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DEVELOPMENT OF THE MODEL HOVERCRAFT

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Abstract
This article presents the hardware requirements and the functionality of the hovercraft vehicle designed by the A-Team for the 9th "Hungarians on Mars" student competition. The article focuses on the electronic and hardware development of the vehicle as well as the design of the hovercraft controller. The article provides a detailed description of the structure of the hovercraft, and We introduce the basic mechanical model for the hovercraft. When we show the mechanical structure we collect the actuators and we would like to introduce the electric hardware which able to control these actuators. The main controller of the hovercraft is the FPGA embedded SoC (System on Chip) development board. This board provides the control signal to the electric hardware and it can move this vehicle. Finally, we introduce the own-built hovercraft created for the 9th "Hungarians on Mars".

Keywords: *hovercraft, embedded system, FPGA, robotics*

1. Introduction

Every year among the electrical engineering students of the University of Miskolc, a number of students participate in the annual ”Hungarians on Mars”, or international robot builder competition. The author has competed on numerous occasions as a member of the university's ’A-TEAM’.

In the *9 th* ”Hungarians on Mars” the challenge was to build a hovering robot and a remote controller, referred to by participants as a ‘Jedi glove’. The glove uses real-time motion sensors to control the hovercraft. The vehicle is equipped with a crane, which is also controlled by the Jedi glove. As part of the competition, the crane must be able to place cubes within ’Tatuin cubes’, boxes of varying heights. The team whose hovercraft places the dice on the Tatuin cubes gain points in the competition.

The remote-control Jedi glove utilizes a gyroscope sensor which responds to the user's hand motions. The data from the sensor is transmitted to the hovercraft via Bluetooth. The sensors at the end of the fingers allow the user to choose between different menus and functions.

Considering the large number of motors (servo motors, DC brush motors, stepper motors) required to build the robot, the author chose to use FPGAs (programmable logic gate arrays), in which separate logic units can operate independently and in parallel.

These individual logic units can operate both independently and in parallel. The ZYBO, that contains a system chip (FPGA + processor) circuit, is used for control. As stated, the article focuses on the design of the hovercraft, and therefore the control glove is not discussed in detail.

2. Requirements

The requirements for the hovercraft in the 9th ”Hungarians on Mars” competition were the following:

- A hovercraft is a vehicle that glides above a thin layer of air.
- The vehicle can be the classic skirted version or one of the a ‘non-flying’ versions (helicopter, quadrocopter).
- The robot may come into contact with the ground, stop whilst gliding, but it must not roll.
- Friction cannot be used for steering (skate-like mechanics).
- All rotating parts of the robot with the potential to cause damage to another robot (metal mesh) must include measures to protect other robots.
- The high-speed rotating propeller must be made of plastic to avoid accidents.
- All robots must be equipped with an emergency stop function.
- Hardware may be mounted on the robot to aid control, for example, an FPV camera.
- Active protection is allowed, which means that fans used for movement can be used to make it difficult for the opponent to advance. The robotic arm can be used to protect cubes that have already been placed in the target area.
- The robotic arm may not include special accessories (blade, flame thrower, air blower) with only tools necessary to manipulate cubes permitted.
- The robotic arms of competing robots may be restricted in their movements; for example, they cannot be held in order to restrict movement. Cubes may only be removed from the target area by mechanical means (they cannot be blown using a fan)
- The robot must be constructed in such a way that the lowest (21cm) cube placed on the target area must not be moved by the use of air movement under any circumstances.
- The cube of another team cannot be permanently picked up or collected.

3. Model of Hovercraft

In this chapter the model of the A-Team’s hovercraft designed for the competition is presented. During the literature review, it was found that typically hovercraft have two propellers (Fantoni et al., 1999; Aguiar and Pascoal, 2001; Chaos et al., 2013) with some having an airfoil (Tran et al., 2020; Cabecinhas et al., 2017). After studying the scientific literature, it was found that the identification of the parameters is the most complicated problem in this research area. Articles (Fantoni et al., 1999; Aguiar and Pascoal, 2001; Chaos et al., 2013; Tran et al., 2020; Cabecinhas et al., 2017) focus on the modelling of certain types of Hovercraft.

The following illustration (***Figure 1.***) is the design of the hovercraft chosen by the A-Team.

X and Y are the coordinate system of the hovercraft environment. The diagram displays two coordinate systems, which are the local coordinate system of the hovercraft (xh, yh) and the coordinate system of the propeller (xr, yr). ω is the angular velocity or curvature. Finally, ψ is the angle of the two hovercraft coordinate systems.

