Bachelor Thesis

Intelligent Heliport for Autonomous Helicopters

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České vysoké učení technické v Praze
Fakulta elektrotechnická

Katedra kybernetiky

ZADÁNÍ BAKALÁŘSKÉ PRÁCE

Student: Ondřej K u n t e

Studijní program: Kybernetika a robotika (bakalářský)

Obor: Robotika

Název tématu: Inteligentní heliport pro bezpilotní helikoptéry

Pokyny pro vypracování:

Student má za úkol navrhnout a realizovat inteligentní heliport sloužící jako podpora při přistávání bezpilotních letounů. Heliport bude vybaven senzorem pro určení relativní pozice přistávající helikoptéry a komunikačním modulem pro podporu přistávající helikoptéry v posledních fázích letu. Aktivní část heliportu navíc umožní pevné uchycení helikoptéry po přistání a bude připravena pro pozdější implementaci automatického dobíjecího systému.

Úkolem studenta je:

1. Nastudovat problematiku řízení helikoptéry a zpracování obrazu pro lokalizaci.
2. Navrhnout a zkonstruovat přistávací platformu.
3. Navrhnout a implementovat algoritmus pro vizuální lokalizaci helikoptéry.
4. Navrhnout způsob komunikace mezi heliportem a helikoptérou pro řízení přistávacího manévru.
5. Demonstrovat funkci zařízení.

Seznam odborné literatury:

[1] Tomáš Krajník et al. – "A Practical Multirobot Localization System" – Journal of Intelligent & Robotic Systems, 2014.
[2] Brandon Frazer et al. – „Dronenet" – Technical Report, University of Central Florida, 2013.
[3] Václav Hlaváč, Milan Šonka – „Počítačové vidění" – ISBN 80-85434-67-3, 1992.

Vedoucí bakalářské práce: Dr. Gael Pierre Marie Ecorchard

Platnost zadání: do konce letního semestru 2015/2016

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děkan

V Praze dne 20. 1. 2015

Czech Technical University in Prague
Faculty of Electrical Engineering

Department of Cybernetics

BACHELOR PROJECT ASSIGNMENT

Student: Ondřej K u n t e

Study programme: Cybernetics and Robotics

Specialisation: Robotics

Title of Bachelor Project: Intelligent Heliport for Autonomous Helicopters

Guidelines:

The student has in charge the design and implementation of an intelligent heliport for assisted landing of unmanned autonomous helicopters. The heliport will be equipped on one side with sensors allowing the determination of the relative position of the helicopter and on the other side with a communication module to assist the landing in its last phase. The active part of the heliport will allow the docking of the helicopter for transportation and will be designed in such a way to allow the further implementation of an autonomous charging system.

The student's tasks will be:

1. Study issues linked to the control of helicopters and to computer vision for localization.
2. Design and build the landing platform.
3. Design and implement the algorithms for visual localization of the helicopter.
4. Design the communication between heliport and helicopter for the control of the landing maneuver.
5. Demonstrate the functions of the equipment.

Bibliography/Sources:
[1] Tomáš Krajník et al. – “A Practical Multirobot Localization System“ – Journal of Intelligent & Robotic Systems, 2014.
[2] Brandon Frazer et al. – „Dronenet“ – Technical Report, University of Central Florida, 2013.
[3] Václav Hlaváč, Milan Šonka – „Počítačové vidění“ – ISBN 80-85434-67-3, 1992.

Bachelor Project Supervisor: Dr. Gael Pierre Marie Ecorchard

Valid until: the end of the summer semester of academic year 2015/2016

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Dean

Prague, January 20, 2015

Acknowledgement

I would like to thank to all people who helped me to successfully finish my thesis. At the first place I would like to thank to Department of Cybernetics for necessary funding and my Thesis advisor Dr. Gaël Ecorchard for excellent guidance. Dr. Ecorchard was always helpful and he was continuously pushing me forward. I would like to thank to AXA CNC s.r.o. company especially to Ing. Adolf Valášek and Mr. David Jílek for allowing me to use a company equipment to manufacture parts to my projekt using milling machinery. Next, I would like to thank to Student Club SiliconHill - project Macgyver for allowing me to use their 3D printer and PCB manufacturing equipment. I also thank to Intronix s.r.o. company for professional PCB soldering and for many advices during PCB designing. My thanks go to MK PLEXI s.r.o. to Mr. Gustáv Filo who helped me with cover design, material usage and provided its fabrication. Next, I would line to thank to Mr. Miroslav Strejc for professional manufacturing pre-inspection of parts for laser beam cutting and its fabrication. At the end I could not forget to thank to my family especially to my father who was continually helping me with the actual montage and logistic.

Declaration

Prohlašuji, že jsem předloženou práci vypracoval samostatně, a že jsem uvedl veškeré použité informační zdroje v souladu s Metodickým pokynem o dodržování etických principů při přípravě vysokoškolských závěrečných prací.

I declare that I worked out the presented thesis independently and I quoted all used sources of information in accord with Methodical instructions about ethical principles for writing academic thesis.

V Praze dne ....

Abstrakt

Obsahem této práce je návrh a fyzická realizace mechanického zařízení - heliportu. Toto zařízení umožňuje přistání bezpilotních helikopter, dronů menších rozměrů či vrtulových RC modelů s kolmým vzletem. Zařízení je schopno přistávající helikopteru vizuálně lokalizovat pomocí senzoru - kamery. Je schopno mechanicky uzamknout helikopteru po přistání a zakrýt helikoptéru před okolním vlivem. Konstrukce a mechanismus heliportu také umožňuje elektrické propojení s helikopterou. Toto propojení je primárně určeno pro dobíjení baterií.

Klíčová slova

heliport, kvadrokoptéra, dobijecí stanice, dobíjení, zpracování obrazu

Abstract

The main content of this thesis is design and realization of a mechanical device that allows the landing of autonomous helicopters, drones or smaller propeller RC models with vertical takeoff and landing. The device is able to visually locate the landing helicopter using a camera. It is able to mechanically lock the helicopter after landing and protect it from external influence. The heliport mechanism also allows the electrical connection with the helicopter. The connection is primarily intended for recharging the batteries.

Keywords

heliport; quadcopter, power station, charging, image processing

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Abbreviations

UAV	unmanned aerial vehicle
CTU	Czech Technical University
AC	alternating current
DC	direct current
PWM	pulse-width modulation
LED	light-emitting diode
2D	two dimensional
3D	three dimensional
ID	identification
CSI	camera serial interface
GPIO	general - purpose input output
BSD	Berkeley software distribution
CPU	central processing unit
HDMI	high definition multimedia interface
SD	secure digital
USB	universal serial bus
AVC	advanced video coding
DMOS	difused metal-oxide semi-conductor
TTL	transistor transistor logic
PCB	printed circuit board
SMD	surface-mount device
THT	through hole technology
ABS	acrylonitrile-butadiene-styrene
UPVC	unplasticized poly-vinil-chloride
CNC	computer numerical control
CAD	computer-aided design
SMAW	shielded metal arc welding
TIG	tungsten inert gas
RGB	red-green-blue
HSV	hue-saturation-value

1. Introduction

1.1. State of the art

In modern times the interest in the UAVs and drones is rapidly increasing. There are many applications where the man is trying to integrate this new technology and develop it. As example we can mention it is often used in film industry, the security or police departments and many others. Companies like Amazon or DHL are experimenting with automatic air mail delivering via autonomous drones[1]. The biggest disadvantage yet is that the helicopters are not as independent units as they could be. Every autonomous device needs some kind of support device to operate. Nothing is more illustrative example than the docking station for a robotic vacuum cleaner. The device based on this docking principle is also needed for flying robots.

When we are creating such a device, why should we merge it with other function? As stated there are several attempts to use the flying unmanned helicopters to goods or mail delivery. Researches form University of Cincinnati Research Institute presented a never-before-seen method. They combined the UAV with a delivery truck to work in tandem[2]. The truck is equipped with a wireless charger for the helicopter. When the helicopter is loaded by the driver it will scan the address from the package and flies to the appropriate destination. The truck will continue on its rounds.

This particular example of usage is perfect for a device such as the intelligent heliport. An idea of heliports mounted on the top of the vehicles can be used in all previously shown examples. This way of connection of unmanned helicopters with other standing or especially movable devices could be perspective and required technology in the near future.

1.2. Opening idea

The idea to build a docking heliport for unmanned autonomous helicopters was given at the beginning of winter semester 2014 by Ing. Martin Saska from Intelligent and Mobile Robotics Group of Department of Cybernetics, Czech Technical University (CTU).

A first prototype heliport made from paper cardboard and plastic was developed at CTU. The device was primarily intended as a prototype for testing the coordination of wheeled and flying robots. Moreover, the device was passive without any sensor equipment or intelligent device. It causes that the landing helicopter did not receive any feedback information necessary for accurate landing and landing itself was unreliable and not precise enough. Ing. Martin Saska offered me to utilize my secondary education in machinery and creative passion to build a durable and permanent device for future research and development. I chose this theme as an Individual project in winter semester 2014/2015. At the beginning of this semester I began to work on my Individual project at first under the leadership of Ing. Saska and Dr. Gaël Ecorchard then as a Bachelor thesis under the leadership of Dr. Ecorchard who became my Thesis advisor.

2. Draft proposal

The starting part of every device design is a summary of requirements. Then we are able to manage basic form of processing. It is very important to create a concept of each system and debate about its functionality.

2.1. Requirements

There are several basic requirements and abilities on the device equipment which correspond to the assignment of my Bachelor thesis.

The device should be equipped with:

- a landing area which contains a sensor for location the landing helicopter;
- a movable casing for covering the landing area with the helicopter;
- a locking mechanism to secure the helicopter after landing;
- a charging mechanism.

The device should be able to:

- visually locate the landing helicopter;
- communicate with the helicopter and assist the landing in its last phase;
- recognize successful landing and approximate position of helicopter after landing.

2.2. Concept

2.2.1. Landing board

The first prototype of landing heliport had only one basic function: to center the helicopter. After a helicopter landed on the platform, four side-walls were erected to avoid the helicopter's fall. These four desks pushed the helicopter from the sides to the center position. The main problem of the design was the impermeable base board. At the last phase of landing, when the helicopter was approaching the plate, the reflected air from the heliport made impossible to accomplish an accurate landing.

The final design should be simple, it should be functional and it also must provide all the following points:

- air permeability;
- locking mechanism;
- electrical connectivity.

The final suitable design has the following form. A landing board is in a form of two grates positioned underneath. Each other landing helicopter is equipped with special landing rods. These rods go through the grates while landing.

As can be seen on the Figure 1 the upper grate has a rectangular meshing and it is used as supporting grate. It is fixed to the frame. The lower grate has a diagonal

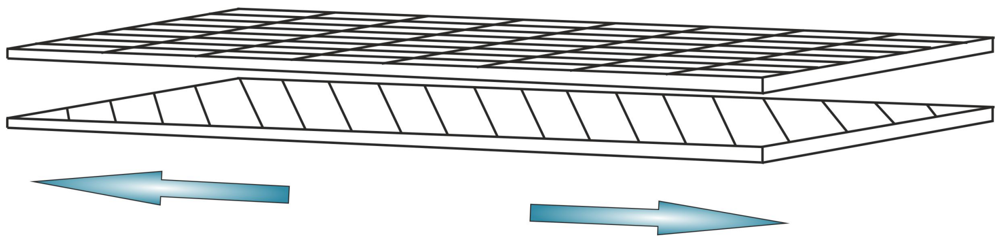


Fig. 1. Landing board concept

meshing and it is used as locking grate. The grate is mounted to linear bearings so it is able to slide under the supporting grate.

Both grates are also electrically isolated from the frame and from each other. This offers the possibility to use them as charging contacts. The landing rods that go through the grates are used as electrical collectors. After landing the helicopter and locking it by the movable grate, the electric circuit is closed.

The grating of the movable grate is mounted in the plastic rim. The reason of this assembly is that after the grate completion each rip of the grate is isolated. This solution allows to track the position of the landed helicopter by measuring the loss voltage in the grate. Because of its location the communication with the helicopter needs to be implement to give the helicopter information about successful or unsuccessful landing.

This final solution is easy to manufacture and meets all given requirements. A disadvantage of this solution is the impossibility to change the helicopters position on the board after landing.

2.2.2. Landing area covering

A part of the device is a cover which protects inner devices an helicopter from external influence during battery charging or transport. This shield should be able to cover the whole landing area including the docked helicopter.

The main requirements on the cover mechanism are the following:

- Simple mechanical design;
- solid and lightweight construction;
- as few actuators/motors as possible;
- small energetic consumption;
- simple control.

There are two basic ways how to solve the moving the cover as it is shown on Figure 2. The cover can be moved to the side or can be rotated. The cover can be in one piece or it can be composed of several parts.

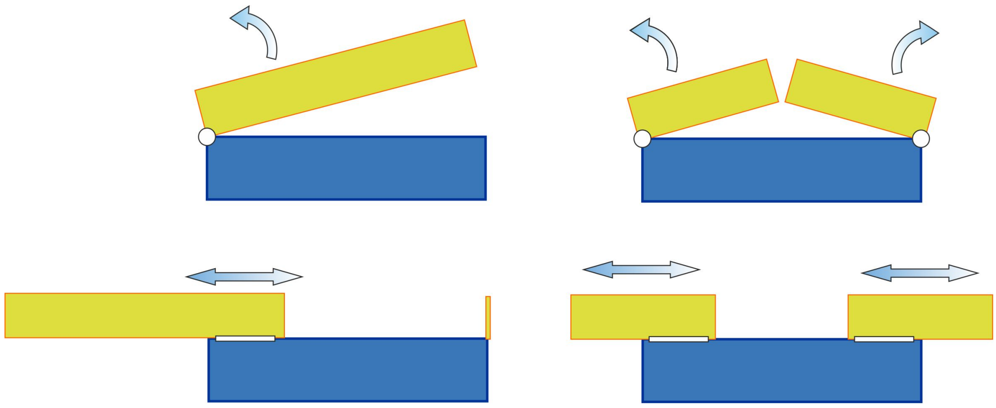


Fig. 2. Basic cover concepts. From top left to the bottom right: Single rotary cover; halved rotary cover; single sliding cover; halved sliding cover

In final design the second variant was chosen. The cover consists of two similar shield parts which are opening to the sides. These parts are connected together by gears, so that the whole mechanism can be driven by only one motor. To provide enough power a DC motor with worm gearbox was chosen. This type of motor is cheap, powerful and simple to control. To control the motor in this particular usage a reversing control has to be used. In addition to that, a PWM modulation can be part of this solution.

