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Automation- and systems technology project work

Ceilbot – Power delivery system

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Description

Ceilbot - Power delivery system

Plan a power delivery system for Ceilbot-robot. The robot moves on seiling using rails. In first phase a conceptual and theoretical study must be conducted in order to define how to realize the practical part. In the second phase the practical part can be built. The first phase alone could have a sufficient amount of work. Second phase can be conducted for example next semester.

Consider different power delivery systems: a) Battery based; 1-2 re-charging locations along/in the end of rails b) Battery based with (almost) continuous recharging; apply available conductive tape and sweeper for re-charging in any location; consider existing (expensive) commercial product vs. self-made low-cost with copper tape. c) High-power continuous feed; minimize/eliminate battery, provide sufficient power continuously for most of expected robot operations; consider if conducting tape has sufficient capacity, explore for options

Communicate with other team members for estimated power requirement and voltage levels and quality of power. Make educated guesses/estimates about power need for actuator and other subsystems. Explore known challenges with multivoltage systems including computers, sensors and electrical actuators. Consider safety issues and back-up in case of power loss, over load and short circuits.

Propose power system design and identify components. Present a plan for the second phase (building the system).

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1 Introduction

Ceilbot is a MIDE-project lasting approximately three years. The goal of the project is to plan and realize a prototype of a service robot moving on ceilings. The project started at fall 2009 and is executed by students of Aalto University. The Ceilbot-robot is going to move along the rails mounted on the ceiling. It will observe its surroundings using Kinect for 3-D-vision. As manipulator the robot will have an elephant trunk like gripper. The robot should be able to move in its working area and help people for example bringing and cleaning up things and doing such light tasks. More information about the project is available at projects home page [1].

Power delivery system is one of the robots subsystems. The goal of this project work was to define the power need of the robot, plan a power delivery system for the robot and document the plans so that someone continuing the project could put them in to use.

2 Options for the power delivery system

When beginning the project it was instructed to consider three different power delivery systems for the Ceibot robot: one based on batteries and one or two re-charging stations, the other one based on batteries and continuous charging and the third one based on continuous power supply with only small battery. The study of this topic could have been wider. With limited time recourses the study of the last two options was left quite brief. This section is mainly based on basic knowledge of electrical phenomena.

The first option was chosen for more specific examination and also for the base of the power delivery system. Main reason was, that it's mechanically easier to implement than the two others. The benefit of non-continuous charging is that non-solid electrical contacts are needed only at the charging stations where the robot doesn't move. The last two options would also have needed closer cooperation with the person planning the trolley of the Ceilbot. As soon as the sweeper matter is worked out, the battery based power delivery system is quite easy to update to continuous charging or to continuous power supply with only small battery.

For safety reasons it's extremely important to avoid short circuiting the poles of the robot's battery. Therefor the mechanical structure of the sweepers and conductors for continuous charging or continuous power supply needs to be planned carefully. The conductors are recommended to be installed inside the rails where the risk that something ends up to short circuit them is smaller. For avoiding switching current peaks the contact between the sweepers and the conductors should really be continuous.

If the continuous charging or power supply is implemented it's also important to protect the battery from over charging. That could be done by a protecting circuit which disconnects the battery from the supplier if the voltage of the battery or the current rises to high.

For the Liko-rails used in the project is available a copper tape. Its current capacity was told to be only 0.6 A, so it could be used only for charging purposes. The other weak spot of this current tape is that at least in the beginning of the spring it was possible to mount only on straight parts of the rails. Probably the company will solve this problem in future. Any way it would be good idea to examine their solution. [2]

3 Electrical needs of the Ceilbot

This section describes electrical needs of the Ceilbot-robot. Different power consumers of the robot can be thought as customers for the electrical system. Their needs of voltage, current and quality of the electricity are tried to take account. Because planning of the robot still continues, all the customers of the electrical system aren't yet known very precisely. It's recommended to check the needs when the planning goes further and all parts of the system are known better.