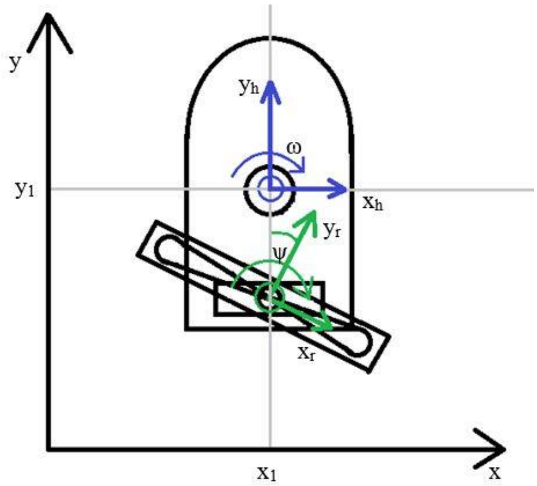


Figure 1. *Model of hovercraft*

The kinematic equation of the rotational coordinate system:

$$\dot{y}_r = v_{y_r} \tag{1}$$

$$\dot{x}_r = v_{x_r} \tag{2}$$

Where v variables are the velocity vector in the rotor coordinate system. The next step is to transform it into the base hovercraft coordinate system. The following transformation is used for the diffeomorphism (Pettersen and Egeland, 1996):

$$z_1 = cos\ cos\ (\psi) * x + sin\ sin\ (\psi) * y \tag{3}$$

$$z_2 = -\ sin\ sin\ (\psi) * x + cos\ cos\ (\psi) * y \tag{4}$$

$$z_3 = \psi \tag{5}$$

The basic kinematical equation for the hovercraft coordinate system is the following:

$$(v_x\ v_y\ ) = (cos\ cos\ (\psi)\ \ sin\ sin\ (\psi)\ \ -sin\ sin\ (\psi)\ \ cos\ cos\ (\psi)\ ) * (v_{x_r}\ v_{y_r}\ ) \tag{6}$$

Calculating the angular velocity is complicated as it was necessary to estimate where the hovercraft's centre of gravity is. The equipment necessary for the required measurements was not available. The following calculations describes the origin of the hovercraft coordinate system and the centre of gravity which are in the same position.

$$\omega = \sqrt{\frac{F_{x_r}}{m * r}} \tag{7}$$

Where the F_{x_r} is a force vector from the rotor which is parallel with the x-axis. The m parameter is the mass of the hovercraft, and the r is the distance between two coordinate system origin.

This chapter introduced the basic model of our hovercraft. Sufficient information on the hovercraft to identify the parameters was not available.

4. Components

As previously described, the building blocks of the hovercraft's electronics are presented in the following illustration of the complete electrical network of the vehicle:

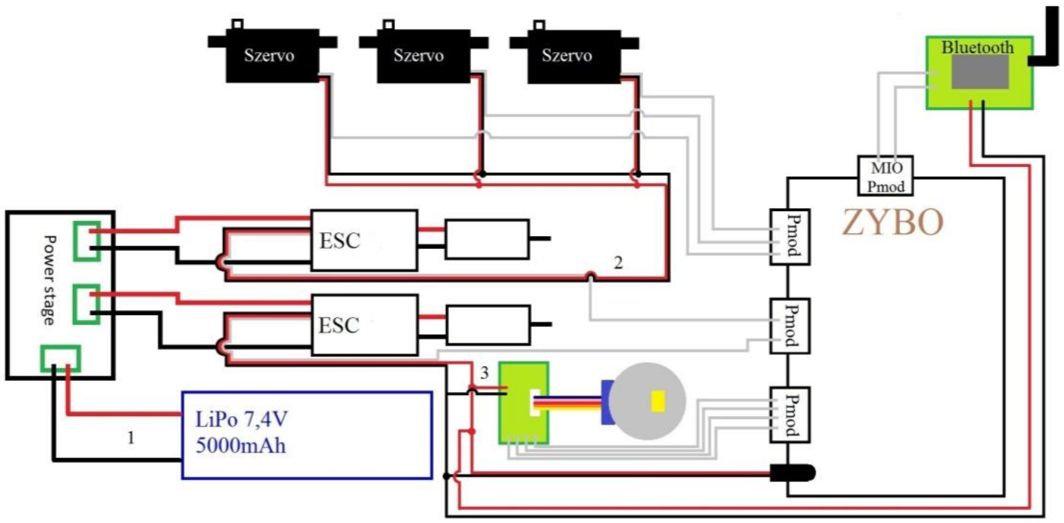


Figure 2. *Electronic block diagram of the hovercraft*

In the diagram the three supply voltage lines are:

- The 7,4V voltage of the battery supplies the 2 ESC-s.
- The 5V output of the ESC drives the three servo motors. The 5V output of the ESC provides stable supply voltage for the ZYBO board, the Bluetooth panel, and the stepping motor driver.

