Copyright © Aalborg University 2015

This report is compiled in LaTeX, originally developed by Leslie Lamport, based on Donald Knuth's TeX. The main text is written in *Computer Modern* pt 11, designed by Donald Knuth. Flowcharts and diagrams are made using Microsoft Visio.

5^{th} Semester
School of Information and
Communication Technologies
Electronics and IT
Fredrik Bajers Vej 7B
9220 Aalborg
http://www.sict.aau.dk/electronics-and-it

Title:
??

Theme:
Digital and Analog Systems
Interacting with the Surroundings

Project Period:
P5, Autumn 2015
02/09/2015 - 17/12/2015

Project Group:
??

Participants:
Amalie V. Petersen
Julien Brehin
Mads R. Gotthardsen
Niels Skov Vestergaard
Romaric Destremau
Thomas Rasmussen

Supervisor:
??

Prints: ??
Pages: ??
Appendices: ??
Concluded: 17/12/2015

Synopsis

??

Publication of this report's contents (including citation) without permission from the authors is prohibited

Contents

Preface

Preface Here

Text by:

Amalie V. Petersen	Julien Brehin
Mads Gotthardsen	Niels Skov Vestergaard
Romaric Destremau	Thomas Rasmussen

Part I

Preanalysis

1 | Introduction

More and more robots appear in everyday life. Automatic vacuum cleaners and floor washers are getting widespread, as the technology is becoming cheaper and better. The vacuum cleaners have matured to a level, where they are been considered for saving man-hours in the elderly care sector.

Outside the walls of our homes lays the next weekly hurdle: Mowing the lawn. A known way to handle this, is to pay the neighbour's teenager to do it. Unfortunately they grow up and move out, leaving the lawns in the residential neighbourhoods behind.

Luckily engineers have stepped in, and provided a more long-term solution: Robotic lawn mowers.

1.1 Robotic lawn mowers

Several manufacturers of electrical gardening machines have started selling robotic lawn mowers in the recent years. In general they use one of two strategies when cutting the lawn:

- Random direction mowers
- Parallel line mowers

Mowers using the random direction strategy will drive in a straight line until a guard wire or an obstacle is detected. They will then turn in a random direction, and continue. See *Figure:* ??

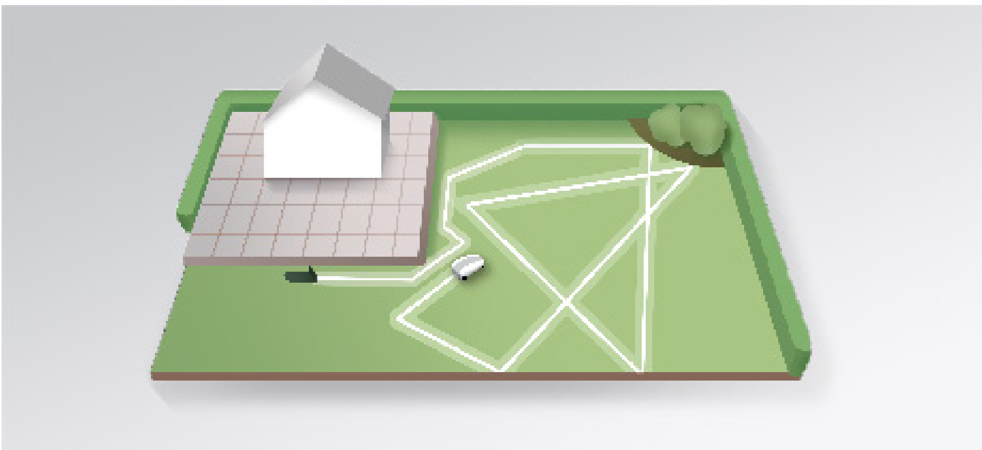

Figure 1.1: Random cut system [source:Bosch]

When the battery is nearly discharged, the mower will follow the guard wire back to the base station for recharging.

Parallel line mowers use a more intelligent control algorithm to optimize the mowing. After an initial learning run, following the guard wire around the lawn to be mowed, it will map the lawn, and cut in parallel lines, see *Figure:* ??. The advantage of this strategy efficiency, as the lawn mower will not run over the same spots more than once. According to Bosch, a given lawn can be mowed up to 30% faster with their Logicut system.

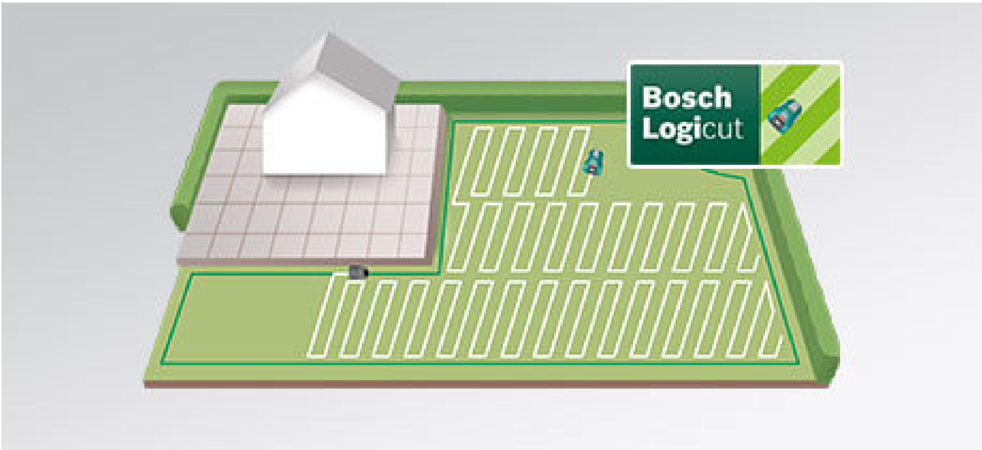

Figure 1.2: Bosch Logicut system [source:Bosch]

Common for both systems is the guard wire, which has to be placed around the lawn and anywhere the lawn mower is not allowed to go, like flower beds, swimming pools, etc.