3.1 Customers of the power delivery system

This far there has been recognized seven different power consumers in the robot. They are customers for the power delivery system and are listed in the table 1. The specific models of motors and other parts came from other members of Ceilbot-team. They are examples of possible usable parts for the robot, but might be changed later. Anyway, they are used in this project work for estimating power consumption and need of different voltage levels in the Ceilbot.

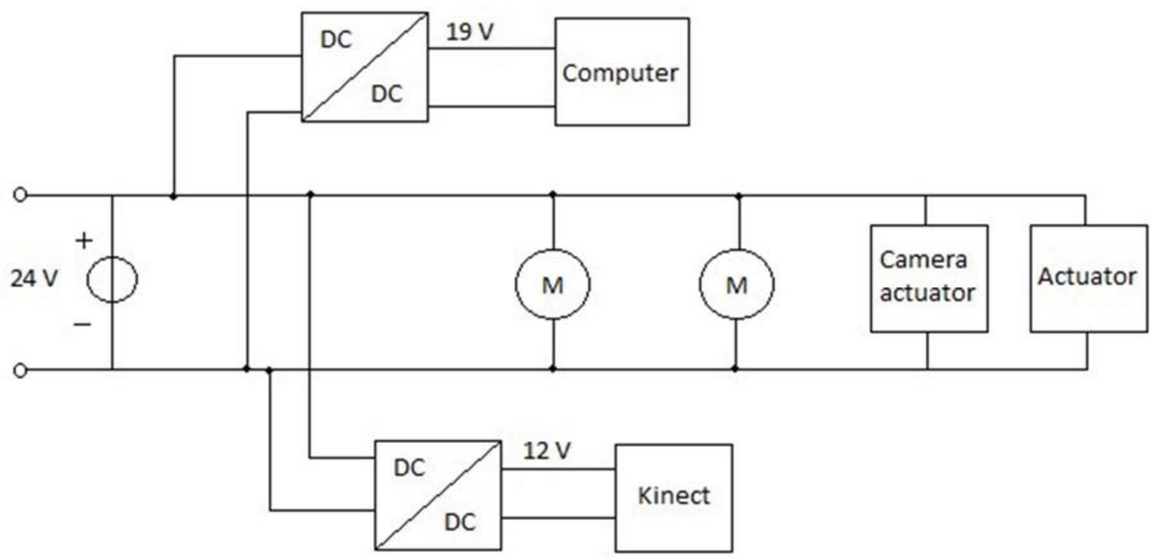
Table 1. Power consumers of the robot

Part	**Name/code**	**Nominal voltage (V)**	**Nominal current (A)**	**Estimated power(W)**
Trolley motor	EC-max 22 25W or EC-max 30 40W	24	1,5	24
Computer	Zotac ION-ITX-A (Atom 330)	19	?	33
Kinect	Kinect	12	1,08	13
Camera actuator, servo	Futaba S5301 Servo High-Torque 1/4 Scale	4.8…6	1,6	8
Camera actuator,	Trinamic QMot QSH4218	Driver supply 24,	1,5	<10

stepper motor		rated 5		
Camera actuator, circuit	-	24	some mAmps	~2
Actuator	?	?	?	100

Trolley motor is used for moving the robot along rails on the ceiling. Ceilbot's own computer handles all needed on board computing and controlling. It also communicates with computer outside the robot. Kinect is used for observing the working environment. Camera actuator moves Kinect so that the robot is able to look not only straight but also around it. Camera actuator consists of two motors and a controlling circuit for the motors. One motor turns the camera vertically and the other horizontally. The elephant trunk like actuator of the Ceilbot will move by servomotors, but the type and power consumption of servos was not yet known. So the estimated power for the actuator is a guess made by the project team.

The diagram of Ceilbot's main circuit is presented in picture 1. The two motors in the picture represent trolley motor and camera actuator's stepper motor. Camera actuator block consists of the control circuit of the camera actuator and the servo. The servo motor gets its power through the control circuit of the camera actuator.



