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Project's main objective was to develop an embedded software for Zumo robot control. To achieve this goal elementary theorems had been learned. These basics include but not restricted to numerical representation in 2's complement format, boolean algebra, PWM modulation and PID control. Study of technical manual and electronics datasheets had been necessary. After sufficient knowledge in embedded system programming achieved, the implementation work started with power management to avoid battery ruining. In the next step a basic decision based line following algorithm was developed. The method gave insight how the robot sees the line and how can the current position be measured. To further experiment with the robot control a basic Proportional-Integral-Derivative (PID) control algorithm was developed. Although the code had been finished, it never got fine tuned, only the proportional part is in use with a sufficiently high coefficient. Tests show, by utilizing 4 sensors instead only the two middle, the smoothness of movement can be further increased. Finally a "simple go inside the circle and stay there" algorithm was written for the sumo-style contest.

Keywords	Devices, Smart Systems, Embedded systems, Electronics

Metropolia

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Appendix 1 Physics

Abbreviation

AC	Alternating current
AD(C)	Analog to digital (converter)
DA(C)	Digital to analog (converter)
DC	Direct current
IR	Infrared
NiMH	Nickel-metal hydride
PID	Proportional, Integral, Derivate (control)
PWM	Pulse-width modulation

1 Introduction

The aim of this project was to study existing technologies and possibly discover new methods to effectively control electronic and robotic systems. The fundamentals of embedded system development was examined and an experimental control software was developed. The main objectives of the embedded software was hardware resource management, overall behavior implementation and predefined task perform. Many basic components of the robot and the micro controller had been explored to achieve these tasks. These modules have been presented in this documentation to provide a complete reference.
In the next chapter all the theoretical knowledge explained, which required to understand the basic operation of the robot's electronic. The third chapter presents the software's actual way of operation. The last chapter brings conclusion and show a possible direction for future development.

2 Theoretical background

First part of this chapter gives insight to theoretical electronic knowledge. The second part presents the electronic modules used in the robot and explains their components' operation.

2.1 Pulse Width Modulation

Pulse Width Modulation (PWM) is a modulation method used to encode information on a carrier signal. PWM is mainly used to empower electronic devices. As the modulated signal alternates between 0 and 1 the device gets an average power instead of continuous output. As a result the devices work in transition between OFF and ON states.

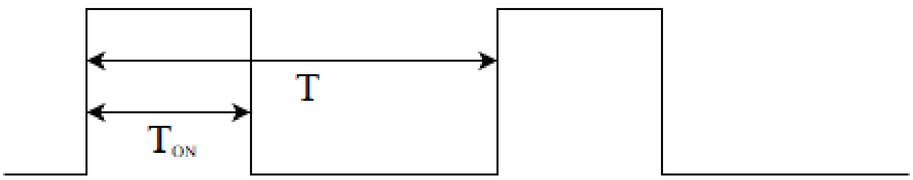

Figure 1: PWM cycle

Duty cycle means the length of ON state (T_{on} in figure) during a full cycle (T in figure). The cycle length or frequency can move on wide spectrum from 1 Hz (1 cycle / second) to 10-100 kHz. (See appendix 1, Frequency)

In this project 1 cycle is exactly 2.56 ms long as 8 bit timer used. Therefore frequency is approximately 390 Hz. 0 value means no movement, brakes are on during the whole cycle. [1]

2.2 PID controller

Proportional-integral-derivative controller or PID controller is a control loop mechanism. The desired position called setpoint (SP). The measured position referred as process variable (PV). The difference of these values give the error value $e(t)$. Based on this error value a new corrected position calculated. Calculation formula has 3 main parts each influencing differently the output.

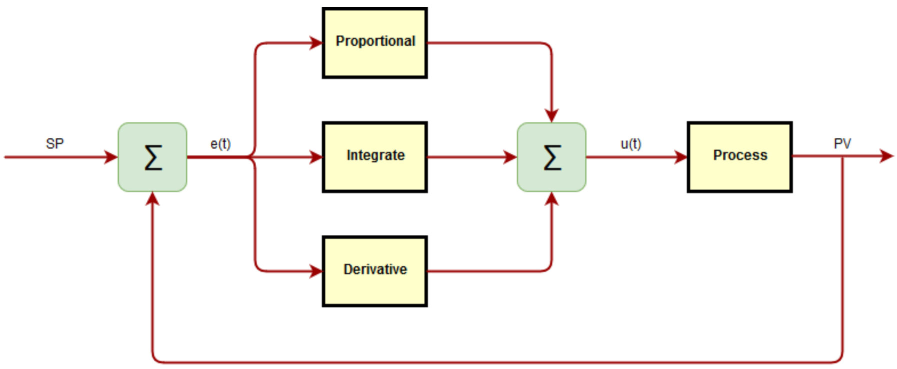

Figure 2: PID controller diagram

The proportional part is contributing linearly, greater current $e(t)$ error value results in greater correction. The integral part collects and integrates past error values. When this integrated error applied, it replaces the error deviation caused by proportional correction. As a result the quickly changing proportional correction replaced by a slowly changing integral correction and the function gets dampened. The derivative part gives a future estimate based on the current changes in the function. It try to zero out the error change rate. Hence the derivative part cannot bring the error to zero.