2.2.3. Helicopter localization and computing

The main improvement over the previous heliport is the helicopter localization. Because of the board grating concept it is not possible to change the position of the helicopter after landing. For that reason it is necessary to localize the helicopter and steer it to the board as accurately as possible.

To localize the landing helicopter the heliport is equipped with an on-board camera. The camera is mounted in the center of the supporting grate. This location permits to easily navigate the landing object to the center of landing grate. To facilitate the localization of the helicopter a LED light mark is added on its bottom. An image from the camera is then computed by a computer embedded in the heliport.

Among devices available at the Intelligent and Mobile Robotics Group (IMR), two are suitable for image capturing and processing:

- Gumstix[3];
- Raspberry PI[4]

The problematic about the final picked device is explained in detail in Chapter 4 and 5. These devices contain a camera and computing power to be able to successfully process an image and locate the landing helicopter.

The computing section also contains a communication part which should be able to send information to the helicopter while landing. So the concept is to control the landing helicopter from a ground-mounted device.

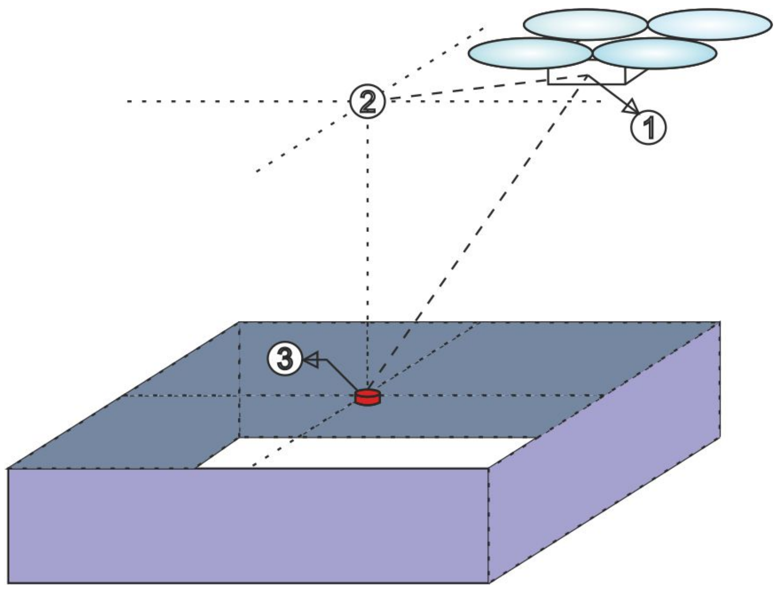


Fig. 3. Camera localization principe - 1. Current possition [X, Y]; 2. Target [X, Y]; 3. Final target

3. Design

In this chapter I am going to introduce used design software. In the next part I am explaining design of most of the components and drawings. It is possible to print and explain every drawing of every component, unfortunately final length of this document would be at least about fifty pages longer when putting each part on a one list of paper. Because of that I am going to pick and explain some of the most important drawings. Complete drawings are available on included CD in Appendix B in standard .DWG and .DXF format. In following text I will show a lists of parts to every explained component with reference to their drawing number.

3.1. Designing software

For 2D design the AutoCAD Mechanical[5] was used. AutoCAD Mechanical is an extension of standard AutoCAD[6] software. The AutoCAD software is a product from Autodesk[7] company since 1982. I was working on AutoCAD Mechanical 2014 Student version available for CTU students by Computing and Information centre of CTU[8].

When the technical documentation is created it is important to stick to the standardized drawing rules[9]. The settings I am using is holding to standards of creating technical documentation and mechanical drawing according for example to norm ČSN EN ISO 128 (01 3114)[10]. Technical norms are continuously developing so reference on this particular norm is only informative.

The AutoCAD software contains many specialized functions for mechanical drawing. These functions are are fully described in latest user documentation of AutoCAD Mechanical[11].

Each drawing is presented in a standard form. As one can see in the Figure 4, every drawing is inserted in the coordinate frame. Each frame contains an ID header with necessary information. These information are:

- File name;
- format;
- drawn by;
- drawing date
- drawing scale
- project name
- main name
- second name
- drawing number

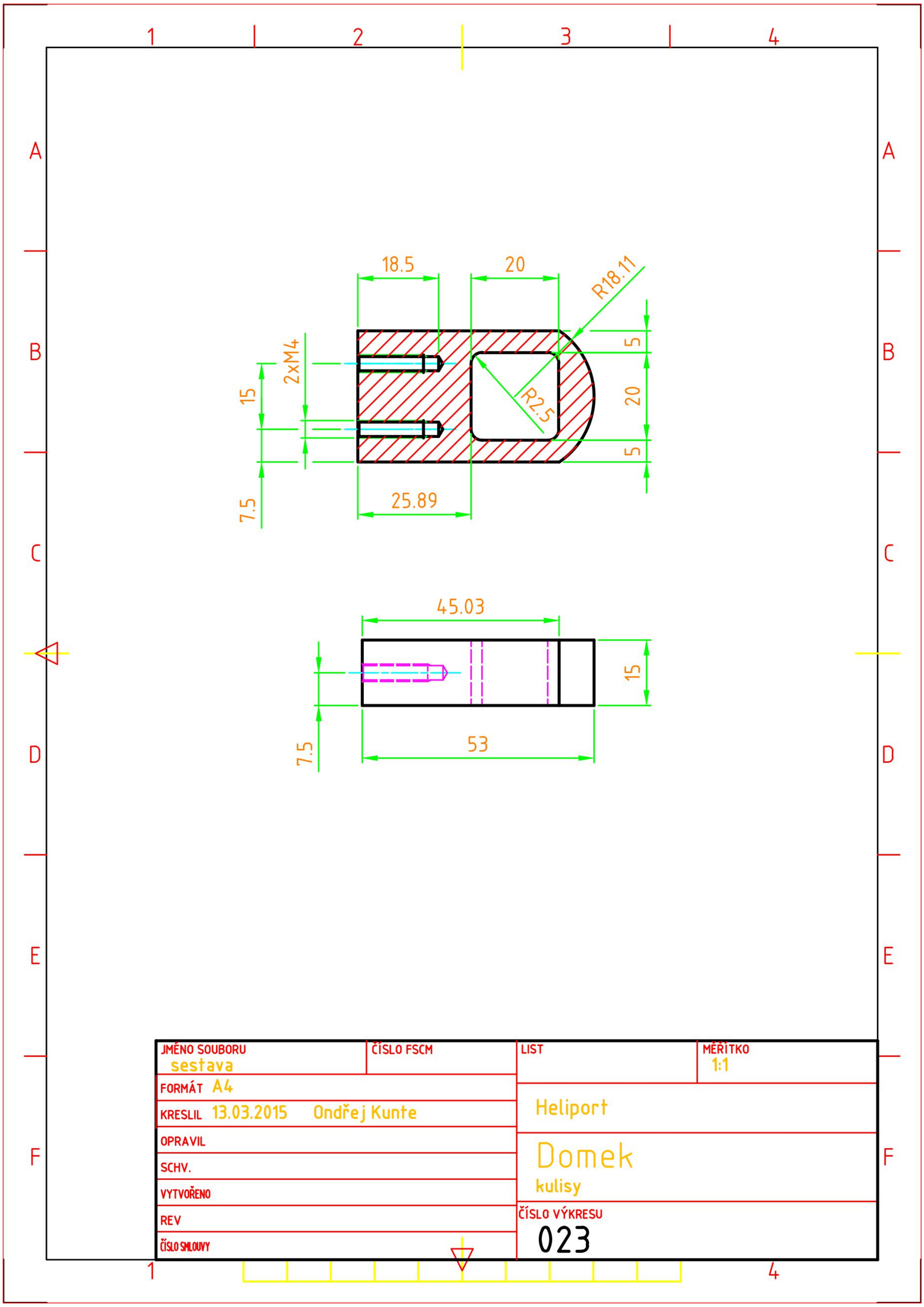


Fig. 4. Standard form of drawings

For 3D design and 3D visualization the Google SketchUp[12] was used. Sketchup is a very powerful tool for 3D drawing produced by Google Inc. There is available free version SketchUp Make and professional payed version SketchUp Pro which contains several added functions for advanced drawing.

The program environment is user-friendly and intuitive unlike most of the other 3D drawing software. Although the SketchUp is simple to learn and use the options of this program is very wide. The software is used in many areas, for example in machinery or architectural design.

3.2. Landing mechanism

The landing mechanism is a complex system consisting of several main parts. As already mentioned, these parts are:

- The supporting grate
- The movable grate
- The sliding mechanism for the movable grate

3.2.1. Supporting grate

All components which this part contains are shown below in the Table 1. The individual drawings are referred by their drawing number. This format of referring will continue with each component for better orientation in manufacturing documentation included in Appendix B (CD).

Drawing name	Drawing number	Quantity
Izolátor nosného roštu	006	10
Distanční podložka nosného roštu	008	10
Nosný rošt - Lišta boční A	036	2
Nosný rošt - Lišta boční B	047	2
Nosný rošt - Lišta vnitřní B	038	10
Nosný rošt - Lišta s okýnkem	039	2
Nosný rošt - Lišta vnitřní A	040	10
Nosný rošt - Lišta zkrácená A	041	2

Tab. 1. List of parts - Supporting grate

The grate itself is mounted together using its shape as we can see on the Figure 5. After welding sides that are creating the rim, the grate becomes one unmountable component. The final structure of the grate is very solid and helps to firm whole frame of the heliport after montage. The grate itself contains mounting holes for mounting to the frame and mounting holes in the center of the grate for camera. We can see the mounting system in the Figure 5. The hole for the camera is placed in the center of the grate because of the helicopter localization concept. The camera looks up and guides the landing helicopter above it until the helicopter lands.

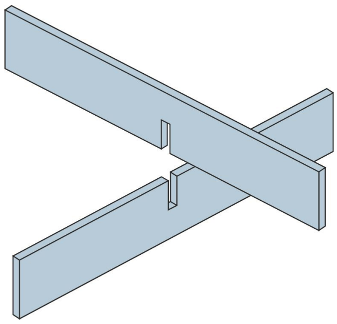


Fig. 5. Supporting grate concept

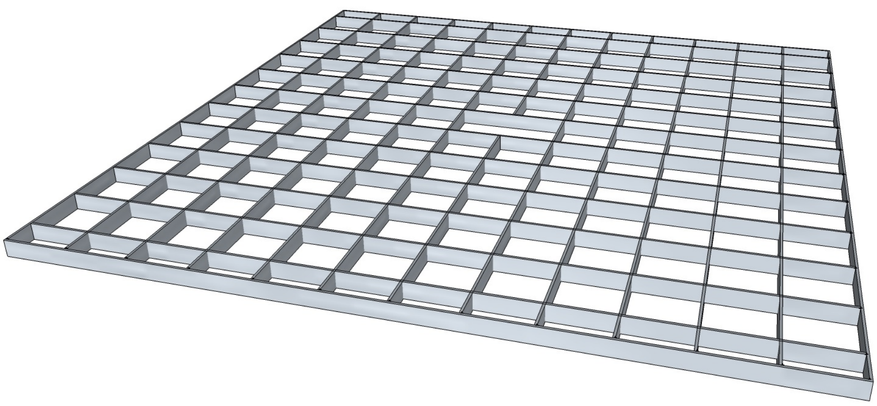


Fig. 6. 3D visualization of the supporting grate

3.2.2. Movable grate

The parts which the movable grate consists are shown in Table 2:

Drawing name	Drawing number	Quantity
Rošt posuvný	004	1
U - profil posuvného roštu	033	4
Rám posuv. roštu rovný A	031	1
Rám posuv. roštu s nástavcem B	032	1
Izolátor posuvných žeber	010	48
Vedení posuvného roštu	014	2
Doraz gumový	009	2
Nástavec	019	2

Tab. 2. List of parts - Movable grate

The grate itself consists of diagonal grating which is mounted to the plastic U-profile frame. Every piece of the grate is isolated from others. We can see the mounting system detail in Figure 7. The sliding guides are also part of the grate. They are connected to the plastic frame by screwed metal steel sheets. The sheets are precisely made to allow good housing position and smooth sliding.

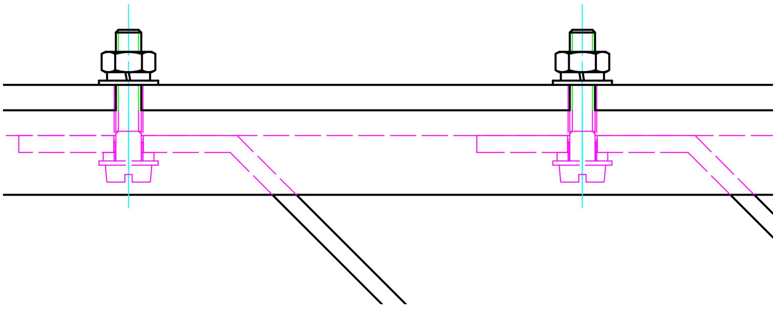


Fig. 7. Movable grating connection

In Figure 10 one can see a complete grate with frame, grating and screw connections.

3.2.3. Movable grate sliding mechanism

The sliding mechanism consists of:

Drawing name	Drawing number	Quantity
Vedení posuvného roštu	014	2
Rameno posuvného roštu	025	6
Kluzná vložka	007	1
Páka posuvného mechanismu	011	2
Domek kulisy	023	1
Kulisa	024	1

Tab. 3. List of parts - Movable grate sliding mechanism

The main parts of the mechanism are two rails with circle cross-section. The surface of the rails is grinded, polished and the rail has tolerance constraints. This surface finish is necessary for smooth motion. Each rail is moving in three housings (Figure 8) equipped with bushings. The bushing is mounted to the housing and pressure-secured in place by a screw. The grate is then mounted to the frame by these housings.

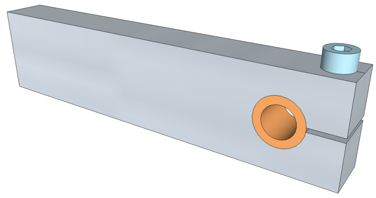


Fig. 8. 3D visualization of the movable grate housing equipped with bushing

The rail endings are threaded. This allows to mount them to the grid. The mounting holes are designed to allows grid and rail adjustment. This guaranties a smooth and precise movement of the grate.