Picture 1. Main circuit of the Ceilbot-robot

3.2 Power budget

This power budget, or estimation of the Ceilbots power consumption, is based on the knowledge of robots different power consumer described in the previous section. The Ceilbot is supposed to work as service robot. It can move in its working area along the rails and for example help picking things and bring them to some certain place. In table 2 there are presented four different working modes with different power consumptions.

In the table "Idle" means the situation when the robot is on but does nothing. "Moving and scanning" means the mode when the robot is moving without carrying anything. It was thought that the robot scans its surroundings all the time when it's moving. "Scanning and operating" is the mode when robot is stopped and is picking or laying down something with its actuator. The most power consuming mode "Moving, scanning and carrying" is when the robot is moving and same time carrying something with its actuator. In that case all electrical parts of the robot are active at the same time. Also the current driven from the batteries is highest at that mode. The powers marked for each part of the robot were approximated. The approximations are tried to overestimate a bit. In case of the camera actuator it was assumed that the motors moving the camera won't need as high current as their nominal current.

Table 2. Different working modes of the robot

Power consumption (W)							
	Trolley motor	**Computer**	**Actuator**	**Kinect**	**2-DoF**	**Tot. Power (W)**	**Current (A)**
Idle	2	21	0	12	0	35	1,46
Moving and scanning	24	33	0	12	15	84	3,50
Moving, scanning and carrying	24	33	100	12	15	184	7,67
Scanning and operating	2	33	100	12	15	162	6,75

For estimating the energy need of the robot two simple duty cycles were counted. In the both cycles the robot moves first form starting point A to endpoint B. Then it picks some object with it, returns back to point A and lays the object down. In the longer cycle the robot moves a longer way approximately 9 meters and in the shorter cycle it moves only few meters. The cycles are presented in table 3.

Table 3. Two duty cycles for the robot

Duty cycles					

Long cycle	Duration 34 s				
Duty	Moving and scanning	Scanning and operating	Moving, scanning and carrying	Scanning and operating	Energy over duty cycle
Time (s)	10	7	10	7	
Power (W)	84	162	184	162	
Energy (Ws)	840	1134	1840	1134	4948
				Energy(Wh)	1,4
Short cycle	Duration 20 s				
Duty	Moving and scanning	Scanning and operating	Moving, scanning and carrying	Scanning and operating	Energy over duty cycle
Time (s)	3	7	3	7	
Power (W)	84	162	184	162	
Energy (Ws)	252	1134	552	1134	3072
				Energy(Wh)	0,9

For estimating the needed capacity of the batteries, some work scenarios for the robot were done. The scenarios are based on the two duty cycles presented in table 3. In each scenario there is first mentioned the time the robot would work without going to charging station. Then the proportion of the time the robot is doing something. The rest of the working time the robot is in idle consuming the idle power 35 W. In the work scenarios 1 and 2 the robot is doing certain amount of cycles. In the scenarios 3 and 4 the robot would continue shorter or longer cycle trough all its working time. In the rest of the calculated scenarios the robot works proportional part of the scenario's duration and idles the rest of the time.

Table 4. Different working scenarios of the robot and needed energy capacity

No.	Work scenarios	Energy (Wh)
1	20 min on, 5 longer cycles	17
2	20 min on, 10 longer cycles	22
3	20 min, longer cycle	49
4	20 min, short cycle	51
5	30 min on, 1/2 longer cycle	124
6	30 min on, 1/2 short cycle	126
7	2 h on, 1/2 of which longer cycle	181
8	8 h on, 1/4 of which longer cycle	501
9	8 h on, 3/4 of which longer cycle	943

3.3 Possible problems with the quality of electricity

At a system, that includes both delicate circuits standing electrical disturbance poorly and motors, converters et cetera generating such disturbances, there is a risk that the system does not work together. The problems derive from electromagnetic interference (EMI) between the parts of electrical system.

