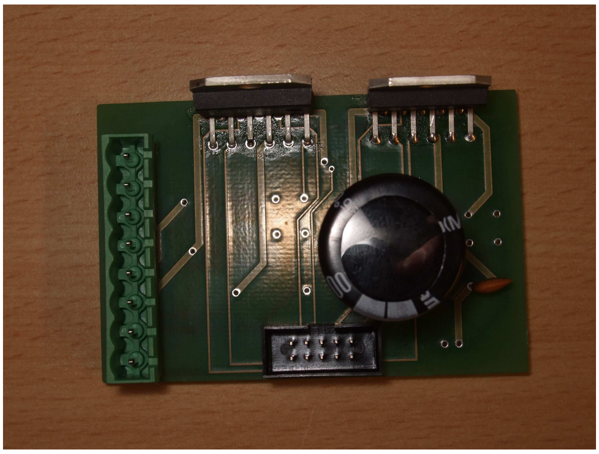
All the circuit boards are designed in a freeware called Eagle. The robot has three basic circuit boards. All circuit diagrams can be found in the Board map in the document files.

The IO board is for the signal routing between the FPGA and the motors and the sensors.



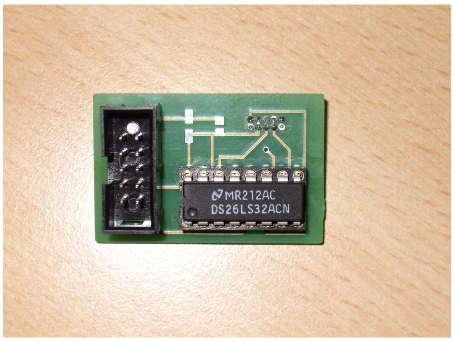
Figur 3, IO board

The stepper motor board is based on a LMD 18200 circuit. It's a circuit that can be used for direct control and power drive for a stepper motor. The circuit can deliver 3 Ampere at continues drive and 6 ampere at peak power and that's enough for our motors. The voltage span is +12 to + 55 volt and we have chosen to run at 36 volt to the motors.

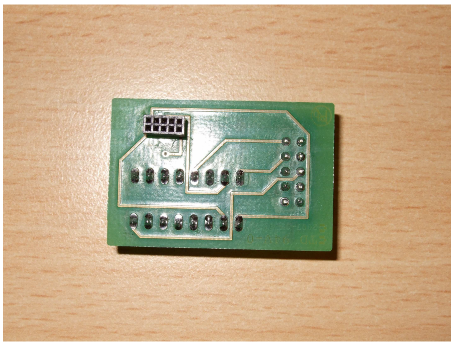


Figur 4, Stepper motor board

The sensor board is based on a DS26LS32. The DS26LS32 is a quad differential line receiver for data transmission. This circuit was recommended by Avago for the encoders. It transforms a differential signal to an absolute signal.



Figur 5, Sensor board circuit



Figur 6, sensor connection

Optocoupler is may be needed between the FPGA and the motor board. This is to ensure that the signals get a correct ground. We have used the Optocoupler bought from ELFA. The circuit board is handmade.

A 9 voltage DC supply is made to power the optocouplers and the wireless RS232.

1.4. Field Programmable Gate Array

A Field Programmable Gate Array or FPGA is a board with programmable connections and logic components. We have an Altera DE2 development and education board that includes:

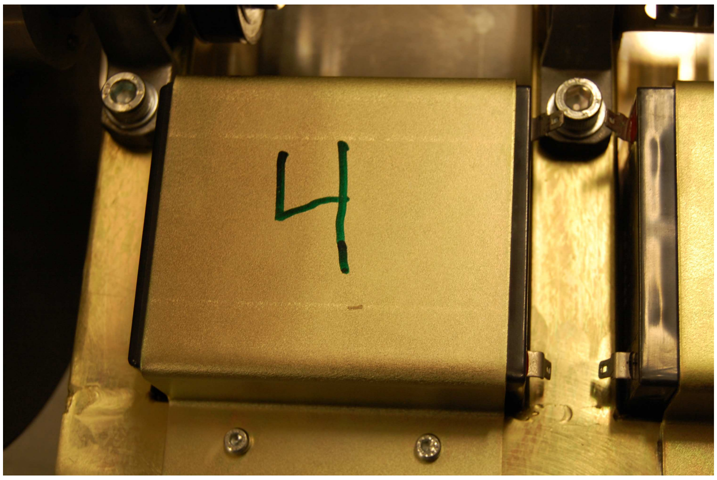
- Altera Cyclone II (2C35).
- 16Mbit Serial configuration device for AS mode.
- Built-in USB blaster with enhanced API link IP
- TV decoder for NTSC/PAL
- 24-bit CD-quality audio codec
- VGA DAC
- USB host and device
- Ethernet 100/10Mbps
- SRAM, SDRAM Flash SD card connector.
- RS232, IrDA, PS/2

1.5. Motors

The motors that are used are stepper motors called KH56QM-961, sold by Aratron. It's a two phase stepper motor, bipolar with a double axis. The motor uses 200 steps per round. The motors are magnetic balanced and a stepper motor is a good choice if you want to have good position accuracy. The stepper motor also has high torque at low speed. The double axis is needed to attach the sensor. The main issue with these motors is vibrations and noise at low speed. The solution to this is to use micro steps but we have used half steps in our control of the motor so we get vibrations. We also had to make a sensor holder and used epoxy glue to attach it to the motor because there was no drilled holed on the back of the motor, see Figure 11, number 7.