This brings us to the problem with existing products.

1.2 Problems with existing robotic lawn mowers

All commercially available robotic lawn mowers requires a guard wire placed around the lawn. This can either be placed at the surface, and be held in place by pegs, or dug down below the surface. The guard wire must be routed around flower beds, etc. as well, see *Figure:* ??

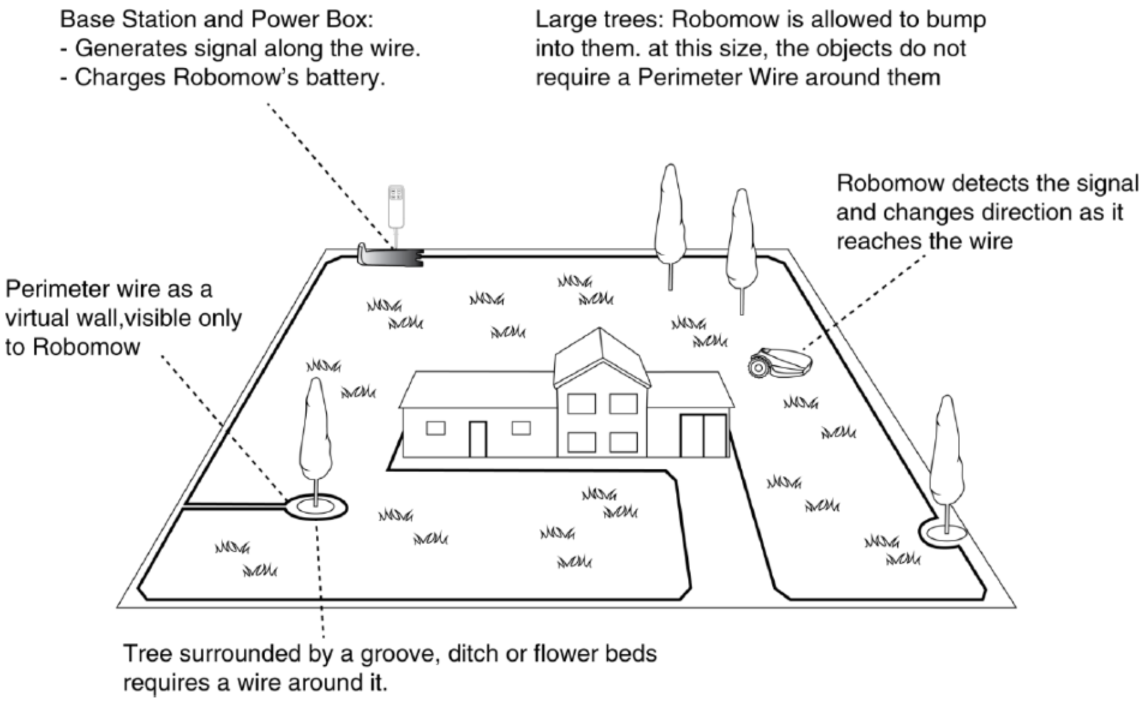

Figure 1.3: Guard wire installation [source:Robomow]

The use of the guard wire for guiding the mower back to the charging station presents another potential problem: in a garden with many restricted areas, the guard wire could get very long. This could therefore make the journey home long, compared to a more direct route. This again uses more battery power, that instead could have been used for actually mowing the lawn.

This will be the motivation for the project: to avoid the work routing a wire around the garden, and as a bonus get more work done on a battery charge, by not wasting power following the wire home.

Then, the question is: What other solutions could be use to get the lawn mower to go where it has to go?
One first step could be to keep track of where it is in real-time.

1.3 The Games on Track (GoT) system

We were provided with the *Games on Track GT-Position* system as a start to be able to determine the lawn mower's position in space.

Figure 1.4: Games on Track GT-Position package [source:Games on Track]

It is composed of four different parts both hardware and software :

- A tracked module, which emits ultra-sound waves. It should be placed on the lawn mower itself while taking care, that the emitting cell is not obstructed by anything.
- Beacons or receivers, placed around the area the lawn mower will move in. Depending on the terrain, anywhere from 2 to more than 20 of these can be used: The more is placed, the more accuracy can be obtained to fight against any ambient noise.
- The central system, which calculates the distance of the tracked module to each beacon, and transmits it to the computer via USB in regular intervals.
- The GoT software aggregates the received positions throughout time, and can be used to draw a map of the terrain (the lawn), and to determine the absolute position of the tracked module.

–Resolved– is t enough? Answe It is according t the GoT site (s reference in LaT comments)

GoT was originally designed for train modelling, but it is easily adaptable for any use of position tracking and seems a good choice, at first, for our autonomous lawn mower. But, why not use a satellite based positioning system ?

1.4 Satellite based positioning systems vs GoT

The reasons why satellite positioning system won't be used in our project are mainly related to accuracy over price ratios and to energy consumption.

Wrong reasons GPS vs GoT, e rated below

Indeed, these kinds of system like GPS or GLONASS would require a dedicated chip to put on the final system. The problem then would be the lack of precision. Although, there are some

–To be reviewe again– GPS use very little powe depending on t accuracy neede cheap standard GPS chips (around USD 10), these only reach around 1 meter of precision in the most ideal situations. On the other hand, the best GPS chips can achieve precisions up to a few millimeters when combined with different augmentation systems (algortihms for instance), but they end up being highly expensive (usually thousands of dollars). They are not generally intended for public use.

pe reviewed – Only applies eap solutions, ential GPS can mm level, but remely expen- This is what e trying to re- with GoT, as a lot cheaper diff-GPS

Moreover, if we add up the slow bit rates satellites can achieve, the signal amplifiers on the receiver, plus all the position calculations and possible augmentation systems, the total energy consumption would quickly rise,thus reducing the lawn mower autonomy, which is not desirable.

pe reviewed – nope, it's a radio re- r, uses almost ower

Indeed, the design of a product has no real value if no one is interested in using it. This is why choices made during this project have to be made in accordance with the final user's expectations.