For commercial products there are standards for electromagnetic compatibility (EMC). In European Union there are plenty of standard specified for devices in different use [3]. The standards are tighter for devises in domestic use or traffic devices than devices in industrial use. They include limits both for electromagnetic emission (EME) the device is producing and emission it should be able to handle with.

Konstantin Kostov describes EMC quite clearly in his doctoral dissertation. Part of the dissertation is also used as literature on course S-81.4100 EMC in Power Electronics. EME is usually divided into radiated and conducted emissions. A good way to reduce the radiated emission is to encapsulate the devise with metallic cover. For conducted emission filter capacitors and inductances can do the job. Also minimizing the conductor loops and using twisted pair cables can help. [4]

4 Batteries

When starting to look for suitable batteries for the Ceilbot few criteria were defined: the battery should be safe in indoor use, they should stand cyclic use and not have memory effect. The battery types were limited to different kind of lithium ion batteries and valve regulated lead acid batteries. Flooded lead acid batteries were excluded from the study because of the risk of spilling the acid.

4.1 Suitable batteries

Valve regulated lead acid batteries would be easier to handle and they are a bit cheaper than lithium ion batteries. Their weakness compared to lithium ion batteries is bigger mass and size for the same energy capacity and longer charging time. Lithium ion batteries need a bit more careful handling. They have both lower and upper limit for their voltage, so they shouldn't be discharged too deeply. Too deep discharge can break the battery and too high charge voltage can even destroy it. Therefore lithium ion batteries need a protection circuit that disconnect them from charger or load if the voltage or current limits are hit. For any type of batteries the current limits should also be followed.[4]

The batteries should of course meet the electrical and mechanical demands of the Ceilbot. Discharging current of the battery should be high enough for all working modes of the robot. The highest needed current was calculated to be less than 8 amperes. The batteries should also be available in Europe and if possible in Finland. That's for avoiding problems with the delivery.

Some suitable batteries are listed in table 5. The energy capacities of most listed batteries are quite large compared to scenarios of needed energy capacity presented in table 4. The reason for that was an error that occurred when changing energies over duty cycles (presented in table 3.) from watt seconds to watt hours. Do to the calculation error the energy needs were assumed ten times higher than was the case in reality. The mistake was noticed only just in the end of the project and the batteries were looked for based on the faulty information.

The LiFeYPO4 lithium ion batteries listed in the table are Thunder Sky batteries manufactured by Winston Battery in China. The web store celling them is known reliable. For this list were picked both individual cells and 12 V batteries. Two of the 12 V batteries (LiFePO4) include also the protecting circuit module (PCM), which is needed when using the batteries. Batteries without the protecting circuit are cheaper but because the circuit will be needed anyway it could be better to by the batteries with PCM. Also the energy of smaller batteries with the protecting circuit is large enough for the robot. The optimal current of smaller battery with PCM (LiFeYPO4) is under the limit of the highest working current of Ceilbot. The charge and discharge currents in the table are optimal charge and discharge currents so the batteries can manage also higher currents. My opinion is that the battery should be chosen based on its optimal discharge current. The maximal continues discharge current for the smaller battery with PCM is 12 A and maximal time for the continuous higher current is 30 min. [6]

The AGM batteries int the table are manufactures by FIAMM. At their datasheet was no clear limit for optimal discharge current. Anyway for the types listed in the table 5 the maximal discharge current is high enough. [7]

As price comparison also two Biltema gel batteries for motor cycles were taken with in review. [8]

At the table 5 in the left are first information about individual batteries or cells and in the right some summary of packet needed to produce 24 V voltage with each batteries or cells. For the LiFeYPO4 batteries the charging time is only 1 h if the maximum charging current 20 A is used. More information about each battery can be found on datasheets. The datasheets of the batteries are as appendixes of this report.