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \tag{1}$$

This mathematical formula contains all three parts. If any part is not to be applied the respective coefficient values should be set to 0. Usually the integral, the derivative or both. [2] [3]

2.3 Cypress CY8 modeling kit

Cypress CY8CKIT is an Arm Cortex M3 based inexpensive prototyping kit. It includes a programmer and debugger modul, making development easier. It is programmed through USB connection. Output terminal is provided on UART port emulated over the USB connection. Software development and device firmware write performed with PSoC Creator IDE software provided by Cypress, the kits manufacturer.[4]

2.4 Zumo robot

The Pololu Zumo is a small size (less than 10cm) tracked base robot platform. The motors and controller are replaceable allowing customized builds. It includes a steel plate, mounted at the front to protect electronics and to provide capability to push objects. Power source is 4 pieces of AA battery.[5]

2.4.1 Power management

The Zumo robot is powered by 4x 1,2V NiMH batteries. The micro controller runs with 5V and 0V. In order to protect the batteries form too low discharge the voltage is constantly measured. If the voltage drop low the user has to be noticed.
Because the micro controller operates with 5V, but the well charged batteries can reach even 1.4V each (sum up in 5.6V) the actual voltage is scaled down to 2/3 (See appendix 1, Voltage division rule). This lowered voltage then directed to micro controllers AD converter unit.[3]

2.4.2 Motor control

Zumo's motors are 6V DC motors.

- Idling: no acceleration and minimum force. Power input: 120mA at 6V.
- Stall: 1.6A / motor. Motor controller restricts current to 1.5A / motor.
- Speed: Run at 400 RPM. The installed gearbox's ratio is 75:1. The top speed is approximately 60 cm/s.

Motor controller unit connects batteries to both motors as instructed by control signals. Motor controller contains H-bridges (DRV 8835). DRV 8835 contains 2 bridges, thus capable to control 2 motors simultaneously.

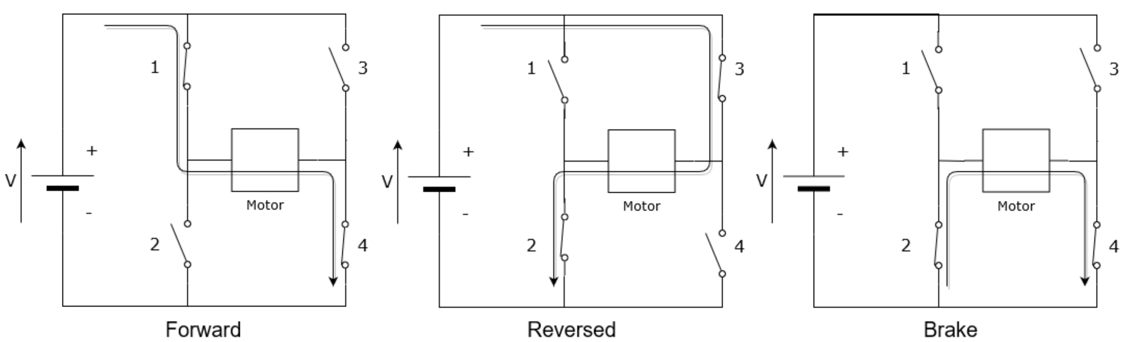

Figure 3: 3 states of motor controller

Electronically there are 3 states the H-bridge can be.

- Forward: direction set to 0, PWM set to 1
- Reverse: direction set to 1, PWM set to 1
- Brake: direction left as it was before braking, PWM set to 0

In brake mode the motor has changed to generator and shorted. In practice this means wheels locked. There is no mode when wheels can freely roll. [3]

2.4.3 Line detection sensors

Zumo has 6 infrared light based sensor positioned at the front. Because IR light is out of visible spectrum, 2 red light led also placed on board. The IR led's light reflected from the surface under the robot back to the sensors. Amount of reflected light is measured using indirect AD conversion. Reflected light activates IR sensitive transistor which close circuit. The current flowing in the circuit is integrated in a capacitor until voltage reach defined level. Time to reach defined level is measured with a micro controller counter. If the surface is white, it has good reflection, so the big current charge the capacitor in short time.
The actual measurement happens in three steps.