1.5 Potential consumer expectations

Usually, we can think of a few priorities consumers will have when buying a product, whatever it is, and some more specific to technical products.

Here for instance, the autonomy of the vehicle (both in energy and for the navigation), and the overall cost should be considered. The GoT system itself has a cost (USD 606.00 for a basic package) beyond anything a normal customer would probably pay for a lawn mower. But despite that, it appears, at first, to be a good solution for us in terms of accuracy and energy consumption compared to GPS-like systems which are even more expensive for the same accuracy.

olved– insert approximation - not so true lly

These are the types of preliminary considerations that will influence this design process for an autonomous lawn mower.

2 | Design Consideration

In this chapter the system is designed with a top-down approach. First a use-case of the functionalities in the system is described, in order to give an overall view of what the system must be able to do. Hereafter, constraints set by time limitations as well as a focus on the main scope of the project, in regards to the prototype, is considered. Based on the use-case description and the prototype constraints the requirements for the systems prototype are listed.

2.1 Use-case design

To give an overall view of what the system should be able to do, a UML use-case diagram is used to consider and describe the main functionalities and operators in the system, see *Figure: 2.1*.

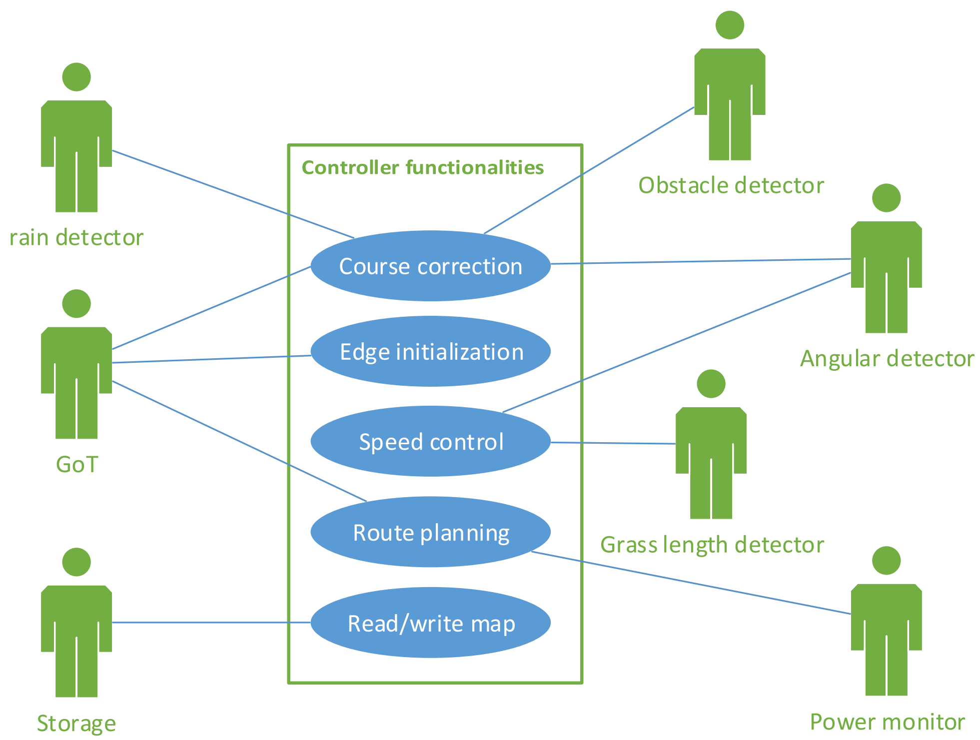

Figure 2.1: Use-Case Diagram

The main purpose of the system is to automatically navigate in a specific area which is confined by the *edge initialization* functionality. This functionality handles the marking of the areas edges. The functionality is only used in the initialization process of the system. The concept is to only use the functionality after the GoT system has been positioned in the area. The consumer then takes the system around the edges of the grass, while the GoT system tracks its positions. It is therefore only necessary to reinitialize the system, if the GoT satellites has been moved. While the edge is being tracked, the *edge initialization* uses the *read/write map* functionality to store the information collected, in storage.

The route in which the lawn mower is to navigate, in the specified area, is provided by the functionality *route planning*. *Route planning* uses the information, about the specific area, which is collected from the storage, to plan the most optimal route. Furthermore the *route planning* needs information about the systems power level to insure the functionality is considering if the system needs charging and therefore have to return to the charging station at some point on the route.

The *read/write map* functionality as described earlier, handles the communication with storage. Hence it stores information, received from the *edge initialization* and collects information from storage when the functionality *route planning* needs it.

To insure the system is moving with a desired speed (in a straight line and in a turn) or a speed which is fitted to the height of the grass, detected with the *grass length detector*, a *speed control* functionality is necessary in the system to control the motors. To insure the *speed control* can deliver the desired speed an *angular sensor* is utilized.

The last functionality, *course correction* is used when the system strays of the path calculated by *route planning* or if the path gets blocked. The obstacle which is blocking the route is detected by the sensor *obstacle detector*. Furthermore the GoT system and the *angular detector* will detect if the system is not on the desired path, or if the system starts to slip. Also, if it starts to rain, which is detected by the *rain detector*, the system has to return to the charging station. Finally, the *course correction* sends the calculated data to the functionality *speed control*.

The overall functionalities of what the system must be able to do has been described. Now the different constraints on the system will be considered and the project prototype should be established.

2.2 Prototype Constraints

Before the prototype can be established, some considerations has to be made in respect to the time limitations and the main scope of this semester. The aim of the project is to create a functional proof of concept prototype of an automated lawn mower. The following section includes a brief description of the technology on which the prototype is constructed, along with argumentation for eliminated functionalities.