A servomotor is used for the actuation of the sliding grate. One part of the movable grate mechanism is a special designed gear which transmit the rotational movement of the servomotor into a translational movement of the grate (Figure 9). Transmission of movements is made possible by an inner coulisse. The coulisse also enables to lock the grate at its end positions. The force that is needed to lock the landing rod is provided by two compression springs. In Figure 10 one can see the whole movable grate with the moving mechanism attached by the housings to a frame.

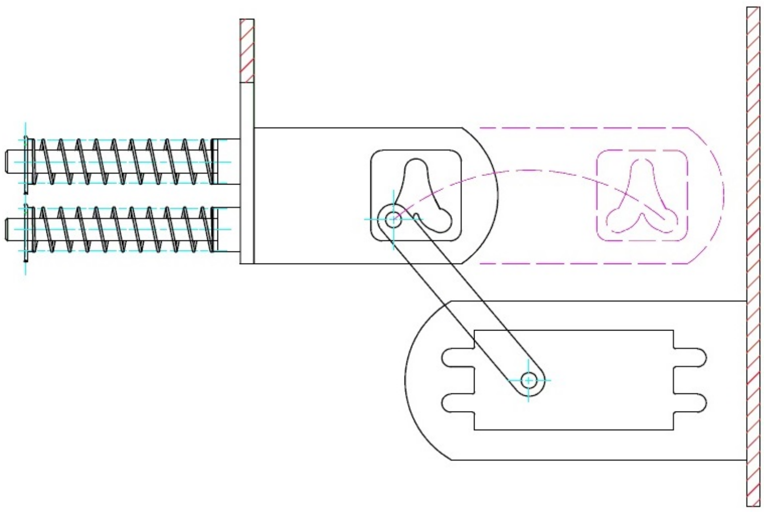


Fig. 9. Movable grate mechanism with coulisse

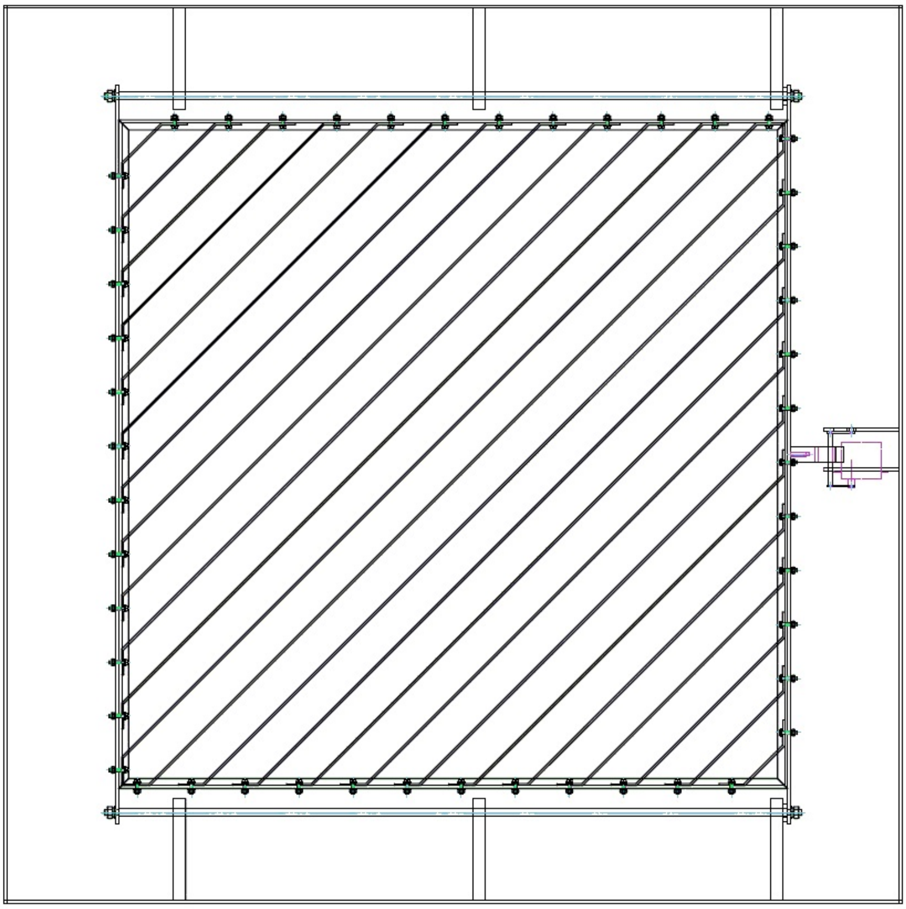


Fig. 10. Movable grate mounted to the frame - top view

3.2.4. Landing rod

The landing rod except the light beacon (section 6.1.1) is only one mechanical device mounted directly to the helicopter. There are four rods mounted in the helicopter. The landing rod design must to allow the helicopter both landing on the heliport and on the ground. The inner structure has to be durable to prevent damage caused by possible crash of the helicopter and also functional because the main function of the landing rod is the charging collector.

For that reason the rod was designed in a form of a hollow tube. The inner hollow is used for the power line and it also increases the strength of the rod. In the Figure 11 and Figure 12 one can see the first and second design of the landing rod. The first design match with the basic functionality. The rod is equipped with the two charging contacts. Between the contact there is a tube extension used as the rod locking element. Above contacts there is the stop plate and finally mounting system of the rod. The landing rod was primarily designed to manufacture by the 3D printing technology (section 5.2.6) so the final material of the rod is plastic. Therefore it can be made with this technology the rod was composed of several parts and ten glued together. The design was not very satisfactory. The rod was heavy and not resistant and resistant against the accidental hits.

The second improved design is based on the first model. It is equipped with the same charging contact and the locking system. The stop plate was replaced with new permeable and lighter model. The new mounting system which uses the plastic ties is lighter and with smaller dimensions. It also enables easier replacement of the rod in case of damage. The rod consisted from three parts which are joined together by the cone junctions and flexibly locked together by inner placed rubber band. Thank to this solution in case of crash the rod structure unclench the joining and the rod will not be damaged.

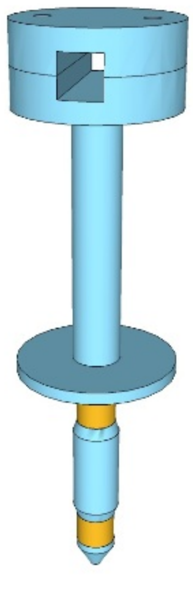


Fig. 11. First version of landing rod

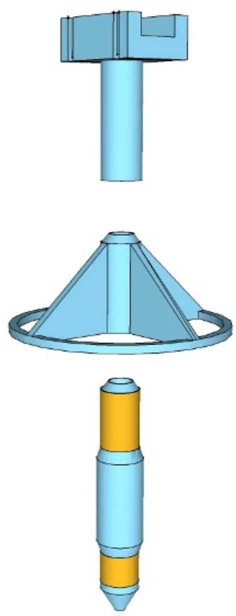


Fig. 12. Second version of landing rod

3.3. Cover mechanism

However the following reality may not be obvious, the cover mechanism is the most complex part of the heliport device. It contains the most moving parts and with limited manufacturing possibilities there is not many opportunities to adjust the finished design. Final design must be functional and compatible with other components in the device. It means that it was necessary to think about how to fit safely the system into the device and make the final influence on the other components as small as possible.

As mentioned in the draft a rotary mechanism was chosen. Instead of shifting mechanism it has simpler design and it is technologically easier to manufacture. When you are operating with shifting mechanism you also need to count with a space where the cover is shifted and adjust surrounding area and the design itself. The rotary system in the final design interfere the surrounding space much less. A disadvantage of the rotary system are bigger demands on the actuator.

3.3.1. Covers

The most important part of the mechanism is obviously a cover. It must be capable to cover the landing area, it must be firm and lightweight at the same time. The weight is very important because of the easy manipulation and less strain on the engine.

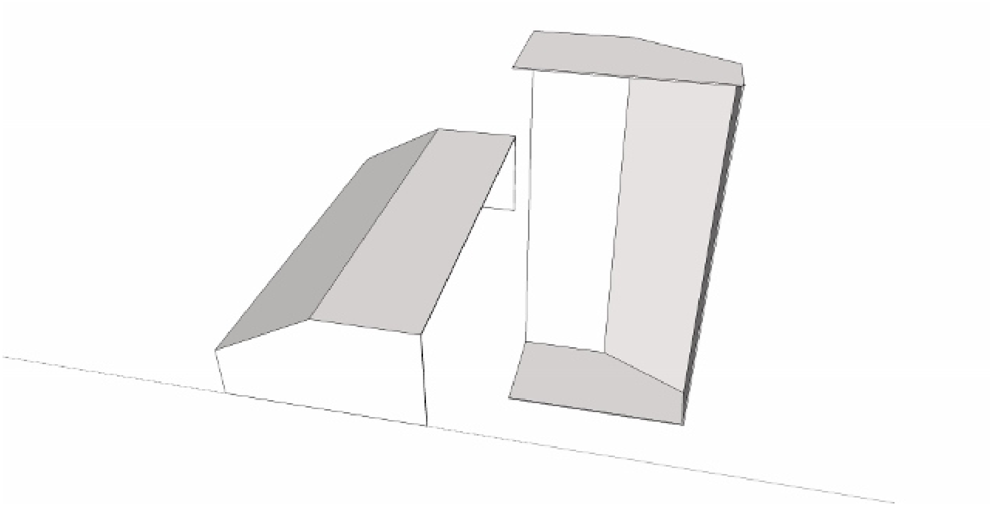


Fig. 13. 3D visualization of cover design

To minimize final torque applied to the motor the cover was halved and both halves are driven by one motor by gears. To reduce the weight a special material was used. The material and making of cover was provided by the MK PLEXI s.r.o. company[13]. More info is given in Chapter 5. The final product is in compare to metal sheets or plastic glass very solid and lightweight. One half of the cover weights approximately two kilograms. It is also easily machinable for example for future drilling and other future improvements.

Shape of the cover was chosen for its functionality and simple production. Because the board material was used, the sides of the cover were easily fitted together using its sandwich structure. Because of that the final half of cover consists only of three parts.

Inner edges are created by milling the groove in desired angle, bended and glued. Side boards are attached by glue and reinforced with aluminium L profiles.

In technical documentation the cover consist only from one drawing:

Drawing name	Drawing number	Quantity
Kryt	042	2

Tab. 4. List of parts - Cover

3.3.2. Cover gears

The main problem of the cover mechanism designing was how to transfer the motor torque to the each half of cover. The movement of both halves needed to be synchronized, precise and not so much complicated. It also needs to be durable and functional.

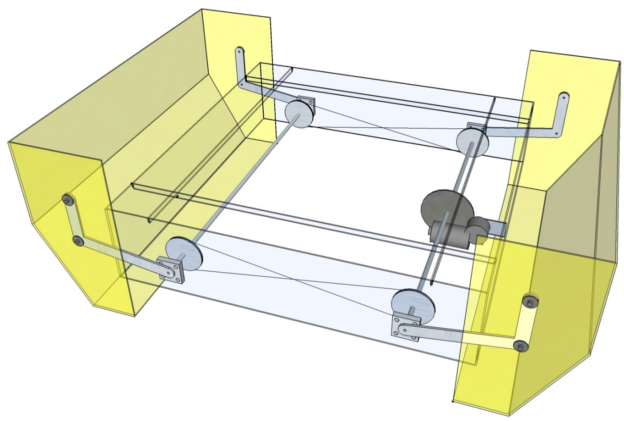


Fig. 14. 3D visualization of cover mechanism

Two shafts with rope wheels were designed. The shafts are mounted by ball bearing housings to the frame so they can rotate freely. One shaft is set as a major, the second one is set as a minor. The minor shaft is connected to the major shaft by crossed steel ropes. These ropes transmit the motor torque and they also provide synchronized movement. Crossing of the ropes also causes that minor shaft is rotating in the opposite direction to the major shaft. To prevent the rope slipping a rope locking had to be designed. These locks are mounted on the ropes in places where the rope is still in contact with the wheel. At the wheels rim there is a latch for the lock to secure the rope against the slip.

Endings of shafts were milled and threaded. The final shape of these ending allows to transfer the torque to the cover levers which are attached to the covers. Position of covers can by calibrated by position of minor shaft housings or by the rope tensioner.

Shafts are mounted by four housings to the frame. Because of the force applied on the shafts the ball bearing housings were chosen. The type of the bearing is number 6000 2Z made by ZKL Bearings CZ a. s. company[14]. The housings were made by milling with precise made pockets for the ball bearings. Every bearing is then pressure-molded to the housing.

The motor is directly mounted to the frame by motor holder. A part of the motor holder is capturing the gear reaction force of major shaft. Torque from the motor is transmitted by reduction gear to the major shaft. Reduction gear lowers the speed and boosts the torque. The goal was to maximize the conversion ratio of the gearing.

The movable grate mechanism is composed of the following parts:

Drawing name	Drawing number	Quantity
Buben rozety	018	1
Ozubené kolo motoru	016	1
Kulisa pohonu krytu	017	1
Náboj	015	5
Domek ložiska reakce	044	1
Hřídel pohonu krytu	013	2
Kolo vnější	027	8
Kolo vnitřní	028	4
Zámek lanka	020	4
Domek ložiska 6000	012	4
Páka krytu	026	4

Tab. 5. List of parts - Cover mechanism

3.4. Frame

Frame is basic part of the device. Every component of the device must by mounted in its stable position. For that reason the frame is equipped with many montage holes or holders suitable for mounting any designed component. Dimensions were based on used helicopter and also dimensions came from logistic possibilities and size of available trunk of a car.

Parts which the frame is composed from are:

Drawing name	Drawing number	Quantity
Bočnice boční	001	2
Bočnice čelová s vybráním	002	1
Bočnice čelová holá	003	1
Držák nos. roštu spodní	034	2
Držák nos. roštu horní	035	2
Výztuha	029	4
Držák motoru	030	1
Uložení serva plné	021	1
Uložení serva vybrané	022	1

Tab. 6. List of parts - Frame

Frame is designed for mounting all parts of the device such as:

- cover bearing housings
- cover motor housings
- supporting grate

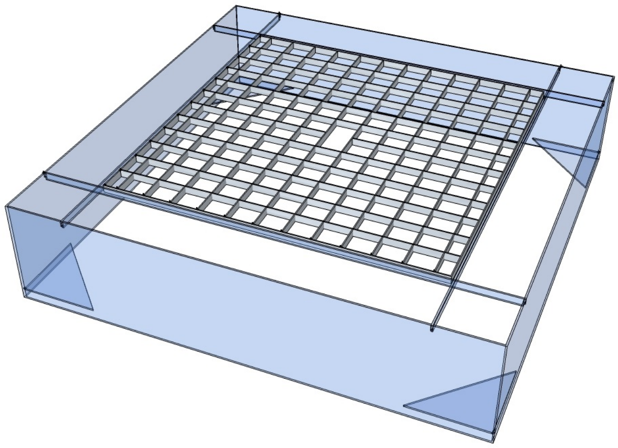


Fig. 15. Simplified 3D visualization of frame with supporting grate

- movable grate
- side boards for equipment mounting
- chassis

The main frame structure consists of four side boards which are welded together. To prevent precise welding, sides for welding are specially profiled. These profiles also made impossible to accidentally switch boards when welding. The structure firmness is improved by welded triangle pads which are also used as a chassis mounting points.