- Initial situation: Even when no measurement is happening some current might still flow eventually charging up the capacitor.
- Capacitor discharge: When the micro controller measurement pin gives 5V output, on both sides of the capacitor will be 5V. Consequently the capacitor discharge in 1…2 μs.
- Measurement: Micro controller measurement pin set to input and a timer is started. Capacitor starts to charge again as fast as the IR-sensitive transistor allows it. When capacitor charge reach about 2.5V, voltage at measurement point drops below 2.5V and the pin value turn to 0. Capacitor keeps charging up to 5V. Time to turn from 1 to 0 is measured.

Measurement procedure always takes 1 ms. Different sensors have different sensitivities. Environmental lighting also affects measurement as sun light contains plenty of infrared light.[3]

3 Realization

3.1 The embedded software and mechanics

Flow charts

3.1.1 Voltage measurement

Library for battery management is named <ADC_Battery>. It is part of micro controller standard library and the source can be found in 'codegentemp' folder. Prior to use, it has to be initialized with ADC_Battery_Start() command. Actual measuring is not instantaneous. The process is started with the ADC_Battery_StartConvert() command.
Wait to finish measurement is achieved in one step: ADC_Battery_IsEndConversion(ADC_Battery_WAIT_FOR_RESULT). The actual value is queried with ADC_Battery_GetResult16() instruction. As the micro controller operates with 5V, measurement range is 0V - 5V. The AD converter is 12 bits unsigned therefore the return value is in 0 - 4095 interval. The formula of actual voltage:

$$volts = \frac{ADcode}{4095} * 5 * 1.5 \tag{2}$$

. As mentioned in Chapter 2's Zumo robot section, battery voltage scaled down to 2/3. The trailing multiplication by 1.5 in the formula compensates this scale down.

3.1.2 PID / Error calculation

3.1.3 Sharp turn calculation

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3.1.4 Motor speed programming

3.2 Timing

Gantt charts

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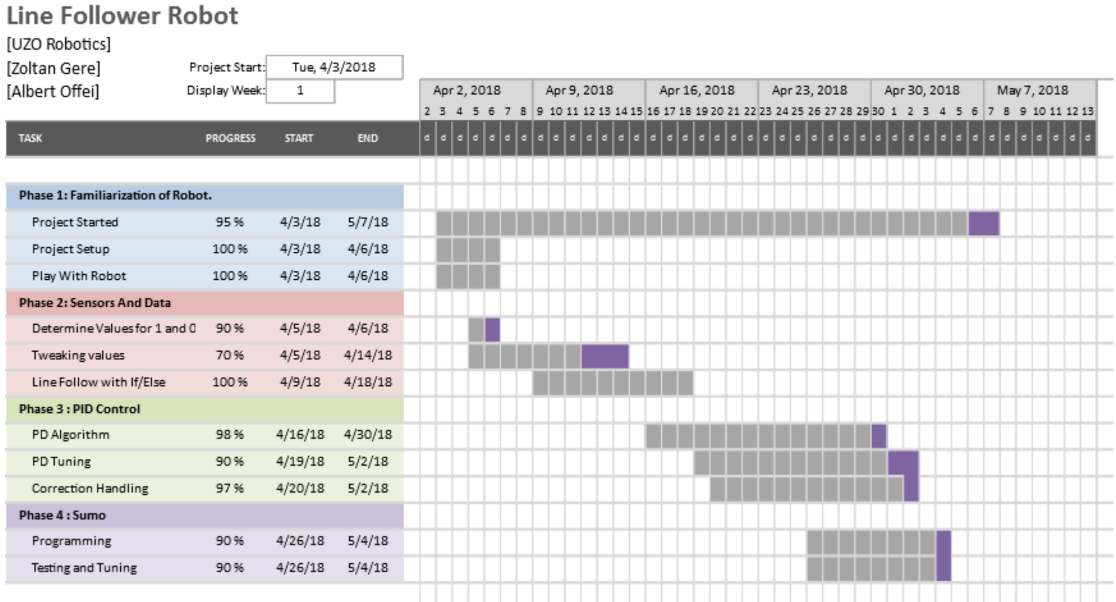

Figure 4: Development timeline

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4 Conclusion

Summary and Conclusions. This section summarizes the thesis and its objectives and results and makes recommendations. It answers questions such as: What was the purpose of this thesis? What was the thesis based on? What was discovered or what was the outcome? To what extent were the objectives of the thesis achieved? What would not be known if this work had not been carried out? What recommendations can be made, i.e. what should the case company/organization do based on the findings/outcome of the thesis? What was left unexplained? How could research be continued? How can the thesis be used? In addition, this section may also reflect on what was learned during the entire project. Again, absolutely no new theory is introduced here.