2.2.1 Technology Base

The technology which has been provided for the prototype is a tracked vehicle, seen on *Figure: 2.2*. The vehicle comes with a brushed DC motor which provides power for rotation of the wheels, connected with the belts, and a servo motor which utilize breaks, connected to the wheels, to control the ratio of the differential steering. Furthermore the tracked vehicle includes two hall sensors, one by each belt, which keeps track of the speed, of the belts, by measuring pulses from magnets mounted on the front wheels. The testing will take place in Aalborg University Vicon Room, where the GoT system is installed and calibrated with the appurtenant transmitter, which is mounted on the tracked vehicle during test.

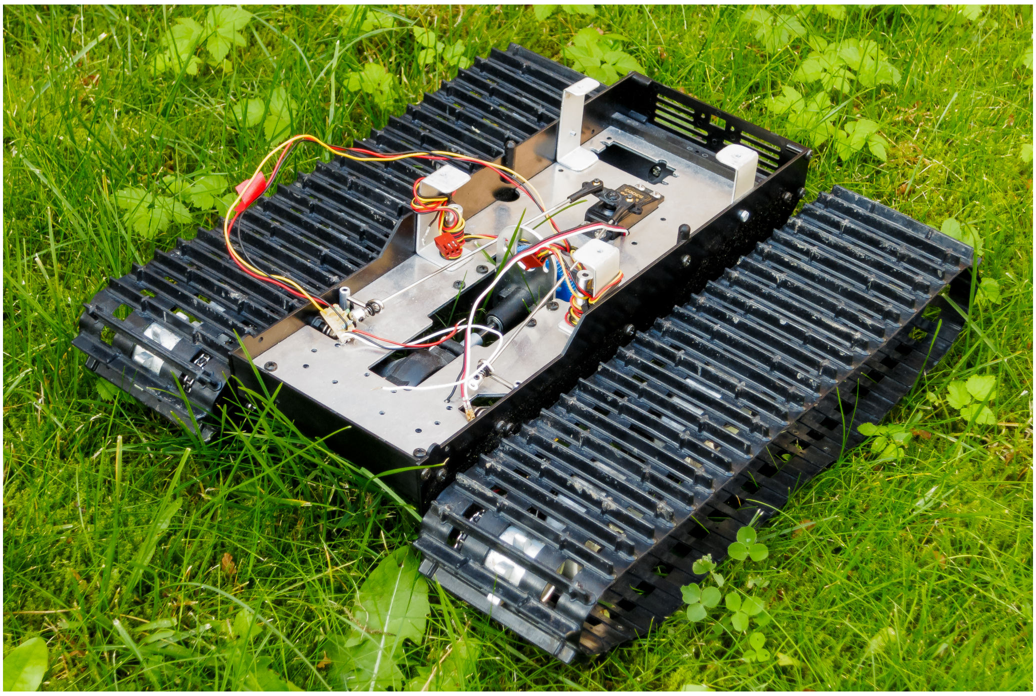

Figure 2.2: The provided belt vehicle

datasheet of the vehicle

2.2.2 Grass Length Detection

Detection of the grass length to control the speed of the lawn mower thus ensuring an evenly cut lawn, is a submodule which can be added at any time. Since it is not fatal for a working system and might even be unnecessary depending on time between each mowing of the lawn, it is decided to exclude this functionality from the initial design.

2.2.3 Rain Sensor

As the lawn mower is supposed to work outside, it is important to consider that it may be raining, and that an electronic device can be affected by those environmental issues. Even if the electrical part is waterproofed, there is a mechanical threat, a rain sensor could then warn the system to order the vehicle to get back in time. It is possible to build the vehicle aware of those issues and add mechanical modules to secure it. However, the prototype will only be tested indoor, so this type of sensor will not be necessary in a prototype design.

2.2.4 Obstacle Avoidance

The lawn movers path might not always be clear, there could be some garden tools, tables or chairs, or people walking in it. The vehicle should be aware of what is in front of it at any time, to correct its path and get around the obstacle if necessary. To avoid this the sensor could be a pushing button to detect a solid strong object, or an ultrasound detector if the object is breakable. As the aim of the project is to control the path of the vehicle by using angular positioning sensors, a proximity sensor will not be included. Static objects could be registered on the map to avoid these issues.

Furthermore the edge mapping functionality will not be included in the project which instead will focus on a quadratic map predefined in the test room.

2.2.5 Power Monitoring

Power monitoring could be implemented by measuring the voltage across the batteries, to ensure that the lawn mower is not running out of power, and to ensure the vehicles calculated route passes the charging station before the power runs too low. This and the charging station will not be in the prototype, since it is beyond the scope of the project this semester and is not crucial for a working prototype.

2.2.6 Prototype

(to be continued)

Part II

Design & implementation

Part III

Test & conclusion

Appendix

A | The Games on Track GT-position system

The Games on Track GT-Position system, shortened GoT, is a GPS system which uses radiowaves and ultrasound to locate the object. The system is build up by three hardware components, the transmitter, receiver and master.

Transmitter

The transmitter component is placed on the object, which needs to be located. To indicate the objects position, the transmitters emits out ultrasound waves to indicate where it and the object is positioned. The transmitter component runs on 2 AA-batteries and therefore does not need an external power-source.

Receiver

The receiver component is placed around the area where the object, with the transmitter, has to be located. The receivers assignment is to search for the ultrasound waves, which the transmitter is emitting. The ultrasound waves received by the receivers, provides information containing the distance between the specific receiver to the transmitter located on the object. To be able to calculate the exact position of the transmitter and the object, a minimum of three receivers is necessary. however, more receivers can be added to the system for more reliability and the ability to cover a larger area. For the receivers to work at a high efficiency, they should be placed 1 to 2 meters apart and not on a single line. But if receivers shall cover a bigger area, they can be placed up to a distance of 5 meters between them, however, this would affect the measurement and thereby make it less reliable. Each receiver have a maximum range of 8 meters and as seen on *Figure: 2.3*, the three receivers should be placed in each others reach. The receivers needs between 14 to 20 volt DC. Thus, making the receivers able to be powered through a computer charger if necessary.