Table 5. Examples of suitable batteries [6, 7, 8]

Batteries									Packet for 24 V				
Type	Model	Nominal voltage (V)	Nominal capacity (Ah)	Nominal energy (Wh)	Mass (kg)	Dimensions (mm)	Dicharge current (A)	Charge current (A)	Pcs neede	Energy (Wh)	Mass (kg)	Charging time (h)	Estimated prise (euro)
LiFeYPO4	LP12V20AHB	12	20	240	3	181 x 167 x 77	10	10	2	480	6,8	2,0	232
LiFeYPO4	LP12V40AH+	12	40	480	9	225 x 208 x 125	20	20	2	960	18	2,0	370
LiFeYPO4	LFP020AH	3,2	20	64	1	152 x 71 x 42	10	10	8	512	6	2,0	224
LiFeYPO4	LFP040AH	3,2	40	128	2	116 x 190 x 46	20	20	8	1024	12,8	2,0	376

LiFePO4, PCM	LP12V12AHP	12	12	144	2	151 x 101 x 98	6	6	2	288	3,8	2,0	174
LiFePO4, PCM	LP12V17AHP	12	17	204	3	181 x 167 x 77	8	8	2	408	5,6	2,1	242
AGM (FIAMM)	FG21201/2	12	12	144	4	151 x 98 x 94		3	2	288	7,5	4,0	130
AGM (FIAMM)	FG21803	12	18	216	6	181 x 167 x 76		4,5	2	432	11,8	4,0	164
AGM (FIAMM)	FG22703/5	12	27	324	9	166 x 175 x 125		6,8	2	648	17	4,0	230
Gel (Biltema)	YB16L-B	12	19	228	7	175 x 100 x 156			2	456	13,2		148
Gel (Biltema)	YB14L-A2	12	14	168	4	134 x 89 x 160			2	336	8,54		118

4.2 Charging of the batteries

For the charging of batteries one or two charging stations are needed. The charging station should be planned compatible with the trolley of the Ceilbot. One charger could be wired to two charging stations because the stations are not in use at the same time. The charger type should be chosen according to the battery chosen for the Ceilbot.

For the AGM or gel batteries almost any 24 V charger with constant current under the maximum charging current of the battery is suitable. The listed LiFePO4 batteries with PCM may replace AGM batteries directly so I assume that the same charger that suits for AGM batteries suits for them also. Suitable chargers could be for example following. The prices were found from Puuilo’s wet store [9].

Einhell Charger BT-BC 15 approximately 55 euros

Charging current 6V/12V/24V for normal charging is 7A/8A/7,5A and for fast charging 15A/15A/10A.
Weight: 6 kg

Einhell Charger BT-BC 30 approximately 130 euros

Voltage: 230 V ~ 50 Hz
Current in: 2,3 A
Power in: 430 W
Voltage out: 6 V / 12 V / 24 V DC
Current out 6 V: 0,7-21 A arith. / 0-9-30 A eff.
Current out 12 V: 1-20 A arith. / 1,6-30 A eff.
Current out 24 V: 1,8-14 A arith. / 3-20 A eff.
Charging ability: 3-400 Ah
Weight: 11,9 kg

With the last one the charging current can be chosen by the user.

For LiFeYPO4 batteries without PCM the charger should be meant to charge such batteries. From GWL Power is possible to order also chargers. One suitable charger for listed in the table 5 could be charger POW12V20A [6]. Its technical information is presented below:

Model	POW12V20A
AC Input	230V AC 50Hz, 6A
Output	24V DC 20A
V-nom	24V I-CC 20A
V-deep	22V
I-min	7A
V-max	32V
Size	87/150/150 mm
Weight	1.8 kg

5 Converters and protections

The focus of the project work moved to looking for suitable batteries for the robot. So the examination of suitable converters, filter and protection was left quite short. With more time in use deeper investigation of the topic would have been in order. Here are presented some solutions, but they might not be the best.

