Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Autonomous Systems Lab
Prof. Roland Siegwart

Semester Thesis

Design and Control of a Bicopter UAV

Spring Term 2018

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Declaration of Originality

I hereby declare that the written work I have submitted entitled

Your Project Title

is original work which I alone have authored and which is written in my own words.[1]

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Contents

Preface

This semester project was proposed by Autonomous System Lab.

Thank you to Karen and Zachary to help me along the semester to succeed this project.

Abstract

Hier kommt der Abstact hin ...

List of Figures

Symbols

Symbols

ϕ, θ, ψ	roll, pitch and yaw angle
b	gyroscope bias
Ω_m	3-axis gyroscope measurement

Indices

x	x axis
y	y axis

Acronyms and Abbreviations

ETH	Eidgenössische Technische Hochschule
EKF	Extended Kalman Filter
IMU	Inertial Measurement Unit
UAV	Unmanned Aerial Vehicle
UKF	Unscented Kalman Filter

Chapter 1

Introduction

1.1 Description of the project by ASL

Design and Control of a Bicopter MAV

Design and control of a UAV using only two rotors, and additional actuation to allow for full position and orientation controllability.

Keywords: MAV Control Design Omnidirectional

Description

Omnidirectional UAVs present numerous advantages over traditional UAVs for aerial interaction and unobstructed observation.

This project aims to develop a UAV using only two rotors, and additional actuation to allow for full position and orientation controllability.

As a semeter thesis, this project would target demonstration of the system in simulation. As a masters thesis, the project would include integration of a real platform and evaluation of real flight performance.

Work Packages

- Investigate morphology and actuation
- Evaluate controllability
- Design a controller for omnidirectional flight
- Test in simulation and evaluate performance

If masters thesis:

- Build system
- Flight testing and performance evaluation

Requirements

- c++ coding experience
- Knowledge of ROS recommended

If masters thesis:

- System integration experience

1.2 Goals

???

1.3 Workflow

Worked every weeks on it. Present my progress and advancement each week to my supervisors

1.4 Timeline

At the start of the project, the expected plan showed in the figure 1.1 was ambitious. Therefore it was difficult to respect it along the semester because it also was some courses to attend and we added to build a prototype during the first part of the semester.

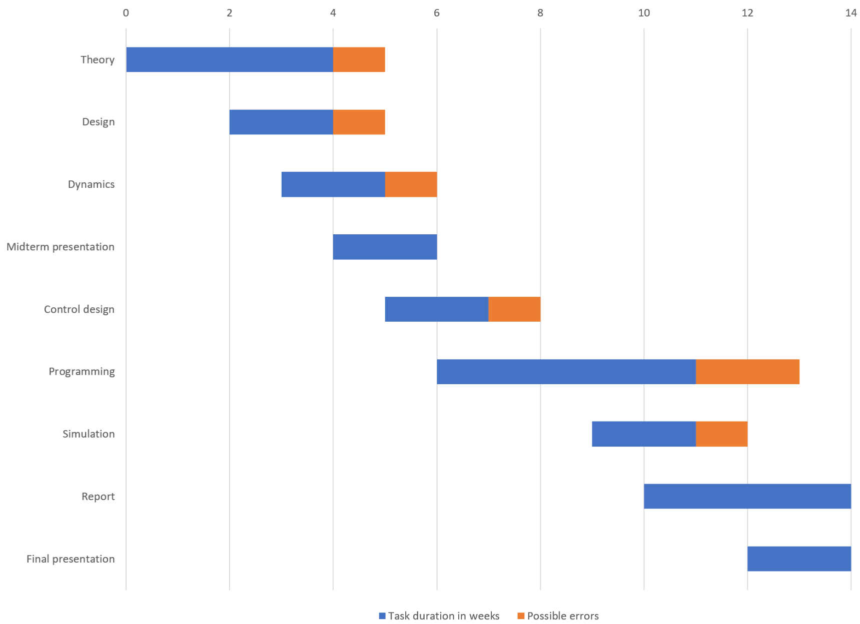


Figure 1.1: Expected plan for the semester project

So, the real planning would become ...