4. Equipment

4.1. Processing hardware

4.1.1. Raspberry PI

Raspberry PI is one of the smallest PC in the world. It was developed by the Raspberry Pi Foundation[4] which was trying to make the informatics and computer science taught in schools more accessible and cheaper. The final product is a board with the size slightly bigger than a credit card. The cheapest version is available for around 25 US dollars.

The model board B2 with dimensions 67,6x 30 mm contains:

- CPU BCM2836 made by ARM Cortex-A, clocked on 900 MHz
- 1 GB RAM
- Graphic processor VideoCore IV, compatible with OpenGL ES, 1080p, MPEG-4
- HDMI audio/video output
- 3.5 mm JACK audio output
- SD/MMC slot
- 2x USB port
- RJ45 ethernet connector
- 12xGPIO pins
- Camera Serial Interface (CSI) bus connector

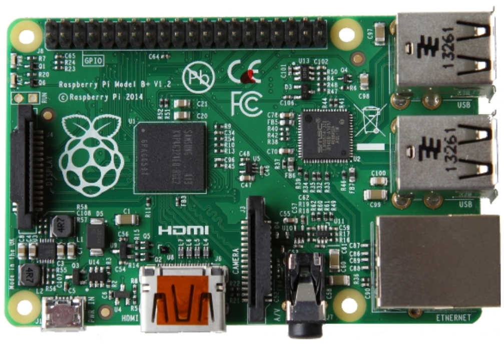


Fig. 16. Raspberry Pi B2 version - front side view)

The Raspberry PI operates on Raspbian OS which is based on Debian operating system. Raspberry does not include the hard disk. The system implementation and data storing is provided by the SD memory card.

4.1.2. Raspberry PI camera module

Raspberry camera module[15] is one of the available accessory for Raspberry Pi. The size of the board is only 25x24 mm and it is connected to the main board via 15pin flex cable to the CSI (Camera Serial Interface) connector. Basic technical information are given in Table 7.

Sensor resolution	5 megapixels
Angle of view	54x41°
Video	1080p at 30 fps with codec H.264 (AVC)
Max fps	up to 90 fps at VGA

Tab. 7. Raspberry Pi camera module - basic parameters

4.1.3. Arduino Uno

The Arduino Uno is a control board containing a microcontroller based on the ATmega328[16] made by Atmel. The board uses the inner programmed microchip as a USB-to-serial converter and the board design includes all supporting parts of the microcontroller. The provided support also includes the programming software with development environment. It allows to very easily program the microcontroller using only PC and USB connection.[17]

The Arduino Uno(Figure 18) has 14 digital input/output pins of which 6 can be used as PWM outputs and 6 analog inputs. Additional parameters are given in Table 8.

Microcontroller	ATmega328
Operating voltage	5V
DC current per I/O pin	40 mA
DC current for 3.3V pin	40 mA
Flash Memory	32 KB of which 0.5 is used by bootloader
SRAM	2KB
EEPROM	1 KB
Clock speed	16 MHz

Tab. 8. The Arduino Uno basic parameters

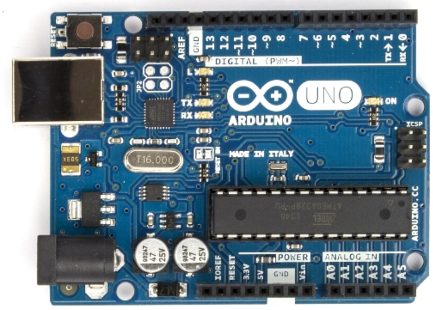


Fig. 17. Arduino Uno - front side view (taken from [17])

At this moment the Arduino Uno is not really necessary in the heliport project. The control of the cover motor and other peripheries can be done by GPIO outputs of the Raspberry. On the other hand realizing the servo control and additional periphery control via Arduino is easier and there is no need to utilize the processing capacity of Raspberry for such applications. There are a lots of packages supporting periphery control such as servo control or PWM available to Arduino. In future it can be developed many processing functions to the Arduino and another control applications can be added to the heliport also. The Arduino was used considering the future development of the heliport.

4.2. Communication module - XBee

Xbee PRO S2B (Figure) is a small communication module which uses the Zigbee communication protocol which is more explained in section 6.5. It is used in short transmission distances up to 100 meters. The device operates on a frequency of a 2.4 GHz. The common application of devices using Zigbee protocol are in low data rate application such as wireless remote control or transmitting sensor data and other information. This type of communication device was used because of its ongoing application at UAV helicopters of Multi-robot Systems group at Department of Cybernetics, CTU.

Fig. 18. Xbee PRO S2B (taken from[18])

The communication protokol excels with its low power consumption, easy implementation, reliability and also good price. These parametres are balanced with its limited transmission speed up to 35kbps.[18]

4.3. Cover motor

The DC motor is the largest and the most powerful appliance of the device. Because of the chosen system of covers the actuator had to have these specifications:

- high torque
- low speed
- easy gear connection
- easy control
- capable of two-way movement

From these demands it is obvious that a motor equipped with gearbox is needed. In general there are two basic options of high-reducing gearboxes:

- planetary gearbox
- worm gearbox

Rated voltage	12V
Max incrush current	5A
Speed	approx. 40 rpm
Minimal torque	2.2 Nm

Tab. 9. Required motor parameters

The offer of motors with worm gearboxes or motors with planetary gearboxes is very wide. For my purpose I looked for a motor with following parameters.

As final solution a DC motor primarily used as wiper driver from a car was chosen. The motor is equipped with worm gearbox so it provides low speed with hight torque. The required power supply is 12 V. This type of motor is very cheap and because of this and the fact that its parameters already fullfil the requirements make it the most suitable solution for my application.

4.4. Motor control

To control the cover motor the control unit had to be designed. This device should be able to control direction of rotation and speed of the motor. As the most suitable option a full controlled H-bridge[19] circuit with L6203[20] was chosen.

The motor control unit also contains one added circuit part. Although the heliport is designed for +12V power supply, there are several devices which require +5V power supply. This +5V power supply applies to the computing unit, the servomotor control unit and servomotor itself. For that reason the +5V stabilizer circuit was added separately to the motor control unit.

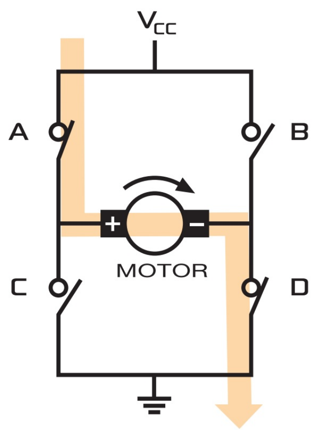


Fig. 19. H - bridge principle (taken from [19])

In Figure 19 one can see the simplified drawing of H-bridge circuit. It generally consists of four switching elements. The most common switching element in this power level is the unipolar transistor in DMOS technology. Transistors are switching diagonally. When transistors A and D are switched on, the DC current flows as indicated in the picture. To reverse the motor rotation the transistor B and the transistor C must be switched on and transistors A and D must be switched off.

4.4.1. L6203

The L6203 integrated circuit is a full H-bridge driver for DC motor control applications. Output transistors can operate with supply voltages of up to 42V and efficiently at high switching speeds up to 100 kHz. The logic inputs are operating in TTL level.

The L6203 contains thermal protection circuit that will disable the device if the junction temperature reaches 150 °C. In Table 10 are given some important maximum values.

Symbol	Parameter	Value	Unit
V_s	Power Supply	52	V
V_{IN}, V_{EN}	Input or Enable Voltage	-0.3 to +7	V
I_{OUTp}	Puled Output Current	5	A
I_{OUTn}	Non-repetitive Output current (< 1 ms)	10	A
P_{tot}	Total Power Dissipation	20	W

Tab. 10. L6203 - Absolute maximum ratings

4.4.2. +5V stabilizer

As +5V power supply the 7805[21] passive stabilizer was used. Due to the small transmitted power the type in SMD package was chosen. In Table 11 one can see the important maximal values of the circuit. This circuit was also used as the light beacon power supply in Section 6.1.1.

Symbol	Parameter	Value	Unit
V_{in}	Input Voltage	40	V
I_{OUT}	Output Current	1	A
P_{tot}	Total Power Dissipation	12	W

Tab. 11. 7805 - Absolute maximum ratings

4.4.3. Circuit design

To create the final electronic device the PCB (Printed circuit board) had to be manufactured. Design of the circuit scheme and printed circuit board was created in Eagle PCB Design Software[22]. Thank to gained knowledge from courses A0B13KEO and A3B35APE taught at our faculty I designed the board without any difficulties. The main focus of these courses was designing and building an electronic device.

In Figure 20 one can see a scheme of the electronic circuit. The circuit is divided into three parts:

- the +5V stabilizer
- the motor control
- the power supply outputs

In stabilizer section there is the stabilizer circuit 7805. On the input of the stabilizer it is connected the smoothing capacitor C3 and the blocking capacitor C4. On the output the capacitors C7, C8 and C11 have the same function. The stabilizer is protected against reverse voltage by a safety diode.

The motor control circuit also contains only one active part - the L6203 driver. The Enable pin of the L6203 driver is permanently "on". Capacitors C1 and C2 connected to pin V_{REF} are recommended by the manufacturer to by-pass the internal reference voltage circuit. The recommended capacity value connected between pin V_{REF} and ground should be 0.22 μF. Capacitors C9 and C10 are starting capacitors. Between outputs the RC filter is connected for filtering parasitic frequencies.

Both levels of power supply are also led out to supply pins and they are secured separately by a fuse. The circuit is also equipped with a green LED diode to indicate input power supply and two red LEDs for indicating the active output and so the motor rotation direction.

The PCB design was also created in the Eagle design software and the final design we can be seen in Figure 21. To reduce the board dimensions most of the circuit components were chosen in SMD technology. Only the connectors and fuses were chosen in THT (Through Hole Technology) design because of its better functionality and easy replacement in the case of fuses. The integrated circuit L6203 is using THT technology as well.

The PCB was then manufactured by classical photo method using the equipment provided by project Macgyver of students club SiliconHill[23]. I do not consider important to explain this method in detail the reader can refer to[24] for a description of how to manage this technology in a small production.

The parts assembling and soldering was professionally done by Intronix s.r.o company[25] due to the SMD soldering. The PCB is not coated with a solder mask.

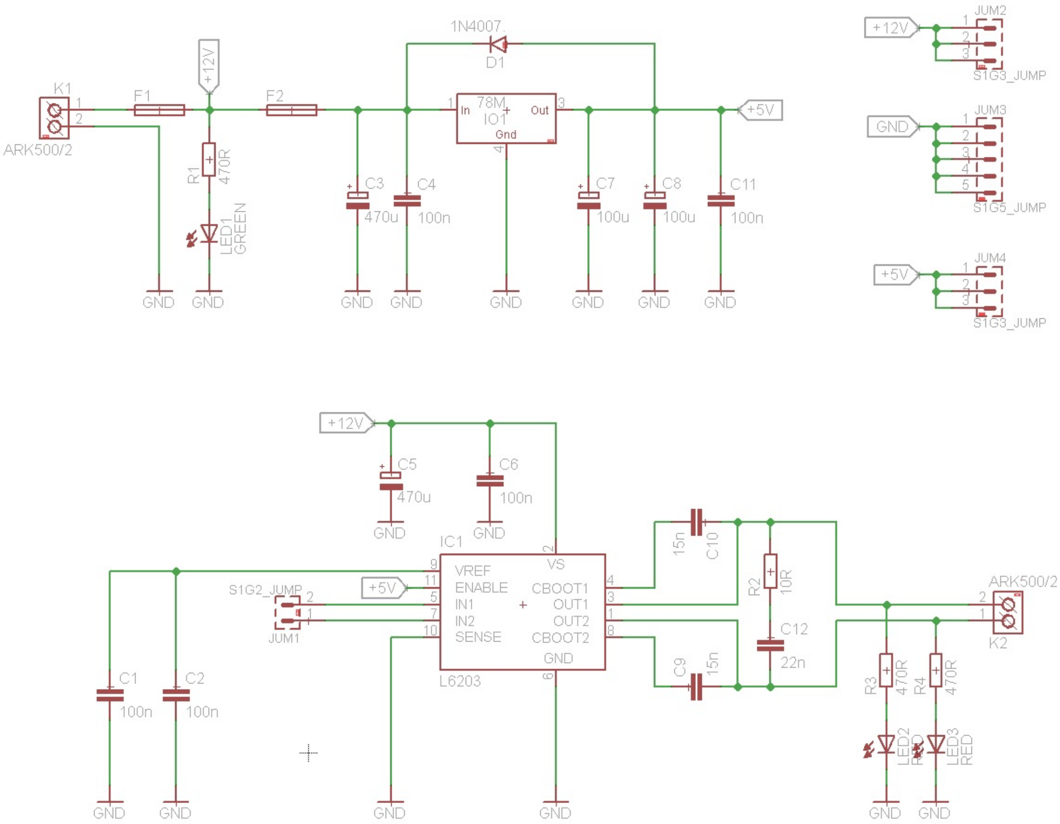


Fig. 20. Scheme of motor control circuit

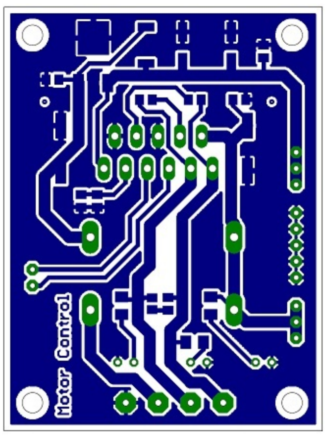


Fig. 21. Printed circuit board of motor control - bottom side view

4.5. Servo

The servo is a standard commonly-used actuator produced in many designs. It contains a motor, gearbox and control electronics in one package. The standard servomotor is PWM controlled by the 3-5V peak to peak square wave pulse. The pulse duration is from 0.9 ms to 2.1 ms with 1.5 ms as centre. The pulse refreshes at 50 Hz (20 ms).