What kind of "
waves" does the
ceiver transmit
to the master?

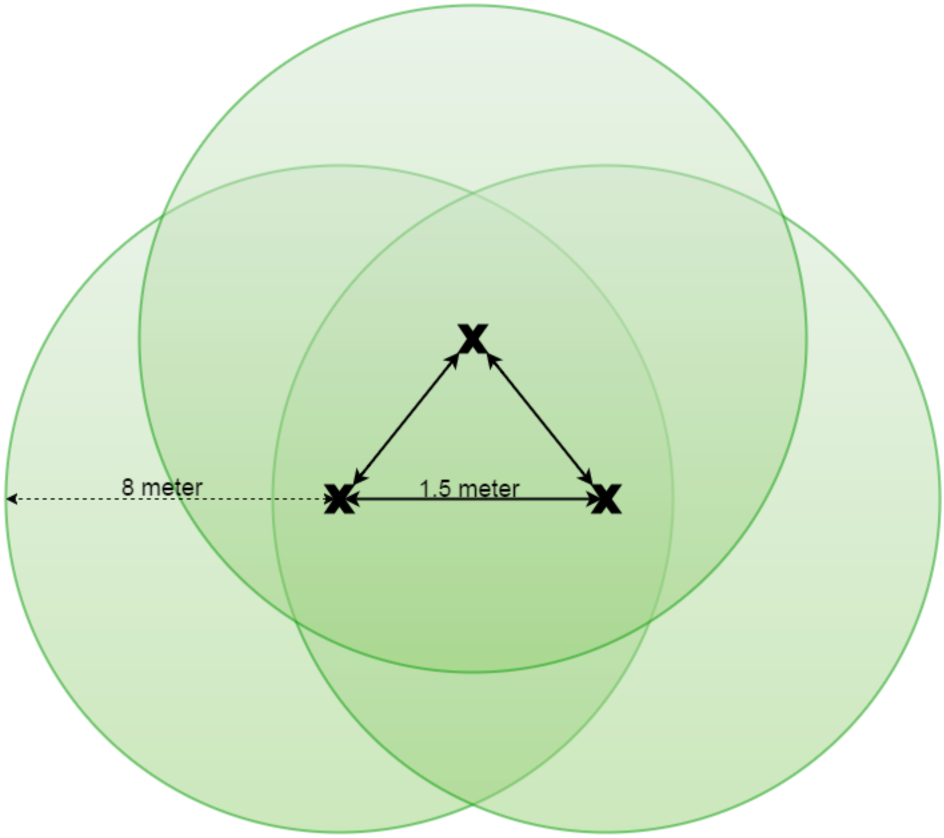

Figure 2.3: Example on a standard setup for the receivers (increase size of text in figure)

Master

The master is a receiver which should be connected to a computer. The masters assignment is to receive the data transmitted from the individual receivers and send it directly to the connected computer. The master is powered through a USB cable, between the master and the computer.

Computer

The program on the computer, which handles the information received from the master, uses the data to calculate the position of the transmitter. This is done with a method call Trilateration. Trilateration is a way of calculating a position, in a three-dimensional space, from three distances (from known locations), with the help of spheres, circles and triangles. Therefore it is necessary for the system to have atleast three receivers, as mentioned earlier. With additional receivers a check up can be performed to ensure the position of the transmitter is correct.

If the receivers have been moved, it is necessary to calibrate the system. This is done with a calibration triangle. The calibration triangle is three markings on the surface, that will be setup to be the zero surface for the Z-axis. One of the points on the calibration triangle is made the origin (0,0,0) of the coordinate system. Another point on the triangle will then be call (X,0,0), in which the line between the first point and the second point will become the X-axis. The last point will be call (X,Y,0) and will determine in which way the positive Y-axis will go. The surface which the calibration triangle is creating, will be the zero surface for the Z-axis, and is horizontal. The distance between the three points is measured and put into the software. Thereafter, with using the transmitter, are the position of the receivers calculated. The transmitter is first placed in the first point (0,0,0), there next the second point (X,0,0) and then in the last point (X,Y,0). At each point the distance to the receivers is measured. Out from this data, about the placement of the points and their distance to the receivers, the software can calculate the position of each receiver, with the help of trilateration.

How should the re- cievers be place how far can the reach, picture?

How do you cal brate, do you m the transmitter around?? but t in the text

mergeconflict w needs to be ad- dressed

The program on the computer, which handles the information received from the master, uses the data to calculate the position of the transmitter. This is done with a method call Trilateration. Trilateration is a way of calculating a position, in a three-dimensional space, from three distances (from known locations), with the help of spheres, circles and triangles. Therefore it is necessary for the system to have atleast three receivers, as mentioned earlier. With additional receivers a check up can be performed to ensure the position of the transmitter is correct. Trilateration does not work, if the three know points is on a single line and therefore shall the receivers be placed in a triangle.

If the receivers have been moved, it is necessary to calibrate the system. This is done with a calibration triangle. The calibration triangle is made of three points on a flat surface and have a distance of 40 to 200 centimeters between them. One of the points on the calibration triangle is made the origin (0,0,0) of the new coordinate system. Another point on the triangle will then be call (X,0,0), in which the line between the first point and the second point will become the X-axis. The last point will be call (X,Y,0) and will determine in which way the positive Y-axis will go. The surface which the calibration triangle is placed on, will be the XY-plan, where Z will go positiv in the direction of the receivers. The distance between the three points is measured and put into the program. Thereafter, the transmitter placed in the three point, with (0,0,0) first and (X,Y,0) last. When the transmitter is placed in a point, the receivers measure the distance between them and the transmitter. From the data, the program can calculate the position of each receiver, with the help of trilateration.