As discussed in the section 3.1 the power system of Ceilbot needs to provide three different voltage levels 24 V, 19 V and 12 V. The main voltage of the system is 24 volts. The voltage of the batteries varies approximately between 22 V and 28 V. If such variation is too much for some parts of the robot a DC-DC converter can be added to balance the voltage. I recommend first to try without that additional converter. The converter should be chosen based on the load. If only part of the devises with nominal voltage 24 V need the converter, it’s unnecessary to buy a bigger converter for the 24 voltage system.

Tapio Hirvikorpi who was responsible of planning the trolley for the Ceilbot suggested a car charger P.SUP.N24-BL to provide the 19 V voltage for the computer. The same devise is suitable also for providing Kinect’s 12 V voltage. The output voltage of that charger can be chosen between 12 and 22 volts. Also the output current 2.0-3.0 A would be high enough for each two device. I didn’t find any efficiency characteristics for the device. It was only told to have good efficiency. The benefit of this solution would be that the converter is easy to get and it’s quite cheap. One P.SUP.N24-BL costs about 23 euros.

The needed protections and safety systems of the robot would be easier to plan if all parts of the electrical system were better known. Anyway some things are clearly needed:

- If the chosen battery is a lithium ion battery without built-in protection circuit an external circuit is needed. The circuit should be able to measure both the voltage and current of the battery and disconnect the battery if the safety limits are crossed.
- Separated fuses for different loads of the power system. We don't want to shut of all the system, if some part of it gets broken. The computer will probably monitor all subsystems of the robot and find out if some part falls of. Fuses meant to 24 V systems with suitable current limit can be found widely.
- One fuse for all the system.

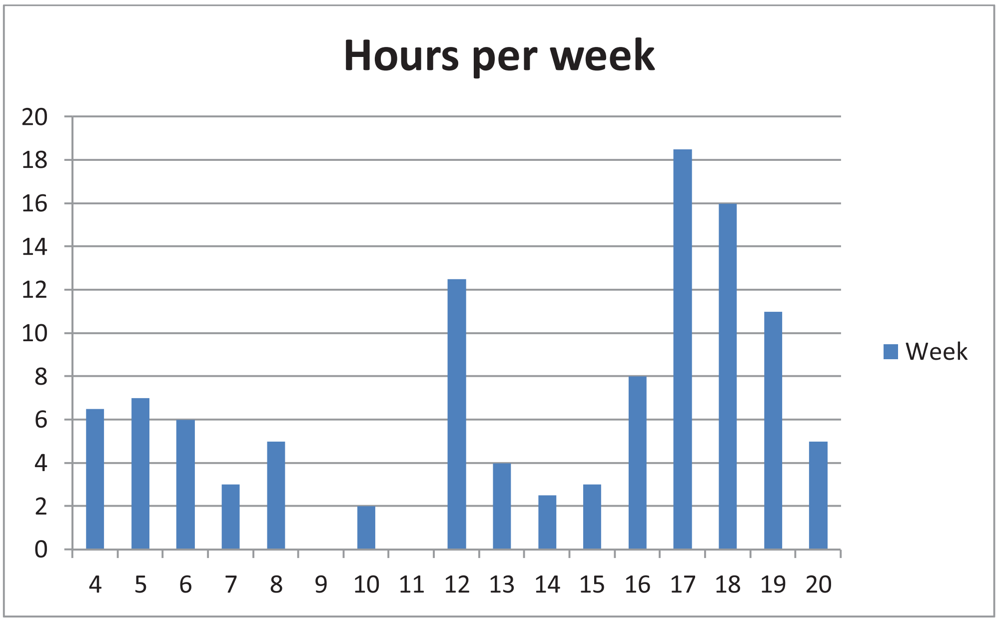
Regardless of the type of the battery measuring of the battery voltage is needed to know when to go to charging station.

The needed filters for the power supply system were difficult to plan with the information available during the project. Anyway, if it occurs that all electrical parts of the robot do not work together some EMC-filter capacitors and shielding the more delicate parts of the electrical system could help. It might be also interesting to measure the EMI of the robot.