The servomotor was used as an actuator of the movable grate as one can see in Figure 9 and Figure 10. This type of driving was used because of its wide availability, simple control and hight torque which the servomotor provides. For moving the grate only one servomotor was required. Because the movement itself is forcefully demanding a servo capable of hight torque had to be chosen.

The digital ultra torque HS-5645MG servomotor produced by Hitec company was chosen. The servomotor is equipped with metal gearbox and dual ball bearings. Other further specifications are given in Table 12. The servomotor comes with many accessories such as many different detachable arms including one made of aluminium alloy which was used in final design.

Operating speed	0.23 sec/60°(approx. 43 rpm) at 4.8V
Output torque	10.3 kgf·cm (1.01 N·m) at 4.8V
Size	40.6x19.8x37.8mm

Tab. 12. Servomotor specifications

4.6. Power supply

The heliport is powered by 12V DC. The required voltage can be delivered by many ways. Depending on the final application the power supply can be used in form of:

- laboratory DC power supply;
- industrial switching power supply;
- 12V accumulator.

The laboratory DC power supply can be chosen in laboratory environment for application development. AC/DC switching power supply can be used in the final application as the final power supply transforming the required voltage from standard power grid of 230V AC in case the device is permanently placed. The 12V accumulator can also be used. This power source can be used in the realized application when the heliport is mounted on a vehicle and powered by the inner accumulator from the vehicle itself. All these power sources have to be able to provide 12V and current of 5A minimally. The current value is based on the DC motor consumption.

5. Manufacture

Manufacturing a custom built or non-serial devices is generally very difficult. The choice of the used material and technology must be taken into consideration while designing the device. In this chapter I am going to introduce all different used manufacturing technologies and materials. Every technology will not be explained in detail but it is necessary to show how many different technologies had to be required in building such type of device. I dispose with a quite wide technology background so all explained technologies were provided by myself or with different companies cooperation.

5.1. Used materials

The choice of the materials is one of the most significant part of the design. A chosen material should meet all the criteria, such as:

- commercially available
- workable by available technology
- functional in final application;
- easy to maintain.

Every presented material is given with its selling name and sales designation. This also includes the providing or manufacturing company if it is possible. Most of the used materials are normalized and, accordingly, technical parameters can be found in engineering tables [26].

5.1.1. Metal materials

Sheet steel hot rolled, EN 10029-A-N This material was chosen as the basic construction material. The frame, motor housing, grate rims and most of the parts are made from steel sheets in thickness of 1, 2, 3 or 4 mm.

Circular pole cold drawn, DIN 671 A pole with diameter 12 mm was used as material for shafts and a pole with diameter of 5 mm as linear guiding of the movable grate mechanism. The same type of material was used as the material for machining rotational small parts. The material has no surface finish.

Circular pole brushed and polished, DIN 670 This pole material was used with diameter of 8 mm for manufacturing rails for the movable grate. The surface is polished and in h9 tolerance (∅8 -0.036 mm).

Aluminium sheet, 485-3 and EN 485-4 This material with 2 mm thickenss was used in the production of the grates ribs thanks to its corrosion resistance and electrical conductivity. The 12 mm and 15 mm thick sheet is used for structural elements such as grate holders and functional elements of mechanisms. A thickness of 20 mm was used for the machining material for the bearing housings of the cover mechanism.

5.1.2. Non-metal materials

Construction plastic It is a semi-crystallic polyamide TECAMID 12, white/black colored. It is used for the plastic sliding bearings, the guiding coulisse and the spacer sleeves. This material was chosen because of it is easy machinable and because of its good mechanic quality.

Plastic material for 3D-printing It is a thermoplastic material. The most commonly used material is ABS (Acrylonitrilbutadienstyrene). It is resistant to low and high temperatures and it is harmless. Due to its properties, it is the most widely used engineering plastic. The crude material for 3D printing is produced in the form of strings of thickness 1.75 mm.

Plastic U-profil This is the profile of UPVC (NOVODUR) manufactured by Fatra a.s.[27], profile type H1353. It is used as the rim of the sliding grate.

Technical rubber Rubbers of different thicknesses are used in various applications as stops or stop surfaces.

Aluminium sandwich sheet, thickness 3 mm This material was used to manufacture the covers of the landing board. The material is not exactly non-metal because of its sandwich composition. The core made of technical plastic (ABS) is covered from sides by the aluminium foil. The final plate is extremely strong and light-weight. The material was provided by the same company which manufactured the heliport cover, MK Plexi s.r.o.[13].

5.2. Used technology

Except the design of the heliport the second most time-consuming and difficult part of the work was purchasing or gaining access to all required manufacturing technologies. Not every technology was easily available but because of my connections and personal skills I managed access to a wide variety of manufacturing technologies. Because of that I significantly lowered the manufacturing time and expenses. In cases the technology was not provided to me I had to enter a standard order into production. In final this included only the cutting technology.

The reason I managed the most of the manufacturing technology by myself is the reason that I wanted to achieve as complex work concept as possible.

5.2.1. Laser-beam cutting

This technology is used for metal sheets non-contact cutting. Non contact technology means that the workpiece is not machined by any mechanical tool. The laser beam cutting is mainly used for steel cutting but it is also usable for cutting different materials such as plastic, paper or stone. The cutting principle is shown in Figure 22.

The focused laser beam heats the material. The material is extremely heated so that it melts or even vaporizes. After the laser beam penetrates completely the material a stream of high pressure gas blows the melted material away and creates a gap.

This cutting method is able to cut steel sheet up to 30 mm thickness. This technology was chosen because it is capable to cut almost any required shape with an accuracy of about 0.1 mm. A small disadvantage might be that after cutting the cut edge of sheet

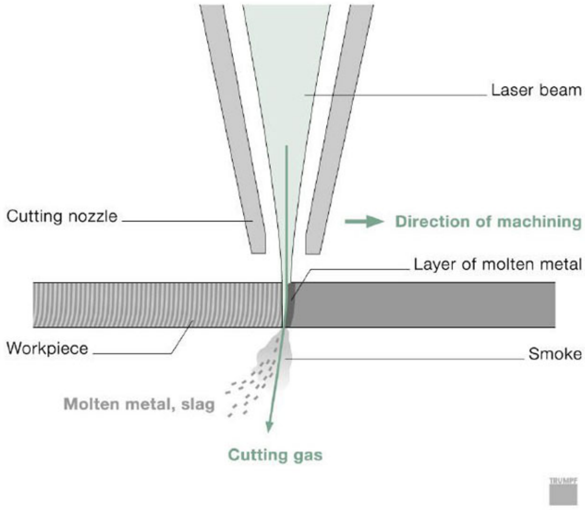


Fig. 22. Laser beam cutting principle (taken from[28])

is heat hardened. The hardened surface make impossible to further machine it. For example for that reason it is impossible to cut thread into the laser cut holes. This technology also is not suitable for cutting thick soft metals such as aluminium. The cut is not smooth and it is conical.

The laser cutting was provided by two companies which both uses the machines made by TRUMPF GmbH company[28]. These companies were Laser Steel s.r.o.[29] and Kovovýroba Kaufner s.r.o[30].

5.2.2. Water-jet cutting

The water-jet cutting is not similar to the laser beam cutting. Instead of the heat based cutting principle of laser beam the water-jet cutting uses mechanical abrasion. The final cut is not affected by heat and the cold cut does not affect the inner structure of the material. The cutting medium is a high pressured water stream. The stream pressure is in the range 500 - 6500 Bar. A clean water stream is used for cutting soft materials such as wood, plastic or light non-ferrous metals. For cutting the hard material abrasive powder has to be added to the water stream. This technology is able to cut almost any material up to 250 mm. The accuracy of this technology is ±0.2 mm but it can vary depending on the cut material thickness. When cutting a very hard material such as stainless steel the cut edge is not perpendicular. On the other hand this technology is suitable for cutting aluminium sheets of large thickness which the laser beam is not capable of. For that reason this technology was chosen.

The water-jet technology and technology information was provided by the AWAC s.r.o. company[31]. All non-rotational parts of the heliport made out of aluminium were manufactured by this technology. Water-jet was also used for cutting the profile of the plastic parts (the coulise of the movable grate mechanism) and for rubber parts cutting.

5.2.3. Punching

Punching is the last used sheet metal processing technology. Unlike the laser beam cutting and water-jet cutting it uses contact mechanical cutting. The machine is basically a fast and precise press equipped with set of differently shaped punches. we can see a symbolic drawing of the press in Figure 23. The press can produce a force of 165 kN. The final shape is limited only with the chosen punches.

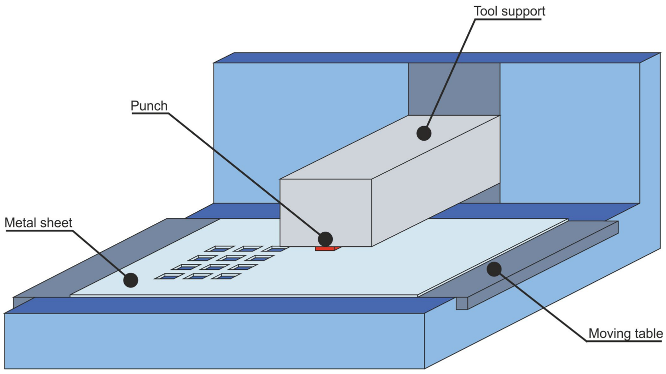


Fig. 23. Punching press principle

The machine is able to create required holes by standard punches or more difficult contours or shapes using their combination and punching the contours around. This technology is very cheap in comparison to non-contact technology . For that reason it was used for creating the gratings for both grates from aluminium sheet. In compare to non-contact cutting the waste of material is higher but it does not influence the final expenses.

The machine punching was processed by the Kaufner s.r.o. company[30].

5.2.4. Machining

Machining has been the most used manufacturing technology. The principle of this technology is based on chip material removal. The final workpiece is shaped by different tools into the required shape by removing the surplus material. The removed material is a waste but in general it is recycled so the final waste is minimized. Many different kinds of machining technology were used such as:

- Drilling
- Rasping
- Grinding
- Reaming
- Cutting
- Edging
- Turning
- Milling

Except milling, all of these technologies were accessible in my technological background. In this fact it allowed me to manufacture most of the parts by myself. This situation helped to shorten the final manufacturing time and eliminate the possible manufacturing problems associated with faulty manufacturing or manufacturing delay. On the other hand it transferred the production time on me. Although the final producing time was shorter the manufacturing was for me highly time-consuming. This fact also keeps the complexity of this work.

I thing there is no need to explain all given used machining technology such as the drilling, grinding or raspering. These technologies are generally known and by explaining them in detail I am not giving any new information to the reader. I am going to explain milling and turning as the most technically demanding and used technologies using chip machining.

Turning :

Turning is used for machining rotational part. The main principle is based on moving the workpiece and stable machining tool. The machined material is clamped into spindle of the lathe and it is rotating. The material is then removed by a turning tool called the knife. The process can be manually operated or controlled by a computer. This process were suitable for manufacturing round bushings, shaft endings or for concentric drilling. All rotational parts were made by this technology, such as shaft endings, housings of bushings and gear housings.

To work I used the center lathe in my technological background. The basic parameters are given in the Table 13. The lathe is no longer produced so the unofficial technical information and photo were taken from[32]. The machine is a standard handle control center lathe for delicate machinery manufacturing. The accuracy of the machine is 0.05 mm in length and 0.05 mm in radius.

Manufacturer	TOS Čelákovice n.p.
Production type	MN-80A
Swing diameter over bed	160 mm
Swing diameter over carriage	90 mm
Bed length	120 mm
Speed range	150-2000 rpm

Tab. 13. Basic parameters of the used lathe

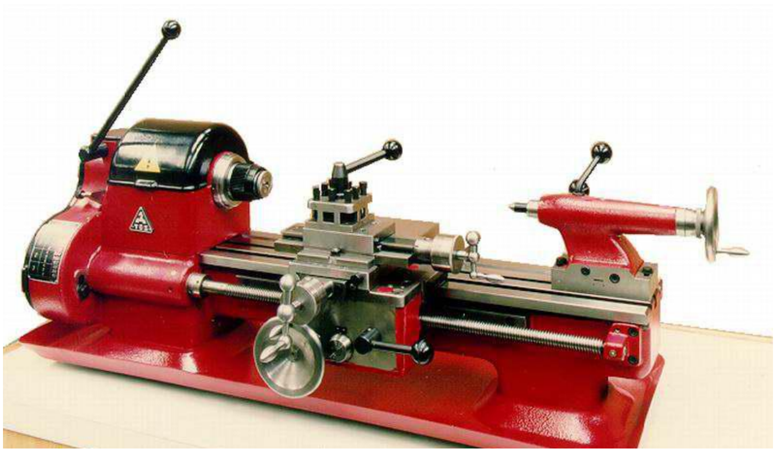


Fig. 24. The lathe MN-80A

Milling :
The milling technology works in comparison to the turning with opposite principle. The workpiece is in stable position and it is machined by the rotating milling cutter. This process can by manually operated or it can be controlled by the computer (CNC). In industrial production the CNC milling mostly dominates so for my work I used the same type of control. It was also necessary because of the manufactured parts. The ball bearing housings for the cover shafts needed to be made by milling technology. The milling had to be precise because of the tolerated pockets for ball bearings. The final workpiece is shown in Figure 26 and Figure 27.

I cooperated with the AXA CNC Company[33] for my milling applications. The company allowed me to use their CNC machining center under supervision to manufacture all needed parts by milling. The machining centers produced by this company use the control system made by Heidenhain Company[34].

Manufacturer	AXA CNC
Production type	VCC
Working area	720x500x600 mm
Max. rapid traverse	25/25/20 m/min
Spindle speed range	6000 rpm
Repeating accuracy	±0.005 mm

Tab. 14. Main parameters of the milling center VCC

Because of the cooperation with AXA CNC Company in the past I am familiar with this control system. For that reason I was able to write the whole control program by myself and also manipulate the machining center to produce all required parts.

The manufacturing process was operated by a AXA milling center, type VCC. A photo of the center and basic technical information are given in Figure 25 and Table 14. Detail technical information are available in AXA CNC website[33].