1.6. Batteries

The batteries are a 12 voltage 2,9Ampere lead-accumulator bought at Biltema. We use six batteries to create two 36 voltage batteries for the motors and a single battery for the FPGA. There are a total of eight batteries on the robot, but only seven is used so there is one extra battery for future use. The batteries are mounted under the robot in a cargo bay.
The battery holder is handmade, a basic sketch is found in the solid models in pro engineer.



Figur 7, single battery.

1.7. Encoder

The encoder AEDA-3300-TAQ from Avago is a miniature high resolution encoder. The resolution is spanning from 600 to 20000 CPR depending on the model. It's one of the smallest high performance encoders on the market. The one we choose have 4000 CPR. We have a total of 10 encoders possible to use on the robot.

1.8. Programming

The processor on the FPGA that we have defined does the calculations for the speed for the different wheels. The programming language is C. All the calculations about the position is made on the FPGA. All the related files are found on the presentation CD.

We use VHDL for programming the motor control and to translate information from the encoders.

We use serial transmission of data that we transfer with a wireless connection

A limitation is the minimum turning radius gives the constraints for the velocity V and ω. If we assume that the distance between the mid joint and the both wheel axis is the same and the max angle is 60 degrees then:

$$\tan\left(\frac{180-\theta}{2}\right) = \frac{r}{a_1}$$

$$r = a_1 \tan\left(\frac{180-\theta}{2}\right) = \left|\begin{matrix}\theta = 60 \\ a_1 = 0.352\end{matrix}\right| = 0.61 \text{ Meter.}$$

We round that number upwards so the limitation in turning radius gives that the quote $\frac{V}{\omega} \geq 0.65$, where V and ω are the control parameters.

1.9. Player driver

The control on the PC side is implemented as a player driver. Player is an interface to communicate with other robots and it's easy to build more modules to the robot such as a laser module.

2. System modules

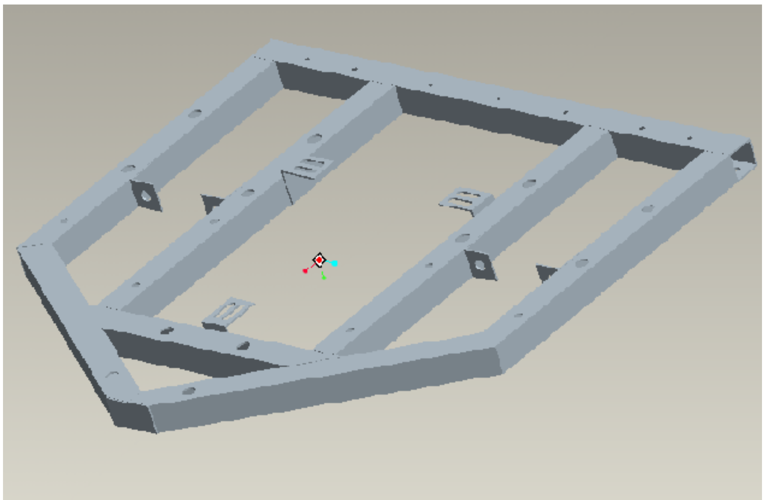
2.1. Framework

The robot two frames are made of welded square pipes. The framework ensures a stiff and lightweight construction. An overview of one of them is shown in figure 8.
The drawings for the pipes are found in drawing_23, drawing_24, drawing_25, drawing_26, drawing_28, drawing_29 and drawing_30.

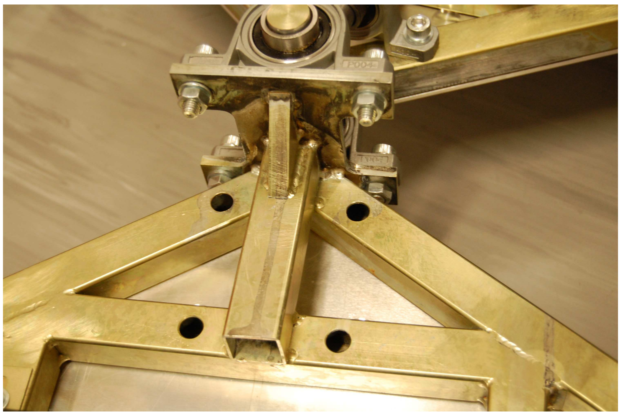
In figure 9 the mid joint welding is shown, and in figure 10 a cover plate is welded instead of the vertical bearing holder. The plate in figure 10 is found in drawing_20.