5 Latex formating helplet

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5.1 Section

Here is an example how to add biblio entry [6] using the “cite” [7, section 4.2]. Note that a paragraph is added by forcing a new line.

And let also try the figure (see figure 5) and internal reference (with label and ref or vref). The reference can be done to any label, for example why not to appendix 1 or to appendix **??**? To note, LaTeX will place the figure to the best place (except with forcing). Let them float till the final of final edit… then force them to not break a paragraph.

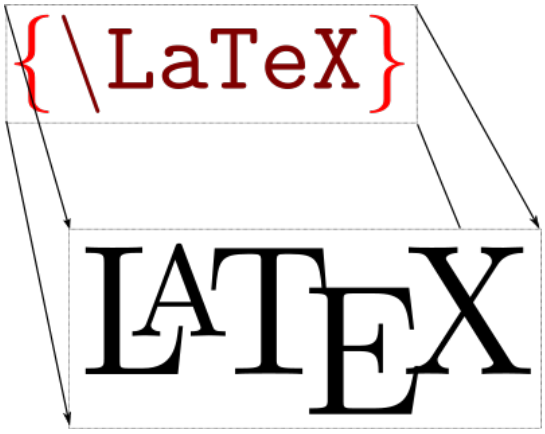

Figure 5: LaTeX cover image (Copied from wikibooks.org (2012) [8]).

Let’s also try a long quote: From the Universal Declaration of Human Rights:

> (1) Everyone has the right to education. Education shall be free, at least in the elementary and fundamental stages. Elementary education shall be compulsory. Technical and professional education shall be made generally available and higher education shall be equally accessible to all on the basis of merit.
> (2) Education shall be directed to the full development of the human personality and to the strengthening of respect for human rights and fundamental freedoms. It shall promote understanding, tolerance and friendship among all nations, racial or religious groups, and shall further the activities of the United Nations for the maintenance of peace.

> (3) Parents have a prior right to choose the kind of education that shall be given to their children. [9, article 26]

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- **A small hack** with list
- is to force the vertical space
- before and after the list

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5.1.1 Subsection

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5.1.2 Subsection with Math

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Ionivahvuus lasketaan kaavalla.

$$I = \frac{1}{2} \cdot \sum z_i^2 c_i \tag{3}$$

$$z_i = \text{ionin varausluku} \tag{4}$$

$$c_i = \text{ionin konsentraatio} \tag{5}$$

Aktiivisuuskerroin $\gamma_{\pm}$ lasketaan kaavalla.

$$\log \gamma_{\pm} = -\left|z_+ \cdot z_-\right| A \cdot I^{\frac{1}{2}} \tag{6}$$

$$A = \text{0,509 (lämpötilassa 25°C)} \tag{7}$$

$$I = \text{ionivahvuus} \tag{8}$$

$$z = \text{ionien varaus} \tag{9}$$

5.2 Section with Source Code

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```

<?php
$userName = $_POST["usern"];
//maybe not?
if ($userName){
  ?>
  <h2>Hello <?php echo $userName; ?>!</h2>
  <p>your message got received.</p>
  <?php
}
?>
```

Listing 1: Descriptive Caption Text

As see in listing 1: Donec et sapien ac leo condimentum vulputate id et tellus. Maecenas hendrerit malesuada interdum. Aenean dignissim sem faucibus elit congue faucibus id non risus. Morbi at dui non tortor pellentesque consequat non eget urna. Cras in sapien dui, a tincidunt velit.

5.3 Section with Table

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Table 1: Some data

Test 1	test 1234 test
Some more date comes here	with more values and if the text is very long it will disappear out of the box unless you force the column size :(

As presented in table 1: Donec et sapien ac leo condimentum vulputate id et tellus. Maecenas hendrerit malesuada interdum. Aenean dignissim sem faucibus elit congue faucibus id non risus. Morbi at dui non tortor pellentesque consequat non eget urna. Cras in sapien dui, a tincidunt velit.

Table 2: Another table with tabularx

Test 1	test 1234 test
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9 international community UN. The Universal Declaration of Human Rights. 1948;Available from: http://www.un.org/en/documents/udhr.

1 Physics

1.1 Frequency

Frequency means for periodical functions (e.g. signals) the number of periods completed in 1 second. Unit of frequency is Hertz (Hz). For example 1 period in 1 second is 1 Hz. 10 period in 1 second is 10 Hz.

1.2 Kinematics

1.3 Electricity

1.3.1 Voltage division rule

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1.4 Infrared light

Infrared light (IR) is 700nm to 1mm section of light spectrum. The wavelength of IR is longer than that visible by human eye. This invisibility gives IR light wide range of purpose.