Fig. 25. The AXA machining center with Heidenhain control system

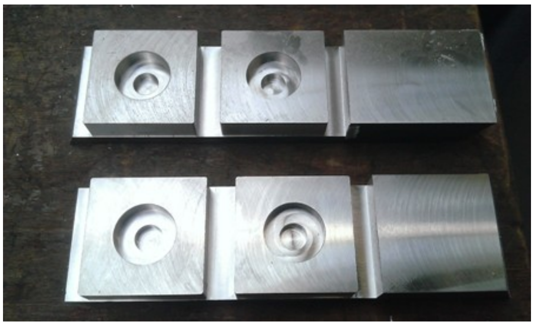


Fig. 26. Milling - first side

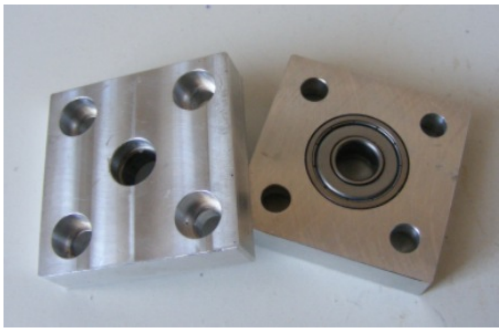


Fig. 27. Final housing equipped with ball bearing

5.2.5. Welding

Welding is a technology used for unmountable joining of metal or non-metal materials. The join is created by applying pressure, heat or both. Surfaces of joining materials are heated so they melt and can be joined together in melted state or with additional material. There are different types of heat sources for welding but the most used technology is the arc welding. Arc welding technologies used in the heliport manufacture were:

- Shielded metal arc welding (SMAW)
- Tungsten inert gas welding (TIG)

In case of shielded metal arc welding an electric arc is maintained between the workpiece and weld coated electrode. The electrode is formed by the wire and the casing. This coating creates a protective atmosphere during welding and transforms into slag. The resulting weld is covered with slag (Figure 28). Slag must by removed at the end of the welding process (Figure 29). The advantage of this technology is the fact that SMAW welding is unassuming for the necessary equipment. For that reason it was used. On the other hand the technology requires a skilled welder.

Fig. 28. SMAW weld with the slag

Fig. 29. adjusted SMAW weld

The TIG welding technology welds using a non-consumable tungsten electrode in an inert gas. The electrode maintains the electric arc, the filler material is added to the weld pool separately. The additive material in wire form, in the case of manual TIG welding, welder holds in one hand. In the second hand he holds tungsten electrode. One part of the electrode is also a dispenser of inert gas, usually argon. This technology was necessary for the welding the aluminium sheets of the supporting grate.

5.2.6. 3D Printing

The 3D printing is in comparison to other technologies the newest technology and it is has become very widespread and used. It is based on different attitude to the workpiece manufacturing. The machining uses different tools to get the material into the final shape by removing the material. The 3D printing basically prints the final workpiece layer by layer without any waste of material.

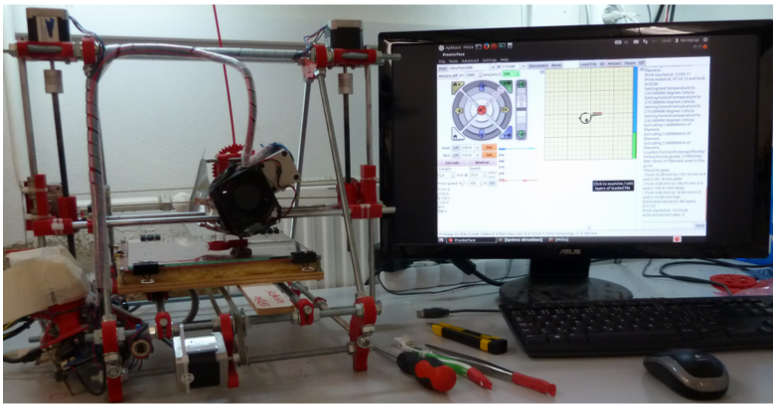


Fig. 30. RepRap 3D printer (taken from [35])

This technology was provided by RepRap 3D printer project of student club SiliconHill[35]. The SiliconHill project uses an international open source 3D prototyping printer shown in Figure 30 called RepRap[36] which is short-cut of Replicating Rapid Prototyper. Most of the hardware parts of the printer can be printed by another printer. The software including firmware and control program is released under GNU General Public Licence.

The 3D printer was mainly used for manufacturing the landing rods of the helicopter.

5.2.7. Painting

The heliport frame is painted to preserve rustproof. Powder coating[37] was used as painting technology. This technology was used because of its thick and resistant paint, good price and slightly rubbery structure which allows future drilling without the peeling.

The powder coating technology uses a paint in the form of a dry powder. The powder is applied on the surface in the electrostatic field. Because of that the painted object has to be electrically conductive. After the powder application the layer of powder is heated on 180°C. The powder melts and join with the surface. The final layer of paint is thick and very durable.

As a color of the paint the RAL 5015[38] was chosen. This particular color is based on CTU official emblem color[39].

6. Localization and control software

In this chapter I am going to introduce the intelligent part of the heliport. The heliport should be able to localize the helicopter and safely guide it to the landing spot. For that reason the object localization and communication had to be designed. It was necessary to study the computer vision localization and use it to create an object tracking algorithm.

After the heliport is able to locate the helicopter it also has to be able to give the landing orders to the helicopter. In the final landing phase the helicopter should be able to successfully land only by following orders from the heliport underneath.

All program implementations are available in CD in Appendix B. The CD among other content contains the implementation of image processing, object location and Arduino control programs.

6.1. Landing principle

6.1.1. Helicopter light beacon

To simplify the localization of the helicopter it has to be equipped with some kind of recognition element. At Department of Cybernetics it is widely used the reflexive board with recognition patterns such as concentric circles or crosses[40]. These patterns are black and white for contrast and its shape is used for measuring different information such as distance of the located object or relative rotation to the observer.

For my application this solution turned out to be unsuitable. When looking upwards the pattern was not clearly visible mostly because of the glare of background light. For that reason an active beacon had to be chosen. The light beacon shown in Figure 31 was designed in the form of two LED stripes. Each stripe lights with a different color. The spacing of LEDs is 12 mm and there are 6 LEDs in each stripe. The stripes are placed in a T-shaped form. It allows to detect the front of the helicopter and its rotation.

Fig. 31. LED beacon

The beacon is powered by a voltage stabilizer placed on its back side. Because the inner supply voltage of the helicopter is about 20V and the nominal power supply of the LED stripe is 12V, the supply voltage had to be stabilized into this lower value. The stabilizer circuit is based on the circuit used in the motor control board (section 4.4). Instead of integrated circuit 7805 the 7812 is used. The 7812 stabilizer is practically the same part as 7805 and it can be reffered by 7805 datasheet[21] but it has different output voltage.

The beacon is placed on the bottom of the helicopter and it is connected to its inner power supply. The right direction of the front side of the board needs to be respected so the top of the T-shape corresponds with the front of the helicopter.

6.1.2. Landing scenario

At the first place it is necessary to set the landing scenario. For that situation the reader can imagine the situation based on Figure 3. The landing itself can be separated to four phases:

- The helicopter will approach heliport so that the helicopter is in the camera view range.
- The heliport locates the helicopter and starts to navigate the helicopter over itself to the center position.
- The heliport gives the landing order to the helicopter. The helicopter begins to land while the heliport still corrects its center position.
- After landing the heliport lock the helicopter, cover it and begin with the charging process.

This landing scenario can be operated without calculating the height of the helicopter. For more accurate landing the height measuring has to be implement.

6.2. OpenCV library

OpenCV is a commonly used framework for computer vision and image processing. It is an open-source library released under a BSD licence and is free to use for academic or commercial applications. The usage of this library is very wide. It has more than 2500 optimized algorithms, which can be used in many applications such as face recognition, object identification, scenery recognition and many others. OpenCV's user community has more that 47 thousand users and the estimated download count of this library exceed 7 milion.

The OpenCV library supports Mac OS, Android, Windows and Linux in C++, C Python, Java and MATLAB interfaces. OpenCV is written natively in C++ and has a templated interface that works seamlessly with STL containers.[41]

6.3. Image processing

Before we are able to track the wanted object from the image preprocessing of the image is necessary. This procedure contains several steps which I am going to explain in this section. Each step is presented on testing sample image (Figure 32) for the best explanation to the reader. The following illustrations are captured directly from the image processing algorithm to present its functionality.

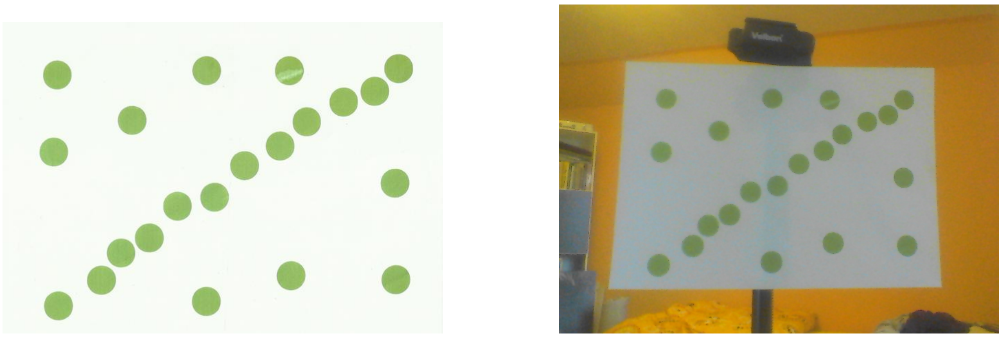


Fig. 32. Testing sample image

6.3.1. HSV transfer

HSV (Hue, Saturation, and Value) is color representation model which well matches with the human color perception. The main feature of this color model is that HSV decouples intensity information from color, while hue and saturation correspond to the color sense of human eye. This representation is very useful for developing image processing. Instead of RGB (Red-Green-Blue) model which makes the final color by mixture of its basic colors the HSV model keeps the color information unaffected. In the Figure 33 one can see the HSV transfer of the sample image.

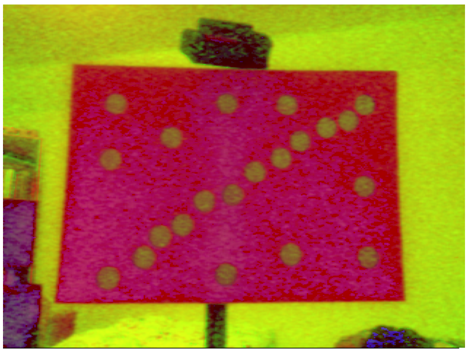


Fig. 33. HSV transfer

The color representation is different because of the color model transfer. When taking the picture the information are saved in RGB color model and after that transferred into the HSV corresponding model. When the image is displayed, the image data are considered by the program as RGB values and the final image gets different color representation.

6.3.2. Thresholding

Thresholding is the simplest method used for the image segmentation. It is used to separate out regions of an image corresponding to the object we want to analyze. This separation is based on the variation of pixel intensity or other information based on the required range of the color model. The result of this method is a binary image.

It is evaluated based on the information of each pixel. In case the information is in the given range of color model it is evaluated to "1". If it is not it is evaluated to "0". The segmentation range has to be set precisely to separate wanted areas.

6.3.3. Morphological operations

Mathematic morphology is based on the assumption that the image object can be represented as a set of points. The result of this operation is noise reduction, error elimination, separation of joined object or filling of the blank spots. The input image is generally a thresholded binary image [42, 43].
The two basic morphological operations are:

- Dilate
- Erode

Erode :
At first place the operation starts by scanning over the image and computing the minimal pixel value overlapped by the previously chosen kernel. After this operation the pixel under the anchor point is replaced with that minimal value. The result is the suppression of small objects and the reduction of segmented areas. This operation suppresses noise and removes unwanted objects.

Dilate :
The dilate operation replaces the image pixel by a pre-shaped kernel. The kernel shape is usually in the form of a square or a circle and it overlaps the original pixel. This maximizing operation causes bright regions within an image to "grow". This operation helps to close the open object or fill the inner holes.

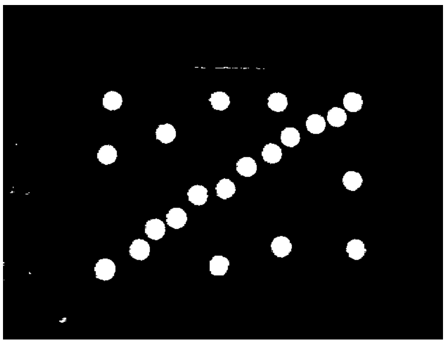


Fig. 34. Thresholded image

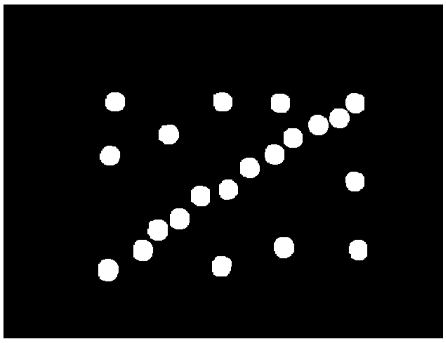


Fig. 35. Image after morphological operations

The result of this operations is a clean image containing only the wanted undivided objects without any noise as one can see by comparing Figures 34 and 35. The output from Figure 35 is necessary for proper object location.

6.4. Multiple object location

The lights beacon consists of several located objects. Because of that the multiple object location had to be used. The light beacon uses the form of two colored LED stripes. For that reason the steps from Sections 6.4.1, 6.4.2 and 6.4.3 were used for both stripes separately.

6.4.1. Contour finding

The first step of object localization is finding its contour. This operation is provided by OpenCV library through the findContour function. This function uses the Suzuki algorithm[44]. The result of this operation is the edge contour around the object mass needed for the further processing.

6.4.2. Object location

The input into this process is the final contour which was given by the previous operation. It is necessary to calculate the moments of the object[45]. Our goal is to get the center of mass also called center of gravity of the object.

Moments are generally classified by the order of the moments. The order of a moment depends on the indices p and q of the moment $m_{p,q}$. The sum $p + q$ is the order of the moment, where p and q are the indices along its first and second axes.