The L-brackets for the encoders and the belt drive is found in drawing_14 and drawing_15 and welded to the frame.

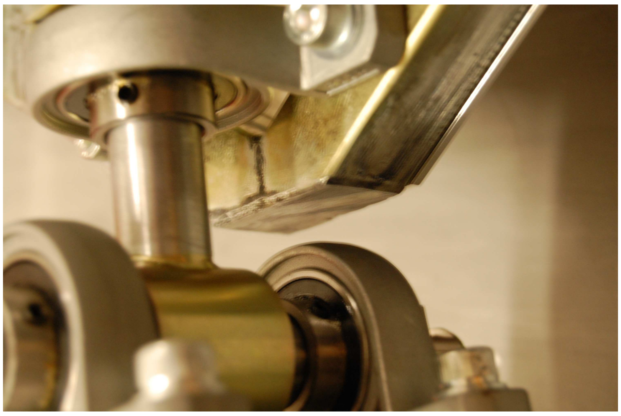
All the drilling is made when the frame is manufactured to ensure that all the holes have the correct distances between each other. The drilling and the placement of the L-brackets are found in drawing_31. To mount the motor block and the bearing housings we use flat head rivet nut in the 11.1mm and 7mm drilled holes. These shall be mounted on the opposite side of the bearings and motor block.



Figur 8, A welded frame



Figur 9, Midjoint welding



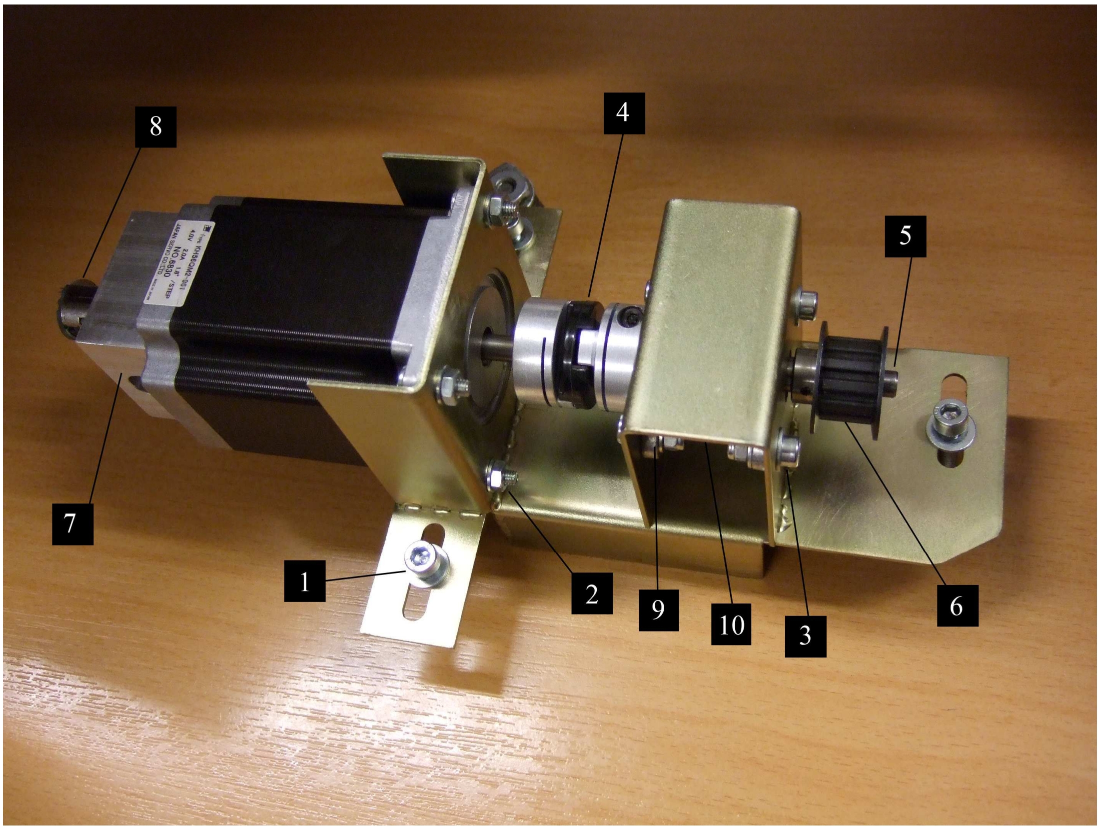
Figur 10, Mid joint welding

2.2. Aluminum plate

The top of the robot is a 3 mm plate that is screwed to the frame with slotted countersunk screw M4-6. On its surface the FPGA and the IO-board are mounted and under the plate the stepper motor boards are mounted. The plate is found in drawing_1. The two parts of the robot shall be connected with a grounding cable between the plates. This plate is used as a grounding plane for the electronics.