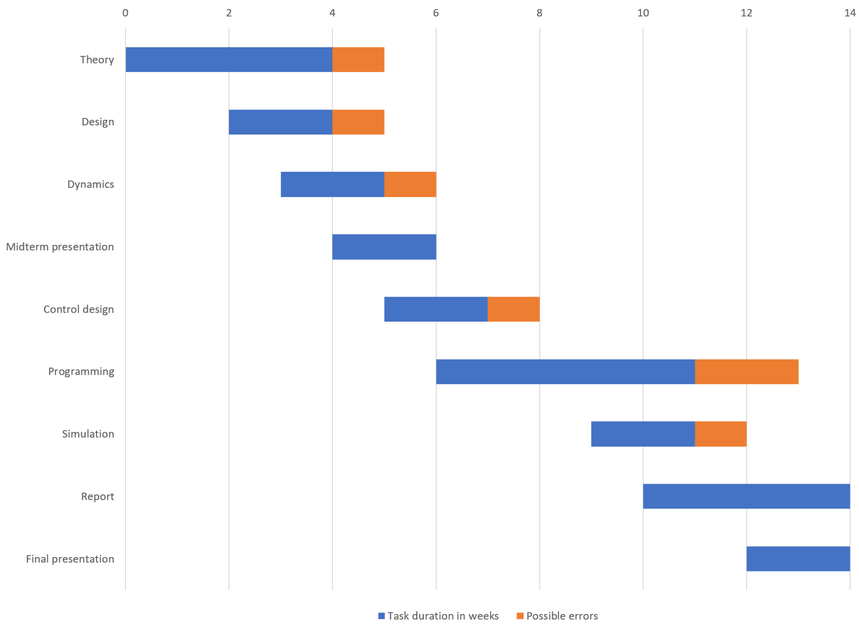


Figure 1.2: Real plan for the semester project

Chapter 2

Design

2.1 Related works

Every helicopter has 2 propellers that one is used to flight it and the other one against the torque created by the first one. The americans invented the Chinook which it also uses two propellers to lift it.
Most of drone has four propellers or more but for a moment, we can see some tricopter. The new generation of multicopter used some tilting motors for adding some degrees of liberty. That increase the changement of orientation in space.

2.2 Specifications

Metric No.	Metric	Importance	Units	Marginal	Ideal
	Weight	8	Kg	Value	Value
	Length	5	m	1	0,6
	Large	5	m	0,5	0,5
	High	5	m	0,3	0,3
	Tilting motor speed	8	RPM	0,3	0,3
	Measure of position of tilting motor	10	Yes/No	60	120
	Time of flight	7	min	Yes	Yes

Table 2.1: Specification table

2.3 Ideas and First Drawings

2.4 Needs for the Bicopter

2.5 The Choice of Components

Id	Type	Number of pieces	Brand	Model	Description	Name of CAD file	Dimension
Electronic							
1	Flight controller	1	px4 autopilot	Pixracer Autopilot		PixRacer	36x36mm w
2	Radio Receiver	1	FrSky	XM EU-LBT 16CH Micro Receiver with SBUS			15*10*3.5m
3	ESC	2	T-Motor	FPV 30A Blheli-32bit 2-4S		Esc_t_motor	26x14mm
4	Motor	2	T-Motor	MN1806 KV1400		MN1806	
100% =>445 gr”							
5	Propeller	2	T-Motor	6*2 CF			
6	Tilting motor	2	DYNAMIXEL	XL430-W250-T		XL430	
7	Power Distribution	1	Matek	Mini Quad PDB with 5V & 12V BEC Outputs	Regulated 5V & 12V BEC outputs	Power_distribution	36x36mm w
8	Battery	1	TURNIGY Graphene	1300mAh 4S 65C Lipo		Battery	78x35x33
Structure							
9	Bearing	4		61803-2RS1			
12	Bearing-holder	4	machining	30x30x6-26mm			
13	Lending gear	1	HOBBYKING			Lending_gear	
14	Slip ring-holder	2				Slip_ring_holder	
15	Slip ring	2		SNF-0310 high current slip ring	10 Amp	Slip_ring	
16	Shaft	2		Carbon fiber diammeter 10mm		shaft_CFRP	
17	Motor-montering	2	3D Printing			Motor_montering	
18	Intermediate Schaft/Tilt	2	3D Printing	12mm diam, inner diam. 10mm		Intermediate _schaft	
19	Gearing	1		d=20		Gearing_small	
20	Gearing	1		d=40		Gearing_big	
21	Structure battery	1		0			
22	Structure level 1	1				Structure_level_1_v1	
23	Structure level 2	1				Structure_level_2_v1	
24	Structure level 3	1				Structure_level_3_v1	