Considering this, the following moments of a function f are defined:

- zero order moment $((p, q) = (0, 0))$

$$m_{0,0} = \iint dx\, dy\, f(x, y) \tag{1}$$

- first order moments $((p, q) = (0, 1)||(1, 0))$

$$m_{1,0} = \iint dx\, dyx\, f(x, y) \tag{2}$$

$$m_{0,1} = \iint dx\, dyy\, f(x, y) \tag{3}$$

where $f(x, y)$ is the nominal binary value of each pixel which can be classified by value of $\{0,\ 1\}$.

The first order moments contain information about the center of gravity of the object. We get the required center coordinates of the object by computing:

$$x_c = \frac{m_{1,0}}{m_{0,0}} \tag{4}$$

$$y_c = \frac{m_{0,1}}{m_{0,0}} \tag{5}$$

All this presented calculations are provided by OpenCV through the function moments. The required inputs are thresholded binary image and edge contour of the wanted object. The output of this process are the XY coordinates of the center of each located object. Based on previous calculations the size filtering can be also implemented. It allows to discard too small objects which were not filtered by the thresholding and morphology operations. The calculated coordinates represent the wanted object location as shown in Figure 36.

6.4.3. Line interpolation

The final operation to successfully locate the helicopter beacon is line interpolation. As indicated, the beacon is in form of a T-shape (Figure 31). For now the program is able to locate each LED as a point with its coordinates as shown in Figure 36. It is necessary to interpolate these points by lines. The final result should be two lines. The intersection of these lines gives the homing center of the helicopter. In Figure 37 and

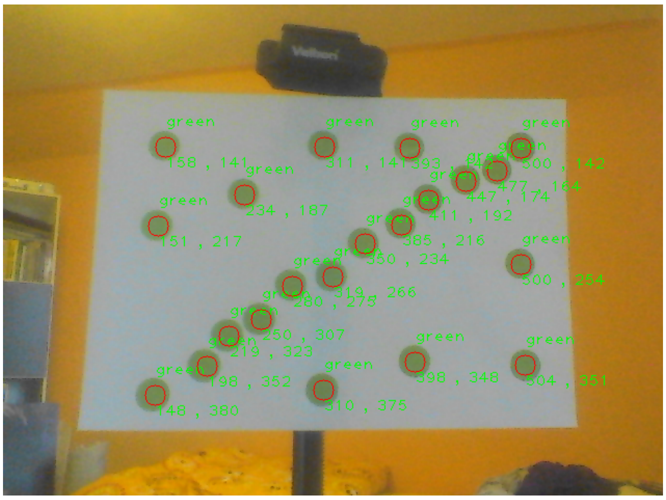


Fig. 36. Image with located objects

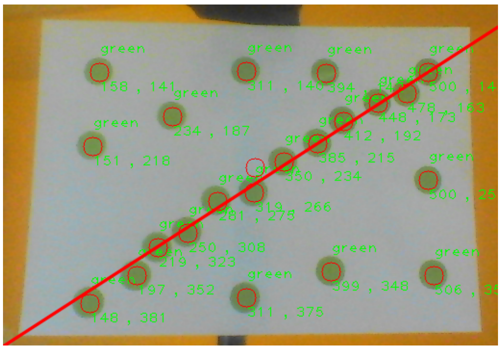


Fig. 37. Sample image - line interpolation

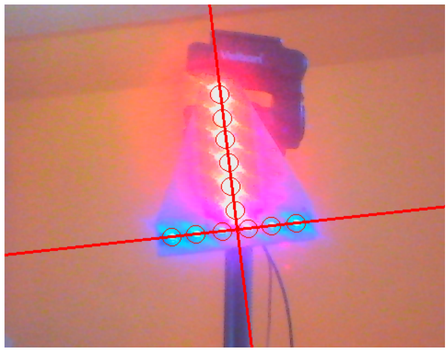


Fig. 38. Light bacon - line interpolation

Figure 38 the final line interpolation in the sample image and in the light beacon of the helicopter are shown.

To fit in the line the RANSAC[46] algorithm and a simple least-squares method[47] was used. The final algorithm should be able to find the group of point in line and interpolate it. The result is in the slope-intersect form of a line equation:

$$y = ax + b; \tag{6}$$

where a is the slope of the line and b its y-intersect .

In Figure 39 one can see the RANSAC algorithm principle. RANSAC is an iterative algorithm. The input data is a set of points. The output is a subset of point called inliners. The algorithm proceeds according to the following steps:

- pick two randomly chosen points
- set a line through these points and set an area offsetting the line
- the surrounding points which are located in the area are marked as inliners and their count is recorded
- the process is repeated a certain number of iterations
- at each iteration the algorithm looks for the largest group of inliners
- the largest group of inliners is set as the output subset.

The final line is fitted to the set of point by the least-square method. If we have a set of points i with coordinates $[x_1, y_1]....[x_i, y_i]$, we can obtain the final line equation in

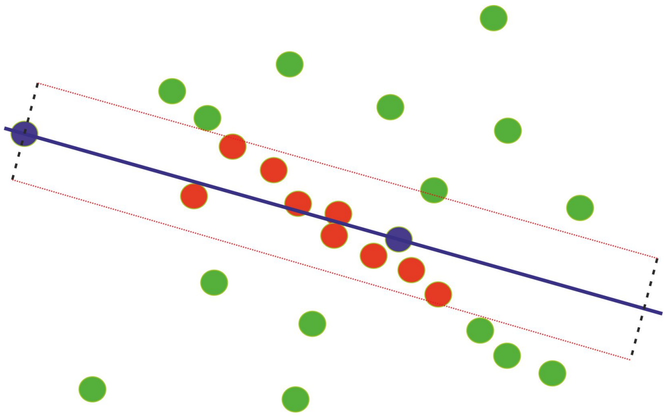


Fig. 39. RANSAC algorithm principle

formgiven in (6). The slope a and the intercept b of the line equation can be obtained by solving the set of equations

$$\begin{cases} a\sum x_i^2 + b\sum x_i = & \sum x_i y_i \\ a\sum x_i + bn = & \sum y_i \,, \end{cases} \tag{7}$$

where n is the number of inliners.

6.5. Communication

As mentioned in Section 4.2 equipment the ZigBee communication was chosen in the communication design. The ZigBee communication protocol is based on IEEE 802.15.4 and it is a relatively new protocol introduced in year 2004. The protocol is using a mesh network shown in Figure 40. Each network module is representated by its unique MAC address. Three module types are commonly used in network :

- ZigBee coordinator module:
  - it is able to communicate with all devices in the network
  - it routes data from other devices
  - not enable to sleep
  - it controls access of other devices
- ZigBee router module:
  - it able to communicate with all devices in the network
  - it must joint the mesh before it can transmit
  - it is able to route data from other devices
- ZigBee end device module:
  - it communicates only with the parent device, router
  - it can receive or transmit data after joining the mesh network
  - enable to sleep to lower power consumption

6.6. Periphery control

For periphery control an Arduino board was used. The manufacturer of this device supports software and development environment. The software and many tutorials are free to download from manufacturer support[17]. The Arduino language is merely a set

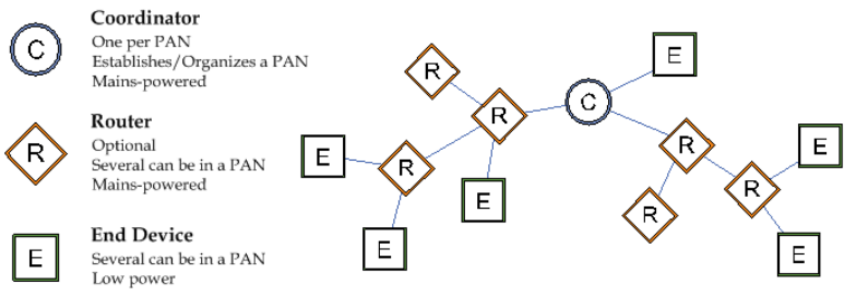


Fig. 40. ZigBee mesh network topology (taken from [18])

of C/C++ functions. The Arduino environment can be extended through the use of many available libraries. For example for my application the servo control library was used to control the movable grate actuator.

6.6.1. Servo control

The servo control is based on Pulse Width Modulation. The square wave pulse is used as the carrier of information which the control electronics of the servo evaluates. The PWM servo-control principle differs from the PWM used for DC motor control (section 6.6.2).

The control signal sends a square pulse every 20ms. The width of the pulse will determine how far the servo turns and what direction. The relevant values of pulse width are approximately the same for most servos as one can see in Table 15 where the commonly used ending stop and center position values are given. The final value can vary for different manufacturers. In Table 15 is also shown certain values of used servo HS-5645MG as indicated in Section 4.5.

Position (°)	Commonly used pulse width (ms)	HS-564MG pulse width (ms)
0	1.25	0.90
90	1.50	1.50
180	1.75	2.10

Tab. 15. Used pulse widths of PWM servo control

From the table information it is obvious that used servo is more accurate than common servos. In real this fact may not be true because of the motor stepping which is generally about 1°. For final application this accuracy is absolutely sufficient.

6.6.2. PWM control for DC motor

The Pulse Width Modulation (PWM) is the most commonly used method of speed control of DC motors. The supply voltage of the motor is modulated in form of square wave pulse with variable duty cycle. By changing the duty cycle we can regulate the motor speed and with the used H-bridge circuit we can also control the direction of rotation. This method of control has a several advantages in comparison to simple modulation by the supply voltage value:

- lower losses,
- stable torque in all range of speed,
- possible linear control from zero to maximum speed.

The main disadvantage of this control are significant losses in the case of a stopped motor (duty cycle 50/50%). For this reason it is necessary to disconnect the control outputs or set them both to the same logic level (engine brake [20]).

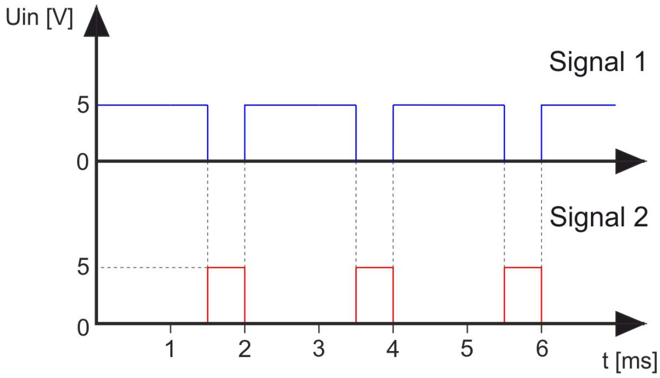


Fig. 41. Illustration of control inputs - 75/25% duty cycle

The control principle is the following. The controlling H-bridge circuit has two inputs as one could see in Figure 20. In Figure 41 we can see the possible control signals to the H-bridge. The duty cycle of the first signal is set at 75%. The second signal is always the opposite of the first signal (in this case 25%). In the case the first pulse is set to "high", the second signal is set to "low". This negation causes switching of the H-bridge. The commonly used frequency is up to 25 kHz. In lower frequencies in range of hundreds of Hz parasitic vibrations can occur. For high frequencies the motor control may become ineffective. For that reason the working frequency should be chosen in range of 1-2 kHz.

When the duty cycle is set at 50% it is obvious that motor is not operating. By changing the duty cycle up or down the rotation direction can be chosen and increasing or by lowering its value the speed of the motor can be regulated. Maximal speeds are given in extreme positions of duty cycle therefore in 0% and 100%.

7. Conclusion

The UAVs are a new and perspective technology. Developing supporting devices for their application is necessary for further improving and expanding of this technology into new areas of utilization. Building such a device as the intelligent docking station is necessary for its next evolution stage and I believe that the docking devices will become a standard part in UAV applications. Demands for this technology are already noticeable and in the coming years the demands will grow.

The main part of this work was developing and building a new device. The final document has a rather machinery character and it was focused mainly on developing, designing and manufacturing the physical device. The machinery character explains the total count of finished drawings which exceeds 40. This fact really shows the scope of the work because every drawing represents one part which was designed and separately manufactured. Although the work is complex and it combines many areas including the electronic design and software implementation, the most difficult and time consuming was the machinery design and manufacture.

Providing the production was for me the most rewarding factor of this work. The fact that student himself provides the total production of his device is unique in its own way and it is not in general a frequent part of the bachelor thesis. Thanks to my secondary education in machinery and many connections in machinery production I had an advantage over other students who could process this subject. Without these advantages I think that it would be difficult to find another student who would be capable accomplishing the work. The manufacture itself helped me to improve myself in personal communication and I received a lot of experience in real production and developing. These facts are for the student very important in his future practical application because in general the student has not many production and industry experience.

The design itself contains several new developed solutions. The developed landing-board system joining the locking and charging function is one its kinds. Joining the charging and locking functions into one system is simply solved and it offers the possibility of practical usage in the future. The design of the cover mechanism was found to be functional including all components such as the gearing and rope system. Some parts of the device are not without some modifications to the original design.

The rim of the movable grate (Section 3.2.2) had to be reinforced to prevent its bending. For that reason a single piece steel sheet rim (drawing number 045) had to be added to the rim composed from the plastic U-profile. For further usage the heliport needs to be equipped with a mobile chassis because of its weight to improve its mobility. The photos of the final design and completed device are available in Appendix A.