2.3. Motor block

The motor block is welded together as bent steel plates. The individual parts are found in drawing_17, drawing_32 and drawing_18/drawing_19 and the screw dimensions and other parts are listed below. There is a difference between the left and the right motor block see drawing_18 and drawing_19.



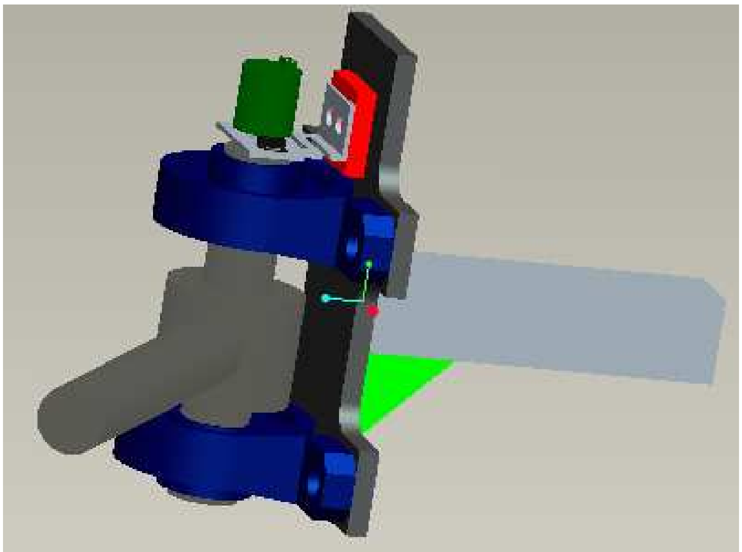
Figur 11, the motor block and numbering of the included parts

Listings of the parts in figure 11 above.

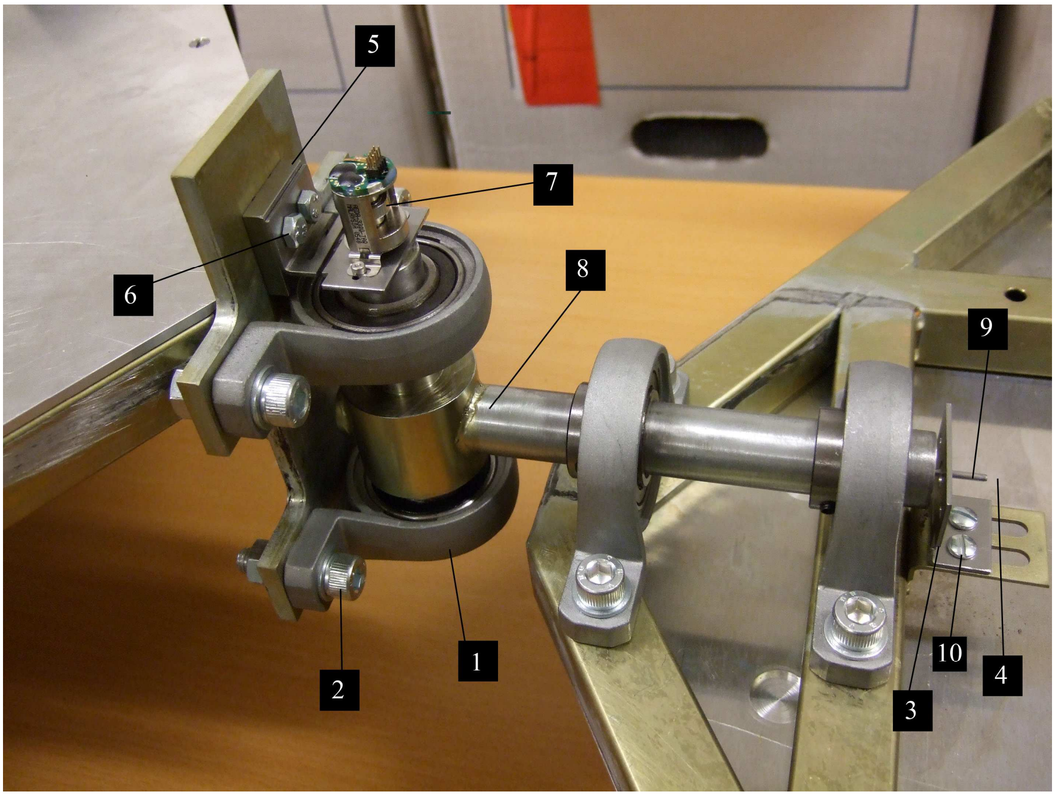
Number	Name and description	Quantity
1	Hex cap pan head screw M4-30, 3 washers	3
2	Slotted pan head screw M3-14, 8 washers	4
3	Hex cap pan head screw M4-12, 8 washers and 4 locknuts	4
4	Oldham coupling, 5mm/6.35mm	1
5	Axis 5mm, drawing_7	1
6	Pulley 12mm	1
7	Aluminium encoder holder, drawing_8	1
8	Encoder	1
9	Flanged bearing housing	1
10	Locking mechanism for the bearings, drawing _16	1

2.4. Mid joint

The mid joint is made by two welded parts that holds together with two bearing housings. One part is welded with parts from drawing_21 drawing_22 and drawing_27 on to the frame. The other half is welded with parts from drawing_5 and drawing_6.