2.6 Final Design Prototyped

Chapter 3

Prototype Building

3.1 Ordered componants

3.2 Mechanical Construction

3.3 3D printing

3.4 Assembly

Chapter 4

System Modelling and Control

4.1 Allocation matrix

Chapter 5

Simulation

5.1 Introduction to ROS

5.2 Model Description

5.3 Nodes

5.4 Control

5.5 Results

Chapter 6

Real flight

?????? NOTHING

Appendix A

Irgendwas

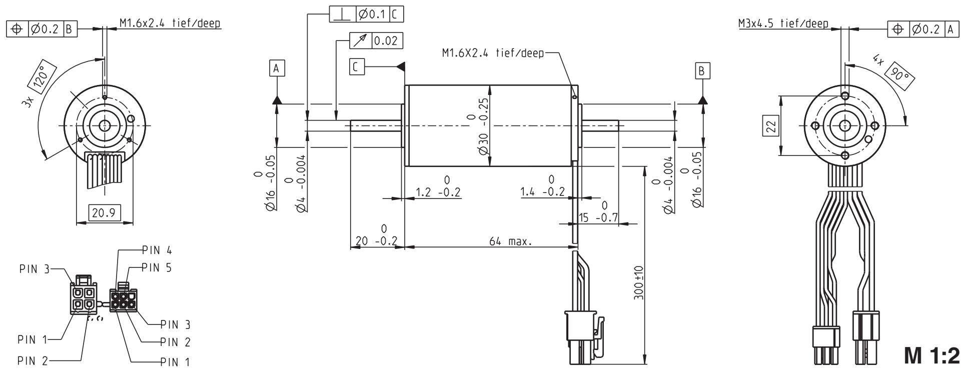
Bla bla . . .

Appendix B

Datasheets

maxon EC-max

EC-max 30 ∅30 mm, brushless, 60 Watt



M 1:2

Stock program
Standard program
Special program (on request)

Part Numbers

Motor Data		272762	272763	272764	272765
Values at nominal voltage					
1 Nominal voltage	V	12	24	36	48
2 No load speed	rpm	7980	9340	9490	9350
3 No load current	mA	302	191	130	95.4
4 Nominal speed	rpm	6590	8040	8270	8130
5 Nominal torque (max. continuous torque)	mNm	63.6	60.7	63.7	64.1
6 Nominal current (max. continuous current)	A	4.72	2.66	1.88	1.4
7 Stall torque	mNm	381	458	522	519
8 Starting current	A	26.8	18.8	14.5	10.7
9 Max. efficiency	%	80	81	82	82
Characteristics					
10 Terminal resistance phase to phase	Ω	0.447	1.27	2.48	4.49
11 Terminal inductance phase to phase	mH	0.049	0.143	0.312	0.573
12 Torque constant	mNm/A	14.2	24.3	35.9	48.6
13 Speed constant	rpm/V	672	393	266	197
14 Speed/torque gradient	rpm/mNm	21.2	20.6	18.4	18.2
15 Mechanical time constant	ms	4.86	4.73	4.21	4.17
16 Rotor inertia	gcm²	21.9	21.9	21.9	21.9

Specifications

Thermal data

17	Thermal resistance housing-ambient	7.4 K/W
18	Thermal resistance winding-housing	0.5 K/W
19	Thermal time constant winding	2.76 s
20	Thermal time constant motor	1000 s
21	Ambient temperature	-40…+100°C
22	Max. permissible winding temperature	+155°C

Mechanical data (preloaded ball bearings)

23	Max. permissible speed	15000 rpm
24	Axial play at axial load < 6.0 N	0 mm
	> 6.0 N	0.14 mm
25	Radial play	preloaded
26	Max. axial load (dynamic)	5 N
27	Max. force for press fits (static)	98 N
	(static, shaft supported)	1300 N
28	Max. radial loading, 5 mm from flange	25 N

Other specifications

29	Number of pole pairs	1
30	Number of phases	3
31	Weight of motor	305 g

Values listed in the table are nominal.

Connection motor (Cable AWG 20)

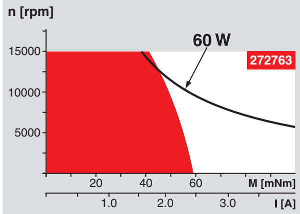
red	Motor winding 1	Pin 1
black	Motor winding 2	Pin 2
white	Motor winding 3	Pin 3
	N.C.	Pin 4
Connector	**Part number**	
Molex	39-01-2040	

Connection Sensors (Cable AWG 26)

yellow	Hall sensor 1	Pin 1
brown	Hall sensor 2	Pin 2
grey	Hall sensor 3	Pin 3
blue	GND	Pin 4
green	V_{Hall} 3…24 VDC	Pin 5
	N.C.	Pin 6
Connector	**Part number**	
Molex	430-25-0600	

Wiring diagram for Hall sensors see p. 35

Operating Range



Comments

Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overloaded (recurring).