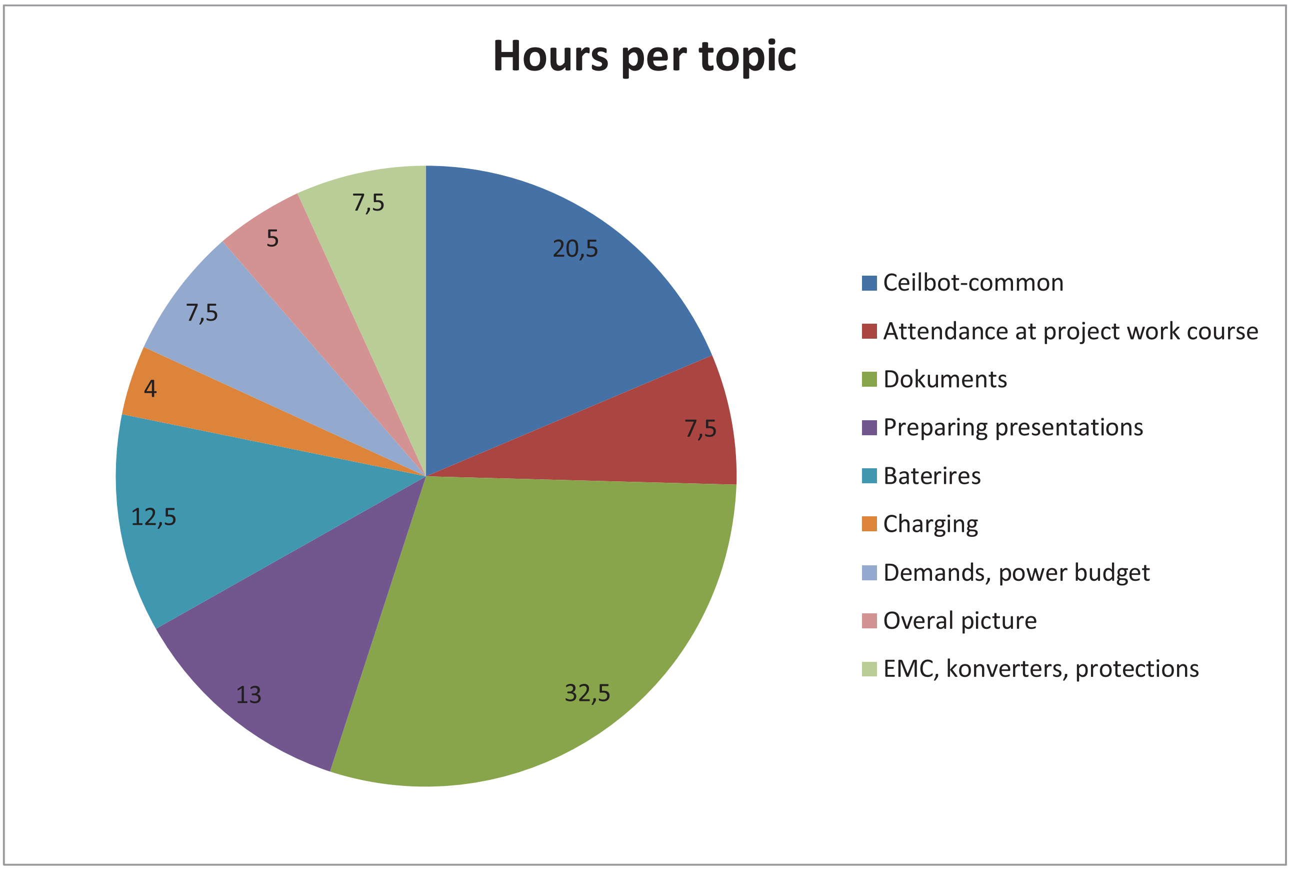
6 Time consumption

In the beginning of the semester I had planned to use on average 8 hours per week working for the project together that would have been 120 hours. The number of realized work hours was approximately 110. The hours were divided in my notes both by the work topic and the week. In the picture 2 is a figure of used work hours divided to each week of the semester. In the picture 3 is a figure of the work hours divided by the topic or activity they were used.