B | Motor Tests

B.1 Armature Resistance

Name: Group 510
Date: 30/09 - 2015

Purpose

The purpose of the test is to measure the Armature resistance R_a.

Setup

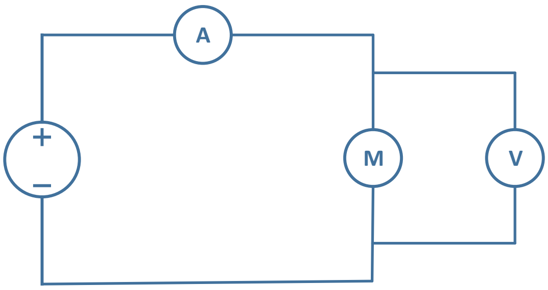

Figure 2.4: Use-Case Diagram

List of Equipment

Example of list of equipment:

Instrument	**AAU-no.**	**Type**
Multimeter 1	60764	Fluke 189 True RMS
Multimeter 2	60769	Fluke 189 True RMS
Power Supply (0 - 32 V) (0 - 10 A)	77076	Ea - ps 7032 - 100
Clamp for fixing the motor	03039	

Procedure

1. Turn on the two multimeters and choose Voltage and Ampere setting respectively.
2. Fix the motor shaft so it does not turn.
3. Choose the first current value (0.5 A) on the current limiting of the power supply.
4. Turn on the power supply and adjust the current limiting in accordance with the ampere meter.

5. Repeat the two previous steps for each measurement of 0.5 A increments up to 5 A.
6. Switch the poles of the power supply and repeat the measurements in the negative direction.

Results

Input (A)	Output (V)
−5.0	−0.07
−4.5	−0.14
−4.0	−0.20
−3.5	−0.27
−3.0	−0.36
−2.5	−0.43
−2.0	−0.54
−1.5	−0.59
−1.0	−0.65
−0.5	−0.71

Input (A)	Output (V)
0.5	0.16
1.0	0.34
1.5	0.53
2.0	0.62
2.5	0.64
3.0	0.75
3.5	0.78
4.0	0.80
4.5	0.83
5.0	0.88

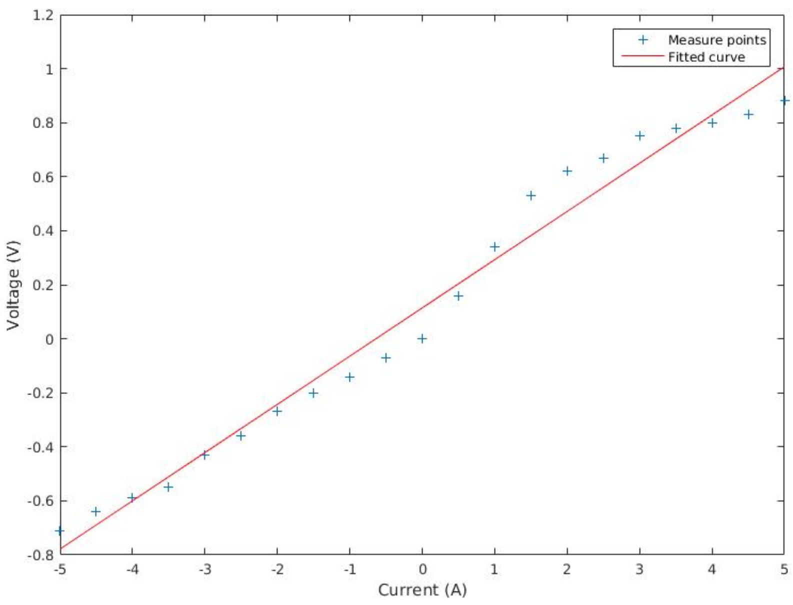

Figure 2.5: Plot of test results

The slope of the fitted curve yields: $R_a = 0.17\Omega$

B.2 Armature Inductance

Name: Group 510
Date: 30/09 - 2015

Purpose

The purpose of the test is to measure the Armature inductance L_a.

Setup

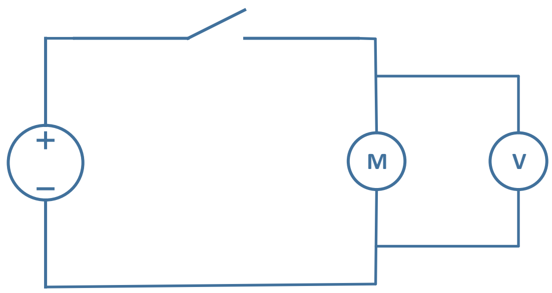

Figure 2.6: Use-Case Diagram

List of Equipment

Instrument	**AAU-no.**	**Type**
Power Supply (0 – 32 V) (0 – 10 A)	77076	Ea - ps 7032 - 100
AC/DC Current Clamp (Output: 100 mV/A)	78550	FLUKE i30s
Oscilloscope	64672	Agilent DSO6034A
Clamp for fixing the motor	03039	

Procedure

1. Fix the motor shaft so it does not turn.
2. Start with the power supply disconnected and turn on the oscilloscope.
3. On the oscilloscope press the "mode"-key choose the "normal"-option and push the "single"-key.
4. To prevent false triggering on the oscilloscope set the trigger value to
5. To give the motor a pulse of 5 V, put the power supply to 5 V and connect it.
6. Insert a USB-pin in the oscilloscope and press the save key to extract the data.