The grey wires mark signal wires. Each one of these connects to the Pmod connectors of the ZYBO board. This chapter refers to the utilized hardware components, their structure, and their properties. Here we introduce the ZYBO board and the other actuator.

One of the most important parts of electronics is the battery and based on the previous experience of the Hungarians on Mars competition, a poor selection of batteries has the potential to cause significant setbacks. It is important to be able to charge the battery quickly and without having to remove or fully discharge prior to recharging. Based on these criteria, the Lithium-Polymer battery, often used in modelling, is the most suitable option.

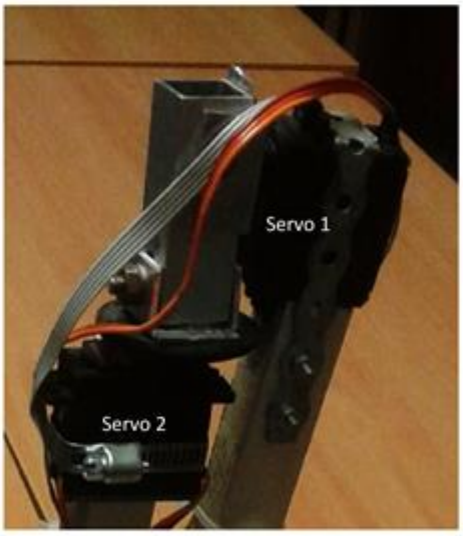
Once the battery is selected, the current power consumption needs to be considered and based on that, it is important to determine the voltage and mAh of the battery.

The two brushed motors consume approximately 6amps each, and including the other motors and electronic components, the total consumption is 14amps when operating all of them simultaneously.

The two brushed motors are compatible with a 2-cell - 3.7V each battery - and therefore have an operating voltage of 7.4V.

Based on this, the chosen battery has two cells, its capacity is 5000mAh, and it is capable of 3C, which means that it is capable of discharging three times the current capacity, which is 15amps.

4.1. Motors



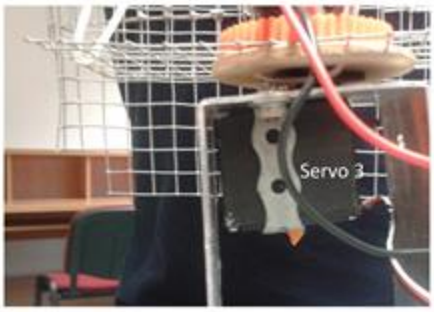


Figure 3. *servo motor 1: vertical movement of the crane servo motor 2: horizontal movement of the crane servo motor 3: horizontal rotation of the propellant motor*

The servo motors are responsible for the horizontal and vertical movement of the rear propellant motors and the crane that is on the hovercraft. One characteristic of servo motors is that, in general, they can only turn 180 degrees, which is controlled by a separate regulator built inside the motor, but usually, mechanical end-position limits are also implemented. It has three outlets: one ground (black), one supply outlet, which is usually 5 V (red), and one driver signal wire which connects to the regulator (white). This type of motor does not require fitting to the driver, power supply pins have to be wired to the correct potential, while the driver pin connects directly to the ZYBO board.

The hovercraft has two brushed motors. These are responsible for the inflation and the advance of the skirt of the hovercraft (one for each task). These are shown in the following pictures.

This type of motor has only two supply outlets which are driven by the level of the voltage that is connected to them. It is also possible to drive the motors with a sampled signal (PWM) at a constant voltage level, in which case the duty cycle of the signal is modified. The product of the duty cycle and the high-level potential of the signal equals the direct voltage that matches the utilized sampled signal. The frequency of the sampled signal is 1,5kHz. The motors are fitted to the ZYBO with two ESC-s, which are driven in the same way as the servo motors. The ESC places the 1,5 kHz PWM signal onto its output to this driver signal.