Figur 12, A solid model that shows the mid joint



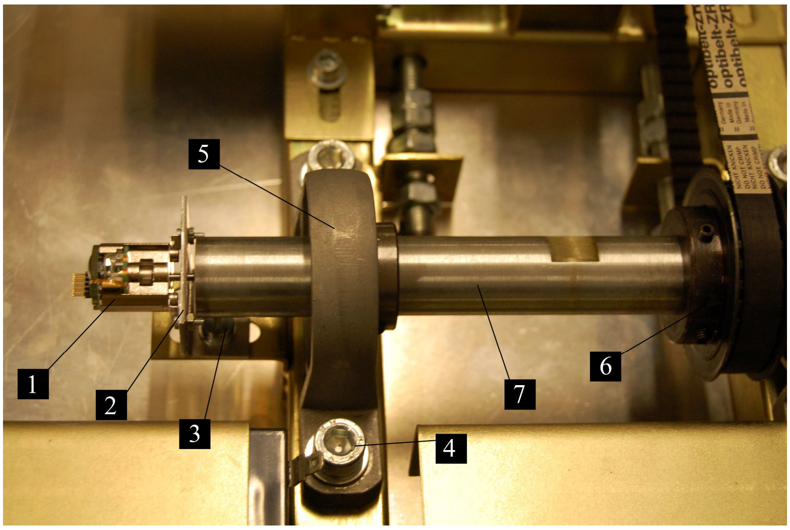
Figur 13, the mid joint and numbering of the included parts.

Listings of the parts in figure 13 above.

Number	Name and description	Quantity
1	Bearing house	4
2	Hex cap pan head screw M8-30, 12 washers 4 nuts	8
3	Encoder holder, drawing_9	1
4	Future location of the roll encoder.	
5	Washer, drawing _13	1
6	Bolt M4-20,2 washers	2
7	Encoder	1
8	Welded mid joint, drawing_5 and drawing_6	1
9	Encoder axis, drawing_2	1
10	Sloted pan head screw M3-10, 2 washers and 2 nuts	2

2.5. Wheel axis

The wheel axis is based on a 20 mm axis. The end of the axis is lathed to fit the wheels, see drawing_4.



Figur 14, wheel axis

Listings of the parts in figure 14 above.

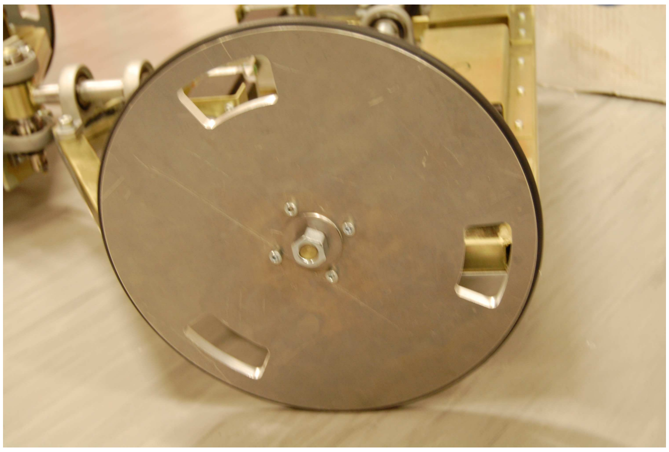
Number	Name and description	Quantity
1	Encoder	1
2	Encoder holder, drawing_9	1
3	Slotted pan head screw M3-10, 2 washers and 2 nuts	2
4	Hex cap pan head screw M8-30, 4 washers	4
5	Bearing house	2
6	Pulley 12mm	1
7	Wheel axis, 20 mm. see drawing_4	1

2.6. Wheels

Two types of wheels are manufactured, a high precision wheel for testing and indoor driving, and an outdoor terrain wheel with lower precision.

Figur 15, Low precision terrain wheel

The low precision wheel above in figure 10 is an aluminum rim manufactured by our workshop. The drawing for the rim is found in drawing_12. The tire we bought is a 12 inch tire for a bicycle at Biltema.



Figur 16, High precision indoor wheel

The high precision wheel above in figure 11 is an aluminium rim made by our workshop. The rim is assembled by two parts. The centre hub is found in drawing_33, and the aluminium pate is found in drawing_34. The two parts is held together by four M5 bolts.

The rubber is made from an o-ring that is glued to the right diameter.

2.7. IO-board

One board is needed. The Circuit diagram is found in Interface_Board1_1.

Description	Supplier and art. Nr.	Quantity
10 pin low profile connector	ELFA 43-155-03	15
26 pin low profile connector	ELFA 43-151-56	1
40 pin low profile connector	ELFA 43-155-60	2

2.8. Step motor board

One board is needed for each motor. The circuit diagram is found in Motor_Board1_1.