Results

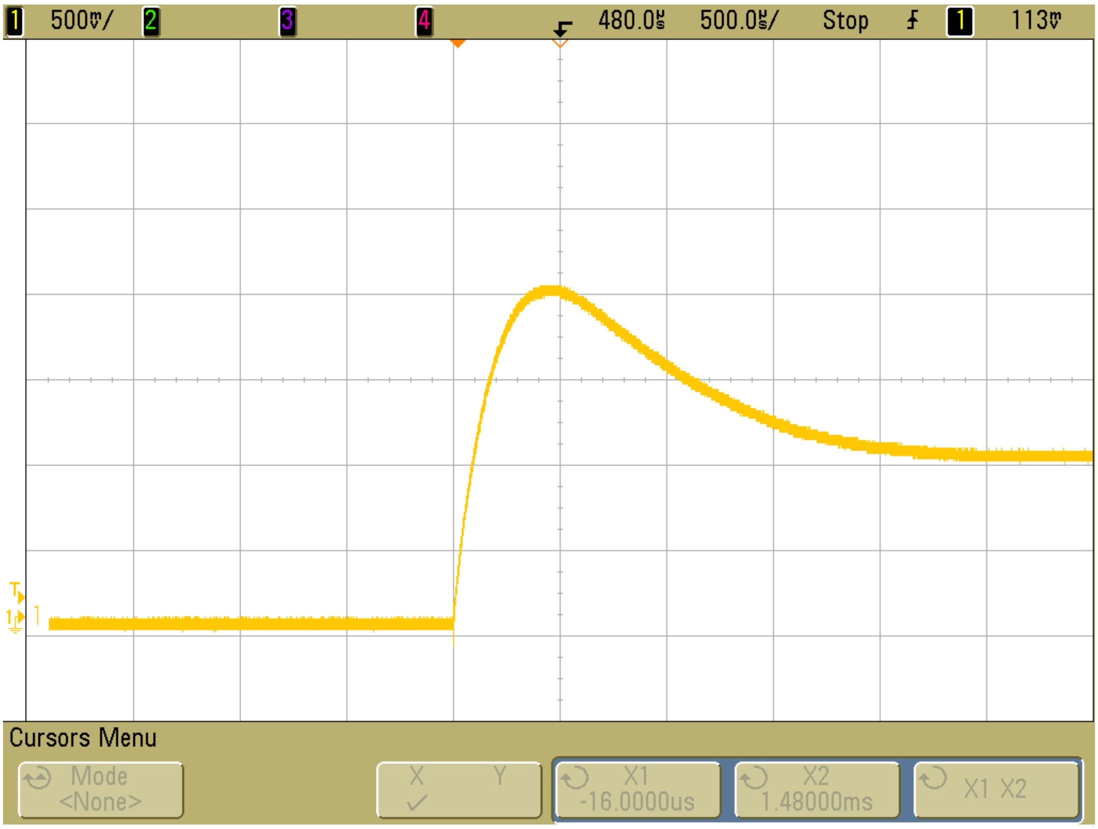

Figure 2.7: Plot of test results

B.3 Tachometer Constant

Name: Group 510
Date: 30/09 - 2015

Purpose

The superpose of the test is to measure verify that tachometer constant (in V) is 0.030 multiplied by the motor constant.

Setup

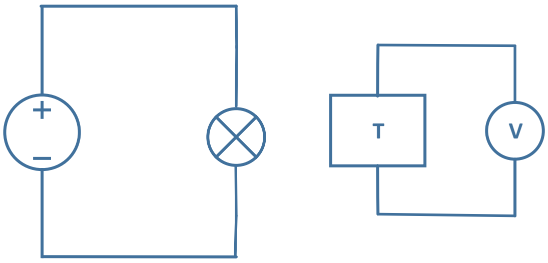

Figure 2.8: Use-Case Diagram

List of Equipment

Instrument	**AAU-no.**	**Type**
Power Supply $(0 - 32\text{ V})$ $(0 - 10\text{ A})$	77076	Ea - ps 7032 - 100
Multimeter	60764	Fluke 189 True RMS
Torque sensor	08772	Icom
Optical tachometer	08246	Shimpo DT-205

Procedure

1. Adjust voltage of power supply till you reach 6 V on the multimeter over the tachometer.
2. Measure the RPM with the Optical tachometer.

Results

Measured: 1933 RPM We use the measured RPM to verity a tachometer constant of 0.03:

$$\frac{1933}{60} \cdot 2 \cdot \pi \cdot 0.03 = 6.07 \approx 6 \qquad [\text{V}] \quad (2.1)$$

B.4 Generator Constant

Name: Group 510
Date: 30/09 - 2015

Purpose

The purpose of the test is to find the generator constant K_e by measuring the motor voltages, currents and velocities, in several steady states.

Setup

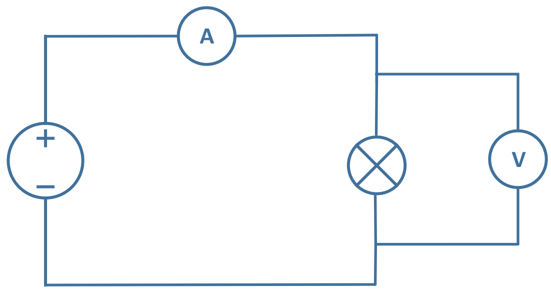

Figure 2.9: Use-Case Diagram

List of Equipment

Instrument	**AAU-no.**	**Type**
Multimeter 1	60764	Fluke 189 True RMS
Multimeter 2	60769	Fluke 189 True RMS
Power Supply (0 – 32 V) (0 – 10 A)	77076	Ea - ps 7032 - 100
Optical tachometer	08246	Shimpo DT-205

Procedure

1. Turn on the two multimeters and put them in ampere and voltage mode respectively.
2. Apply 1 V by use of the voltage mode multimeter
3. Read out the current value from the ampere mode multimeter
4. Read out RPM of the motor using the optical tachometer.
5. Repeat the past 3 steps up to 7 V in 1 V increments.