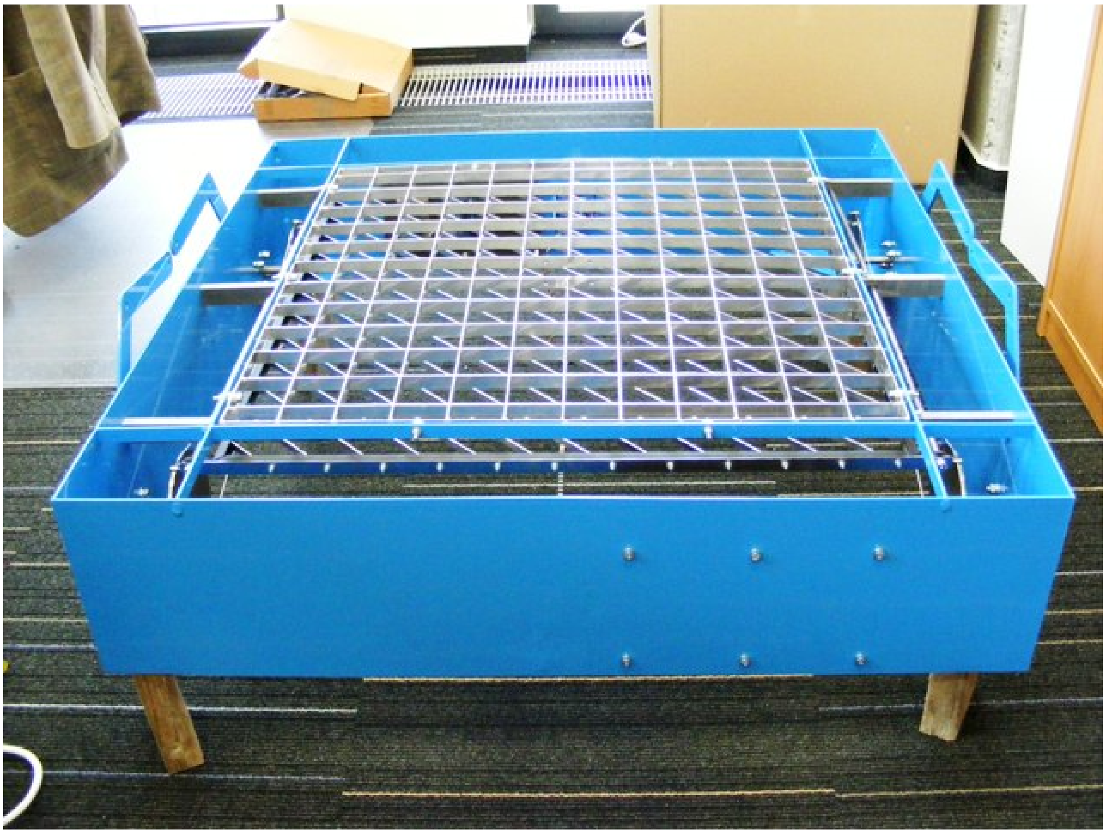
The next segment of this work is the electronic equipment manufacture and application. This part required electronic circuit theory knowledge and experience with electronic parts and circuit design. The result of this part was creating a new electronic device which was used in final application.

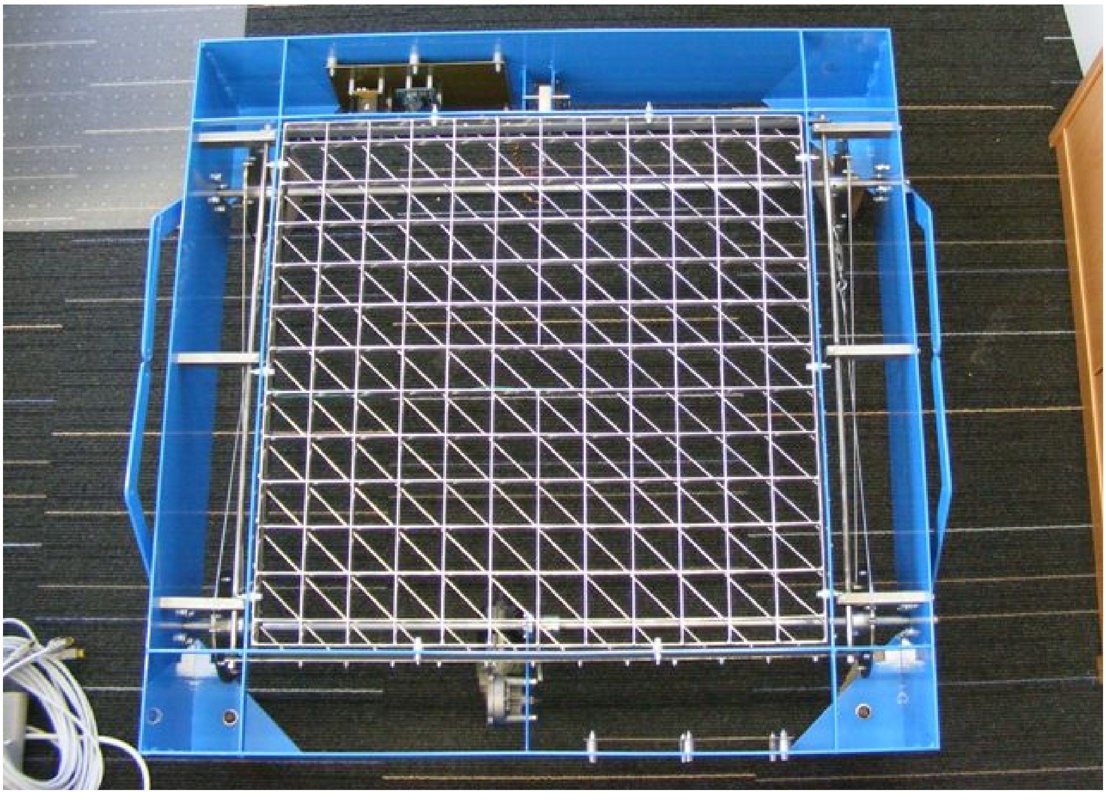
The required software for object location and periphery control has been implemented. Due to the scale of the work I consider the implemented object location software as beta version. For future research and development more complex systems and programs have to be implemented. The used implementation uses only basics functions. The heliport is designed as a device which in the future will evolve. This fact allows to create many possible work subjects focused on the heliport which will be interesting and applicable.

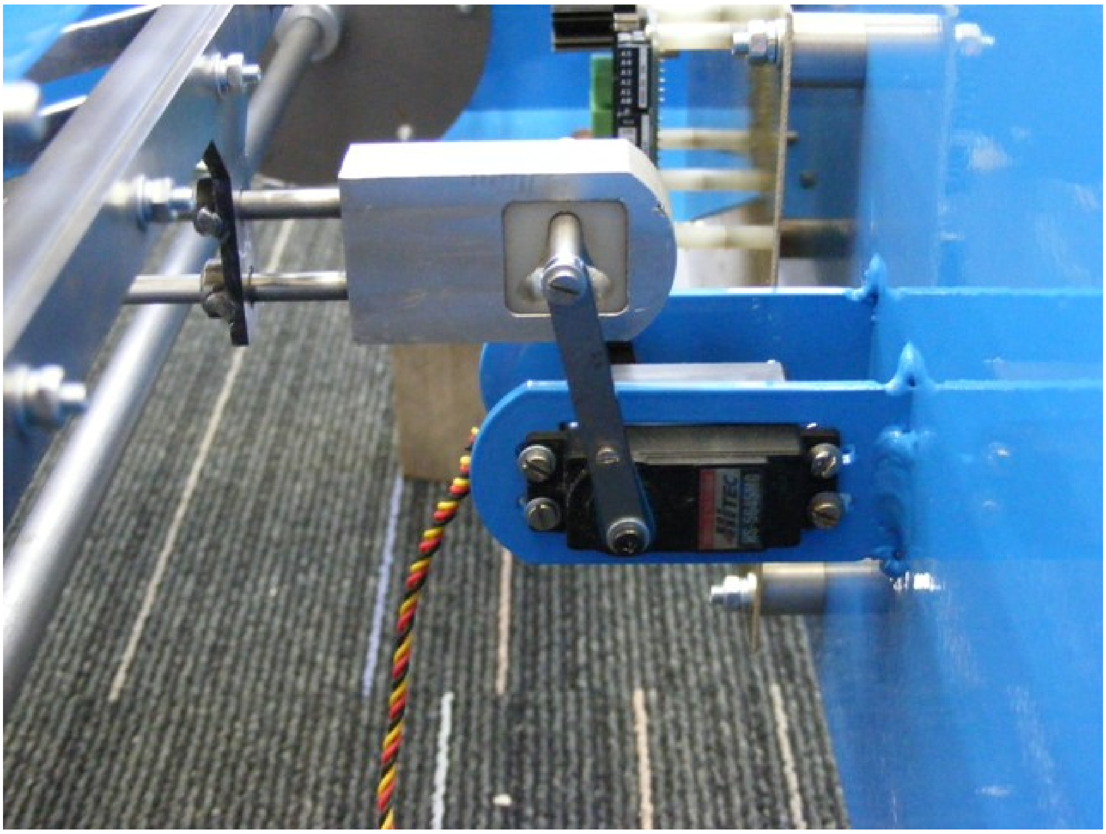
In summary the final device was constructed. It will be used for research and development at Czech Institute of Informatics, Robotics and Cybernetics (CIIRC). The design is adapted to further improvements and allows to add any possible application or function in the future. The opportunity to work on this task was very rewarding. Thank to such a complex work I gained a lot of experience from different technology areas and I experienced the whole production process. It helped me to realize how much more complicated is to design and actually realize the new idea into the real product.

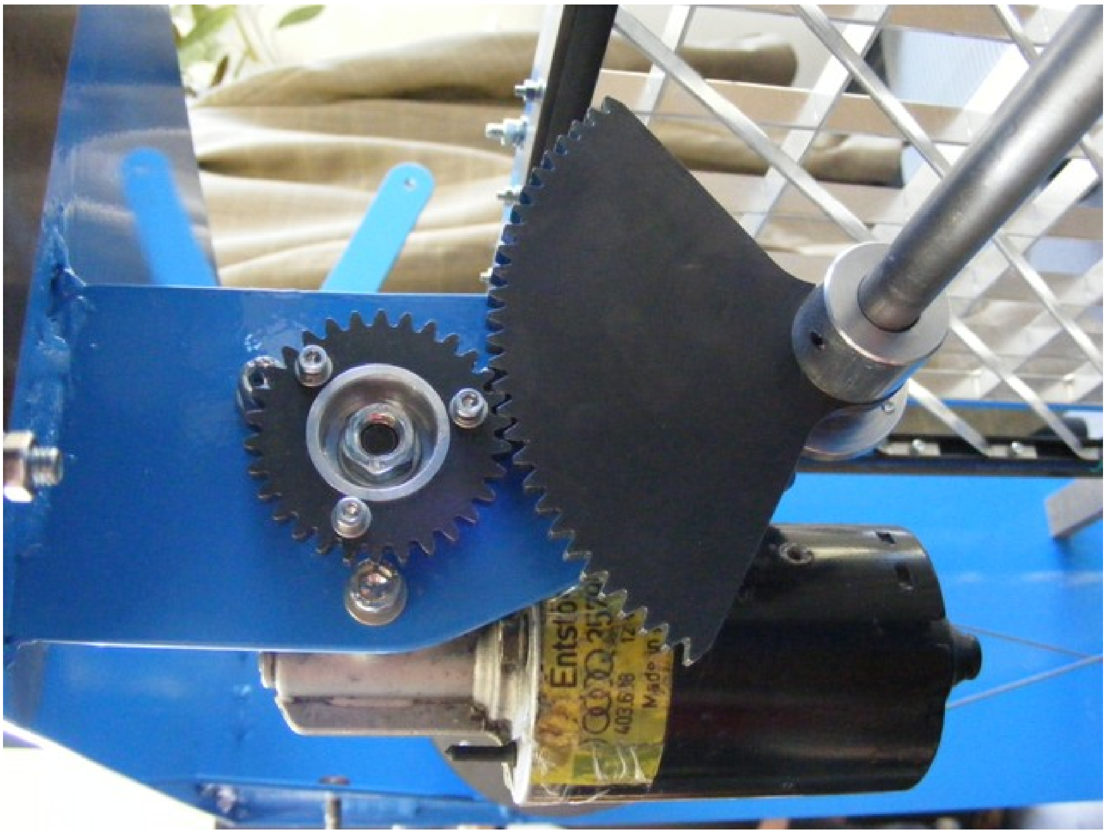
Appendix A.

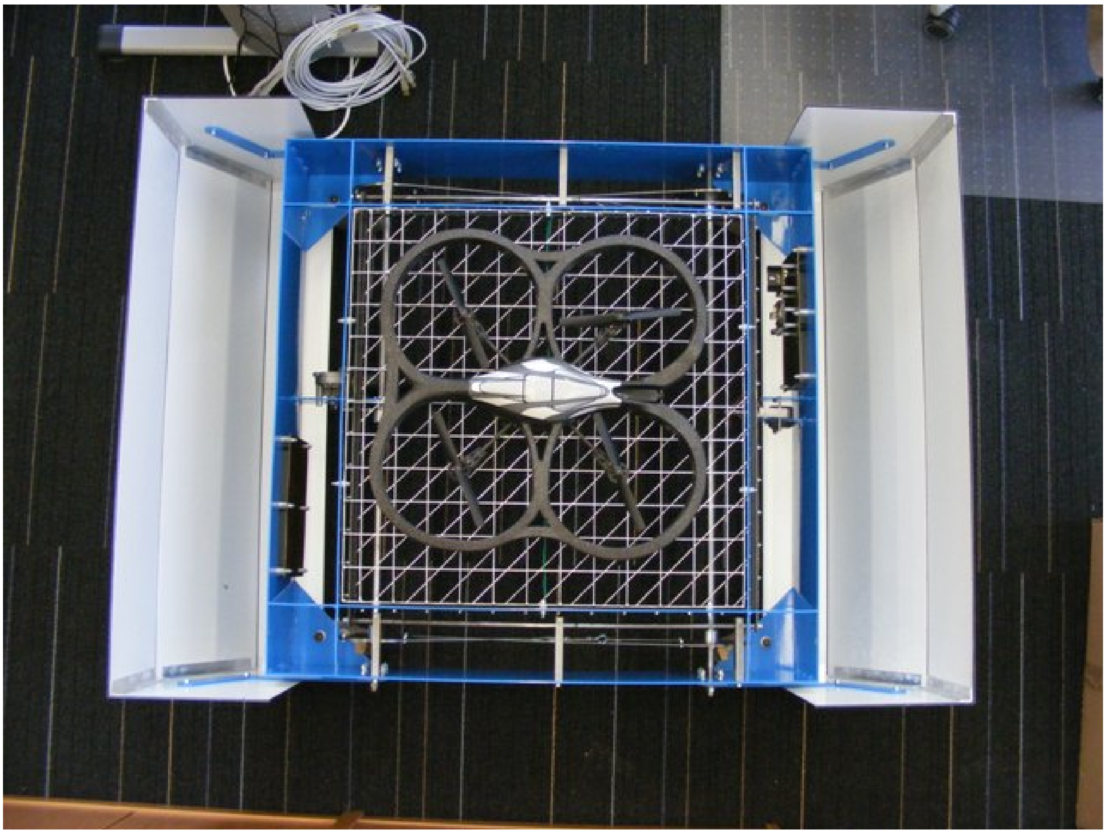
Photographs of the heliport











Appendix B.

CD Content

The list of root directories is shown in following Table 16.

Directory name	Description
thesis	Bachelor Thesis in pdf format
latex	latex source codes
autocad_drawings	complete AutoCAD drawing documentation
sketchup	complete Sketchup 3D models and visualizations
eagle	Eagle project
code	object localization & periphery control source codes
photos	all photographs from manufacture and photographs of the final device

Tab. 16. CD content

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