Description	Supplier and art. Nr.	Quantity
10 pin low profile connector	ELFA 43-155-03	1
8 pin connector	ELFA 48-452-28	1
Capacitor	ELFA 67-544-93	1
Control circuit for step motors	ELFA 73-288-34	2
Capacitor 47 µF 50V	ELFA 67-013-87	4

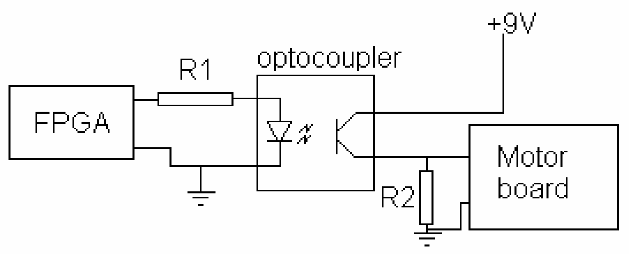
2.9. Sensor board

One board is needed for each sensor. The circuit diagram is found in Enchoder_Board1_1.

Description	Supplier and art. Nr.	Quantity
10 pin low profile connector	ELFA 43-155-03	1
IC Holder	ELFA 48-135-80	1
10 pin dual row vertical socket	Farnell 102-2299	1
IC DS 26LS32 quad differential Line Receiver.	ELFA 73-143-62	1
Capacitor 47pF	ELFA 65-778-52	1

2.10. Optocoupler board

One Optocoupler is needed for each signal to the step motor board. A basic drawing is found in figure 17. The R1=383Ω and the R2=560Ω. Six optocouplers is needed for each motor board.



Figur 17. Basic drawing for one optocoupler.

The table below is the components for six optocouplers for the signals to one motor board.

Description	Supplier and art. Nr.	Quantity
Resistance 383Ω	ELFA 60-717-99	6
IC Holder	ELFA 48-135-80	1
IC Holder	ELFA 48-135-49	1
Resistance 560Ω	ELFA 60-719-97	6
Optocoupler	ELFA 75-362-46	1
Optocoupler	ELFA 75-362-20	1

2.11. 9V DC supply

One is needed for each optocoupler board and one is needed for the wireless RS232, the material for one is found in the table below.

Description	Supplier and art. Nr.	Quantity
L7809 9V 1,5A	ELFA 73-091-23	1
Capacitor 0,1µF	ELFA 65-183-69	1
Capacitor 0,33µF	ELFA 65-184-27	1

2.12. Cable specification

The cables connected from the IO-board and the sensors and motors are listed below.

	Header and pin		Header and pin	Description
IO_Board	J_1-1	Encoder Board	J_2-1	Output A
	J_1-2		J_2-2	Output B
	J_1-3		J_2-3	Out I
	J_1-4		J_2-4	Vcc
	J_1-5		J_2-5	GND

	Header and pin		Header and pin	Description
IO_Board	J_2-1	Encoder Board	J_2-1	Output A
	J_2-2		J_2-2	Output B
	J_2-3		J_2-3	Out I
	J_2-4		J_2-4	Vcc
	J_2-5		J_2-5	GND
	J_3-1		J_2-1	Output A
	J_3-2		J_2-2	Output B
	J_3-3		J_2-3	Out I
	J_3-4		J_2-4	Vcc
	J_3-5		J_2-5	GND

	Header and pin		Header and pin	Description
IO_Board	J_4-1	Motor board	J_1-1	GND
	J_4-2		J_1-2	GND
	J_4-3		J_1-3	PWM-B
	J_4-4		J_1-4	PWM-A
	J_4-5		J_1-5	BREAK-B
	J_4-6		J_1-6	BREAK-A
	J_4-7		J_1-7	DIR-B
	J_4-8		J_1-8	DIR-A
	J_4-9		J_1-9	I-SENSE-B
	J_4-10		J_1-10	I-SENSE-A

	Header and pin		Header and pin	Description
IO_Board	J_5-1	Motor board	J_1-1	GND
	J_5-2		J_1-2	GND
	J_5-3		J_1-3	PWM-B
	J_5-4		J_1-4	PWM-A
	J_5-5		J_1-5	BREAK-B
	J_5-6		J_1-6	BREAK-A
	J_5-7		J_1-7	DIR-B
	J_5-8		J_1-8	DIR-A
	J_5-9		J_1-9	I-SENSE-B
	J_5-10		J_1-10	I-SENSE-A

	Header and pin		Header and pin	Description
IO_Board	J_6-1	Encoder Board	J_2-1	Output A
	J_6-2		J_2-2	Output B
	J_6-3		J_2-3	Out I
	J_6-4		J_2-4	Vcc
	J_6-5		J_2-5	GND

	Header and pin		Header and pin	Description
IO_Board	J_7-1	Encoder Board	J_2-1	Output A
	J_7-2		J_2-2	Output B
	J_7-3		J_2-3	Out I
	J_7-4		J_2-4	Vcc
	J_7-5		J_2-5	GND