Results

Input (V)	Output (A)	Output (RPM)
1	1.7	3684
2	2.2	8063
3	2.6	12021
4	3.3	16746
5	4.1	21966
6	4.8	26420
7	5.6	31447

B.5 Motor Constant

Name: Group 510
Date: 30/09 - 2015

Purpose

The purpose of this of this test is to measure the motor constant K_t.

Setup

Test setup

List of Equipment

Instrument	**AAU-no.**	**Type**
Multimeter 1	60764	Fluke 189 True RMS
Multimeter 2	60769	Fluke 189 True RMS
Power Supply (0 – 32 V) (0 – 10 A)	77076	Ea - ps 7032 - 100
Torque sensor	08772	Icom

Procedure

1. Fix the motor shaft so it does not turn.
2. Turn on the two multimeter in current and voltage mode respectively.
3. Start by setting the power supply at 1 A current limiting.
4. Turn on the supply and note the voltage across the torque sensor.
5. Repeat the previous two steps up to 10 A with 1 A increments.

Results

Input (A)	**Output (V)**
1	0.08
2	0.08
6	0.15
7	0.15
8	0.15
10	0.18

Moment of Inertia

Name: Group 510
Date: 30/09 - 2015

Purpose

The purpose of this test is to find the moment of inertia I, by measuring the motor velocity as a function of time.

Setup

Test setup

List of Equipment

Instrument	**AAU-no.**	**Type**
Oscilloscope	64672	Agilent DSO6034A
Power Supply $(0 - 32\text{ V})$ $(0 - 10\text{ A})$	77076	Ea - ps 7032 - 100
Optical tachometer	77087	Compact

Procedure

1. Turn on the oscilloscope.
2. On the oscilloscope press the "mode"-key choose the "normal"-option, set the trigger to "falling edge".
3. To prevent false triggering on the oscilloscope set the trigger value to
4. Turn on the power supply at 7 volt.
5. Press "single"-key on oscilloscope and cut the power of the motor.
6. Insert a USB-pin in the oscilloscope and press the save key to extract the data.

Results

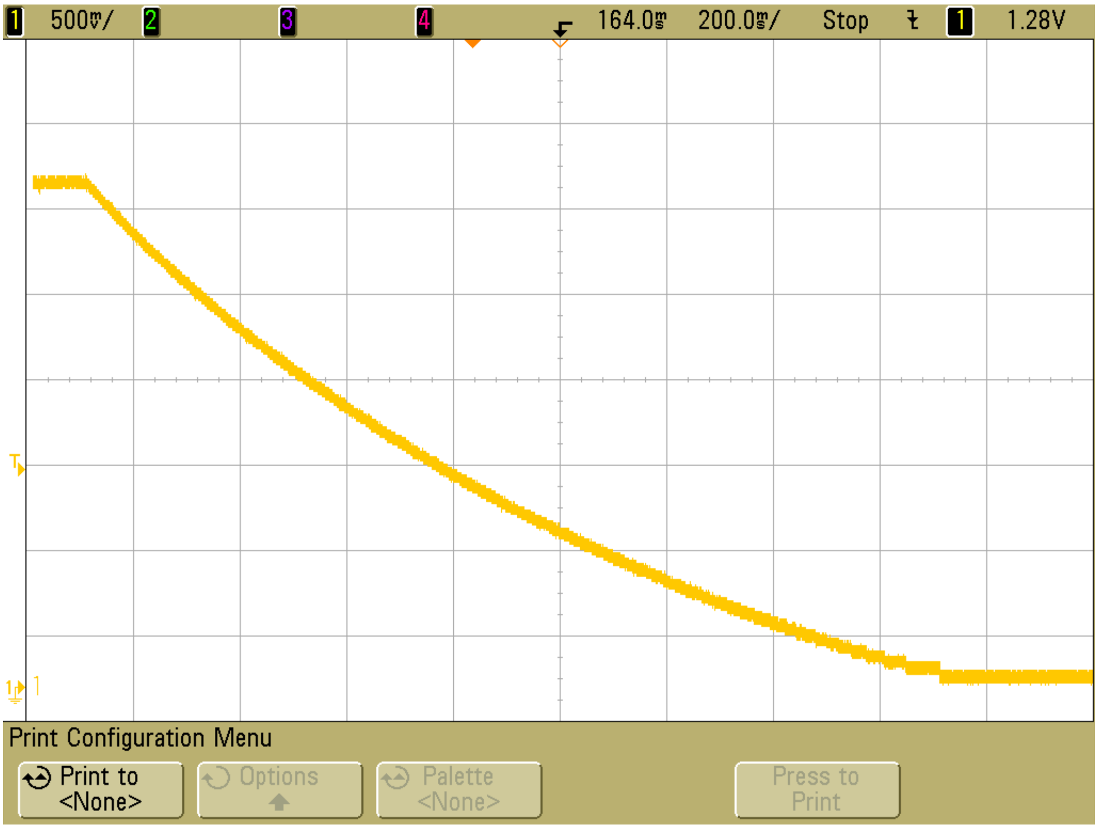

Figure 2.10: Plot of test results

B.6 Time Constant and Gain

Name: Group 510
Date: 30/09 - 2015

Purpose

The purpose of this test is to find the time constant τ and gain, by measuring the step response of the motor.

Setup

Test setup

List of Equipment

Instrument	**AAU-no.**	**Type**
Oscilloscope	64672	Agilent DSO6034A
Power Supply $(0-32\ \mathrm{V})$ $(0-10\ \mathrm{A})$	77076	Ea - ps 7032 - 100
Optical tachometer	77087	Compact

Procedure

1. Turn on the oscilloscope.
2. On the oscilloscope press the "mode"-key choose the "normal"-option, set the trigger to "rising-edge".
3. To prevent false triggering on the oscilloscope set the trigger value to
4. Press "single"-key on oscilloscope.
5. Turn on the power supply at 5 volt.
6. Insert a USB-pin in the oscilloscope and press the save key to extract the data.

Results

Figure 2.11: Plot of test results

Todo list