The picture 3 shows that the work load was not divided evenly on the semester. Two weeks without hours are one when I was ill and the other is the week after exam week when I had to do other assignments. During the project I also noticed that working in short periods of one or two hours is not as efficient as working in longer periods. Because most of my courses ended on week 16 there has been more time to use for the project after that. Documenting of the project and preparing the presentations took more time than I had expected. The reason might be that I checked quite many things while preparing them. Also writing in English is slower than in Finnish. Ceilbot-common topic includes project meetings and other project common happenings.



Picture 2. Used work hours divided by the week.



Picture 3. Work hours divided by the topic.

7 Conclusion

As defined before the project the final plan of building the electrical system was not the result of this project. Hopefully there is anyway some use for studies made for this project work. The estimate of Ceilbot's power consumption was done and is presented in section 3. The starting point for looking for batteries was a bit wrong so the batteries presented in table 5 are quite large. If the electrical parts and so the power consumption and needed peak current of the Ceilbot do not change very much I would choose to use two bigger LiFePO4 batteries with PCM for the robots battery. That battery would weight 5.6 kg and provide about 400 Wh energy storage capacity.

There is still quite much to do. A list of tasks, I think, need to be done is below.

To do:

- Find out the final electrical parts of the robot
- Check the power budget and energies and currents needed in each working mode
- Choose the battery based on previous steps and choose a charger for the battery
- Define if other measurements than voltage of the battery are wanted (or needed) and choose components for measurements.
- Plan the charging operation: communication with main control unit, mechanics of the charging station
- Check the converters for different voltage levels.
- Choose the needed fuses based on first step in this list. Some converters and chargers already have protection against over current, but fuses could still be added because they are quite cheap and breaking them is better than breaking something else.
- Plan how all the electrical stuff is fitted inside the robot.

References:

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[2] Liko-rails, charging solutions. http://www.liko.com/int/international/Products/Overhead-Lifts/Charging-options/ 16.5.2011

[3] European standards, Electromagnetic-compatibility. http://ec.europa.eu/enterprise/policies/european-standards/documents/harmonised-standards-legislation/list-references/electromagnetic-compatibility/index_en.htm 15.5.2011

[4] K. Kostov, Design and characterization of single-phase power filters. *Dissertation for the degree of Doctor of Science in Technology to be presented with due permission of the Faculty of Electronics, Communications and Automation for public examination and debate in Auditorium S4 at Helsinki University of Technology (Espoo, Finland) on the 27th of November, 2009, at 12 noon.* ISBN 978-952-248-186-3

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[6] GWL Power, Thunder Sky LiFeYPO4 batteries. http://www.ev-power.eu/index.php 15.5.2011

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http://www.fiamm.com/linea.php?s=559&BU=4&APPL=39&type=APPL&Country=FIN&Prod=268 15.5.2011

[8] Biltema Gel Batteries. http://www.biltema.fi/ 15.5.2011

[9] Web store for chargers. http://www.puuilo.fi/cat/product_catalog.php?c=46 16.5.2011

Appendixes:

LP12V20AHB battery specification: GWL-LFP-Product-LP12V20AHB.pdf

LP12V40AH+ battery specification: GWL-LFP-Product-Spec-LP12V.pdf

LFP020AH cell specification: GWL-LFP-Product-Spec-20AH.pdf

LFP040AH cell specification: GWL-LFP-Product-Spec-40AH-200AH.pdf

Datasheet for batteries with PCM: GWL-LFP-Product-Spec-PCM.pdf

Datasheet of FIAMM's AGM batteries: Productsheet_FG-eng.pdf