	Header and pin		Header and pin	Description
IO_Board	J_8-1	Encoder Board	J_2-1	Output A
	J_8-2		J_2-2	Output B
	J_8-3		J_2-3	Out I
	J_8-4		J_2-4	Vcc
	J_8-5		J_2-5	GND

	Header and pin		Header and pin	Description
IO_Board	J_9-1	Encoder Board	J_2-1	Output A
	J_9-2		J_2-2	Output B
	J_9-3		J_2-3	Out I
	J_9-4		J_2-4	Vcc
	J_9-5		J_2-5	GND

	Header and pin		Header and pin	Description
IO_Board	J_10-1	Encoder Board	J_2-1	Output A
	J_10-2		J_2-2	Output B
	J_10-3		J_2-3	Out I
	J_10-4		J_2-4	Vcc
	J_10-5		J_2-5	GND

	Header and pin		Header and pin	Description
IO_Board	J_11-1	Encoder Board	J_2-1	Output A
	J_11-2		J_2-2	Output B
	J_11-3		J_2-3	Out I
	J_11-4		J_2-4	Vcc
	J_11-5		J_2-5	GND

	Header and pin		Header and pin	Description
IO_Board	J_12-1	Motorboard	J_1-1	GND
	J_12-2		J_1-2	GND
	J_12-3		J_1-3	PWM-B
	J_12-4		J_1-4	PWM-A
	J_12-5		J_1-5	BREAK-B
	J_12-6		J_1-6	BREAK-A
	J_12-7		J_1-7	DIR-B
	J_12-8		J_1-8	DIR-A
	J_12-9		J_1-9	I-SENSE-B
	J_12-10		J_1-10	I-SENSE-A

	Header and pin		Header and pin	Description
IO_Board	J_13-1	Encoder Board	J_2-1	Output A
	J_13-2		J_2-2	Output B
	J_13-3		J_2-3	Out I
	J_13-4		J_2-4	Vcc
	J_13-5		J_2-5	GND

	Header and pin		Header and pin	Description
IO_Board	J_14-1	Motor board	J_1-1	GND
	J_14-2		J_1-2	GND
	J_14-3		J_1-3	PWM-B
	J_14-4		J_1-4	PWM-A
	J_14-5		J_1-5	BREAK-B
	J_14-6		J_1-6	BREAK-A
	J_14-7		J_1-7	DIR-B
	J_14-8		J_1-8	DIR-A
	J_14-9		J_1-9	I-SENSE-B
	J_14-10		J_1-10	I-SENSE-A

The connections between the motor board and the motor are listed below.

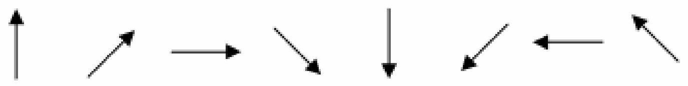
	header and pin		Description
Motor Board	X1-1	Input GND	
	X1-2	Input +36V	
	X1-3		Output 1 winding A
	X1-4		Output 2 winding A
	X1-5		Output 1 winding B
	X1-6		Output 2 winding B

The connection between the encoder board and the encoder is listed below.

	Header and pin		
Encoder board	J_1-1	Encoder	Pin 1
	J_1-2		Pin 2
	J_1-3		Pin 3
	J_1-4		Pin 4
	J_1-5		Pin 5
	J_1-6		Pin 6
	J_1-7		Pin 7
	J_1-8		Pin 8
	J_1-9		Pin 9
	J_1-10		Pin 10

2.13. Stepper Motor control

Related files are stepper_motor_ctrl.VHDL
A counter counts up on a clock signal, and then it's compared with period. If it's equal the current state is updated to next state and the counter is set to zero.



dir1:	1	1	0	0	0	0	0	1
dir2:	0	1	1	1	0	0	0	0
pwm1:	1	1	0	1	1	1	1	0
pwm2:	0	1	1	1	0	1	1	1
brk1:	0	0	1	0	0	0	1	0
brk2:	1	0	0	0	1	0	0	0

Figur 18, Bit description for the motor control

The figure 18 above shows the output to turn the motor axis.
The table below is listing all the signals connected to the stepper motor control.

Signal in	Clock	Clock frequency
	Dir	Rotation direction
	Free	Must be equal to 1 if the motor axis is going to turn free.
	Brk	If Brk equals to 1 then the motor will break.
	Period[31..0]	The number of clock pulses between each step

Signal out	Dir1	Direction for winding 1
	Dir2	Direction for winding 2
	PWM1	PWM signal for winding 1
	PWM2	PWM signal for winding 2
	Brk1	Break signal for winding 2
	Brk2	Break signal for winding 2
	Pulse_in	Control variable

2.14. Quadature encoder

Related files are quadature_encoder.VHDL
Takes in a and b then returns position and period. Index and velocity is not implemented or used yet. The table below is listing all the signals connected to the Quadature encoder.