Assigned power rating

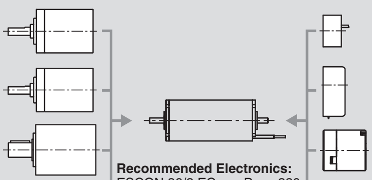
maxon Modular System

Overview on page 20 - 25

Planetary Gearhead
∅32 mm
8.0 Nm
Page 266

Koaxdrive
∅32 mm
1.0 - 4.5 Nm
Page 268

Planetary Gearhead
∅42 mm
3 - 15 Nm
Page 271



Encoder MR
500/1000 CPT,
3 channels
Page 302

Encoder HEDL 5540
500 CPT,
3 channels
Page 308

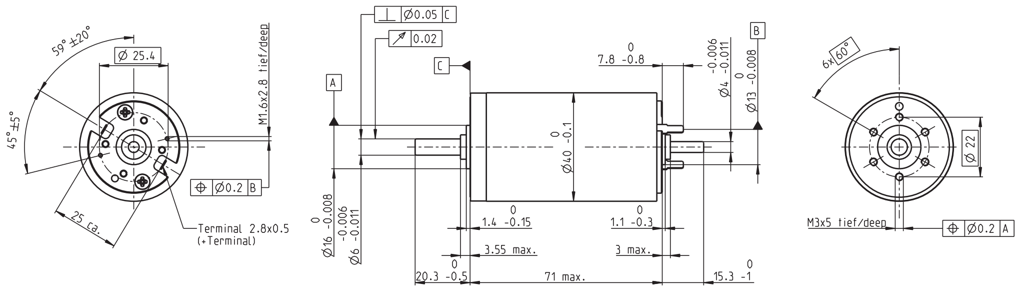
Brake AB 20
24 VDC
0.1 Nm
Page 346

Recommended Electronics:

ESCON 36/3 EC	Page 320
ESCON 50/5, Module 50/5	321
ESCON 70/10	321
DECS 50/5	324
DEC Module 24/2	325
DEC Module 50/5	325
EPOS2 24/5, 50/5	331
EPOS2 P 24/5	334
EPOS3 70/10 EtherCAT	337
Notes	**24**

RE 40 ∅40 mm, Precious Metal Brushes, 25 Watt

NEW



M 1:2

Stock program
Standard program
Special program (on request)

Part Numbers		448588	448589	448590	448591	448592
Motor Data						
Values at nominal voltage						
1 Nominal voltage	V	9	18	24	42	48
2 No load speed	rpm	2850	2850	2780	2920	2690
3 No load current	mA	49.7	24.8	18.1	11	8.62
4 Nominal speed	rpm	2610	2600	2480	2640	2410
5 Nominal torque (max. continuous torque)	mNm	87.8	87.8	88.2	87.6	87.6
6 Nominal current (max. continuous current)	A	2.96	1.48	1.09	0.65	0.524
7 Stall torque	mNm	873	956	794	895	818
8 Starting current	A	29	15.9	9.66	6.53	4.81
9 Max. efficiency	%	92	92	92	92	92
Characteristics						
10 Terminal resistance	Ω	0.311	1.14	2.49	6.43	9.97
11 Terminal inductance	mH	0.0824	0.33	0.613	1.7	2.62
12 Torque constant	mNm/A	30.2	60.3	82.2	137	170
13 Speed constant	rpm/V	317	158	116	69.7	56.2
14 Speed / torque gradient	rpm/mNm	3.27	2.98	3.51	3.27	3.3
15 Mechanical time constant	ms	4.85	4.29	4.36	4.14	4.13
16 Rotor inertia	gcm²	142	137	119	121	120

Specifications

Thermal data

17	Thermal resistance housing-ambient	4.65 K/W
18	Thermal resistance winding-housing	1.93 K/W
19	Thermal time constant winding	41.5 s
20	Thermal time constant motor	809 s
21	Ambient temperature	-20…+85°C
22	Max. permissible winding temperature	+100°C

Mechanical data (ball bearings)

23	Max. permissible speed	3330 rpm
24	Axial play	0.05 - 0.15 mm
25	Radial play	0.025 mm
26	Max. axial load (dynamic)	5.6 N
27	Max. force for press fits (static)	110 N
	(static, shaft supported)	1200 N
28	Max. radial loading, 5 mm from flange	28 N

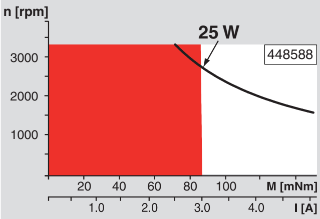
Other specifications

29	Number of pole pairs	1
30	Number of commutator segments	13
31	Weight of motor	480 g

Values listed in the table are nominal.
Explanation of the figures on page 71.

Option
Preloaded ball bearings

Operating Range



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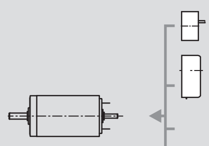
maxon Modular System

Overview on page 20 - 25



Encoder MR
256 - 1024 CPT,
3 channels
Page 303

Encoder HED_ 5540
500 CPT,
3 channels
Page 305/307

Recommended Electronics:

ESCON 36/2 DC	Page 320
ESCON 50/5	321
ESCON Module 50/5	321
EPOS2 24/2	330
EPOS2 Module 36/2	330
EPOS2 24/5	331
EPOS2 50/5	331
EPOS2 P 24/5	334
EPOS3 70/10 EtherCAT	337
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