Signal in	a	Input a from the encoder
	b	Input b from the encoder
	index	Input index from the encoder
	timeclock	Clock pulse that is equal to 1 every 2^{22} main clock pulse.

Signal out	position	The position of the encoder
	period	The difference in position between two timeclock
	velocity	Not implemented, gives the same value as period.

3. Supliers

	Supplier	Quantity
Oldham coupling	ELFA Hub 6.35mm art.nr: 54-651-17 ELFA Hub 8mm art.nr: 54-651-25 ELFA Disk 25mm art.nr:54-653-15	4 4 4

	Supplier	Quantity
Battery	Biltema Lead accumulator 2.9A. art.nr:80-407 Biltema Lead accumulator charger art.nr:37-711 ELFA, Power switch C1550ATBB, art.nr:35-016-08	16 4 2

	Supplier	Quantity
Motor	Aratron step motor. art.nr: 1007737	4

	Supplier	Quantity
Belt drive	Kedjeteknik Pulley 12mm, art.nr: 12XL 037F Kedjeteknik Pulley 30mm, art.nr: 30XL 037F Kedjeteknik Belt 355mm, art.nr: 140XL 037	4 4 4

	Manufacturer	Quantity
Encoder	Avago, high resolution encoder AEDA-3300_TAQ	10

	Supplier	Quantity
Bearings	Nomo, Flanged bearing housing art.nr: UFL 08 Clas Ohlsson, bearing house, art.nr: 30.4684	8 12

	Supplier	Quantity
Wheels	Momentum, 8mm o-ring. Biltema, 12 inch tire Biltema , 12 inch inner tire	4 meters 4 4

	Supplier	Quantity
FPGA	Altera Cyclone II (2C35)	1

	Supplier	Quantity
Electronics	ELFA, 10 pin low profile header, art.nr: 43-155-03 ELFA, 26 pin low profile header, art.nr: 43-155-45 ELFA, 40 pin low profile header, art.nr: 43-155-60	29 1 2

	ELFA, 8 pin header, art.nr: 48-452-28	4
	ELFA IC-holder, art.nr: 48-135-80	10
	ELFA IC-holder, art.nr: 48-135-49	3
	Farnell 10 pin dual row vertical socket, art.nr:102-2299	10
	ELFA, DS 26LS32 quad differential Line Receiver, art.nr: 73-143-62	10
	ELFA, Control circuit for step motors art.nr: 73-288-34	8
	ELFA, Capacitor 1000µF 100V, art.nr: 67-544-93	4
	ELFA, Capacitor 0,1 µF 63V art.nr: 65-183-69	3
	ELFA, Capacitor 0,33 µF 50V art.nr: 65-184-27	3
	ELFA, Capacitor 47 µF 50V art.nr: 67-013-87	16
	ELFA, insulation, art.nr: 75-646-85	10
	ELFA, insulation, art.nr: 75-646-77	10
	ELFA TLP620-4 quad optocoupler, art.nr: 75-362-46	2
	ELFA TLP620-2 dual optocoupler, art.nr: 75-362-20	2
	ELFA Resistance 383Ω art.nr: 60-717-99	12
	ELFA Resistance 560Ω art.nr: 60-719-97	12
	ELFA Experiment board art.nr: 48-326-48	3
	ELFA L7809CV 9V 1,5A art.nr: 73-091-23	3

	Supplier	Quantity
Cables	ELFA, Female connector 10 pos. art.nr: 43-150-16	29
	ELFA, Female connector 40 pos. art.nr: 43-150-73	4
	ELFA, Female connector 8 pos. art.nr: 48-451-45	4
	ELFA, D-sub 9 pos. art.nr: 44-117-08	4
	ELFA, Flat cable 10 pos. art.nr: 55-660-13	15 meter
	ELFA, Flat cable 26 pos. art.nr: 55-660-96	2 meter
	ELFA, Flat cable 40 pos. art.nr: 55-661-38	2 meter

	Supplier	Quantity
Screws	Järnia, locking nut M4	16
	Järnia, nut M4	40
	Järnia, nut M8	16
	Järnia, nut M14	4
	Järnia, washer M4	88
	Järnia, washer M5	12
	Järnia, washer M8	28
	Järnia, hex cap pan head screw M2-4	20
	Järnia, hex cap pan head screw M4-8	24
	Järnia, hex cap pan head screw M4-10	16
	Järnia, hex cap pan head screw M4-20	2
	Järnia, hex cap pan head screw M5-30	28
	Järnia, hex cap pan head screw M8-30	24
	Järnia, slotted, countersunk screw M4-6	14
	Järnia, flat head rivet nut M8	20
	Järnia, flat head rivet nut M5	12

References

Ulf Larsson, Caj Zell, Kalevi Hyyppä and Åke Wernersson. Navigating an articulated vehicle and reversing with a trailer. Computer science and electrical engineering, University of Luleå.