The meaning of ESC is Electronic Speed Controller, potentially one of the most useful components of the hovercraft. It is capable of driving a brushed motor based on the signal that is wired to its input, which is the same as the signal of the servo motor, and it is also capable of providing a 5 V supply voltage, with which the ZYBO board and the other electric components can be supplied. The current capacity of the ESC is 30 A. The ESC, which is used on the hovercraft can be seen in the following photo, along with the electric functions of each of its outlets.

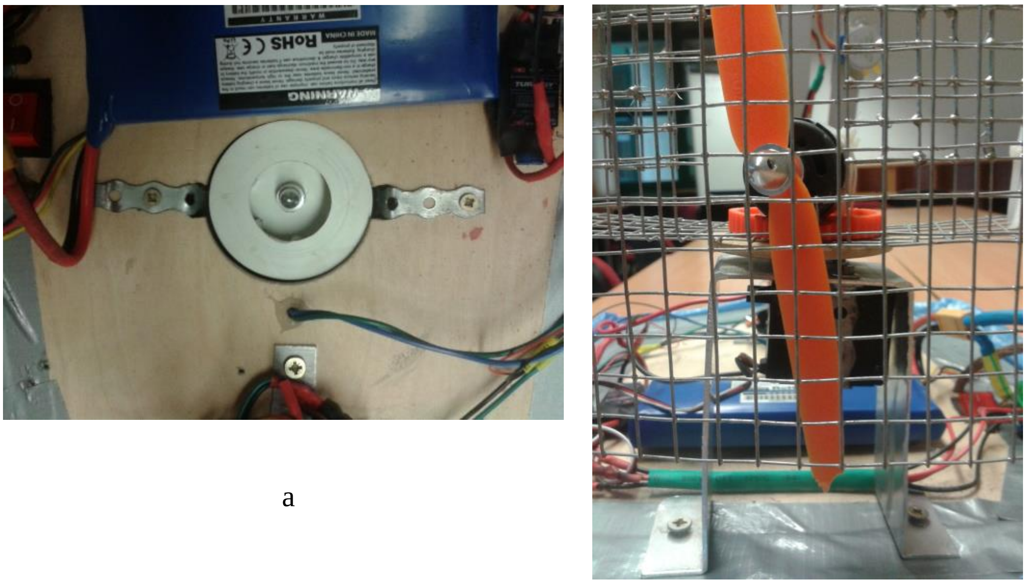


Figure 4. *a.) Propeller for floating b.) Propeller for movement*

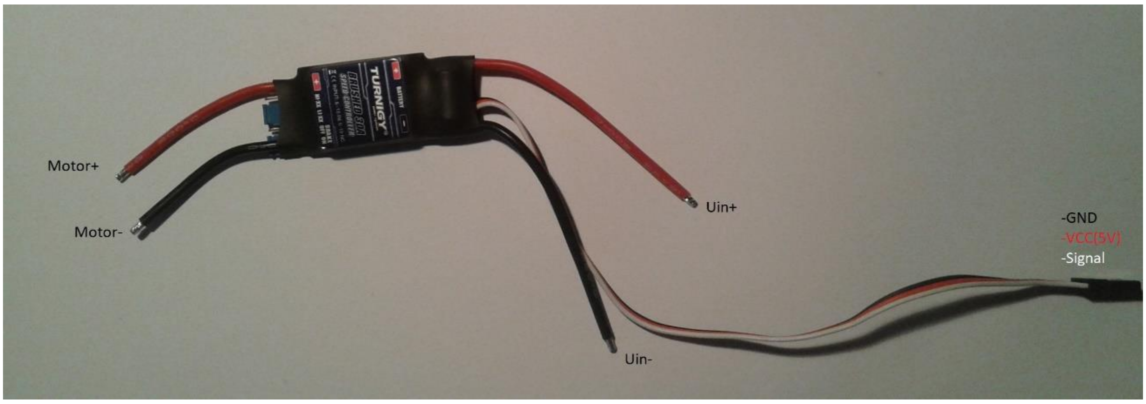


Figure 5. *ESC*

With a unipolar stepper motor, the arm of the crane drives a toothed rack with a gear, which pushes out the cube from the arm. The stepper motor is one of the most unique types of synchronal motors since it has two separate center-tapped coils. The motors can be driven with a digital signal if the center tap of the coils is connected to the ground, after which voltage is applied to the outlets of each coil sequentially. Thus, the digital signal is a 4-bit vector (“0001”), which has to be shifted around, as per Figure 6.

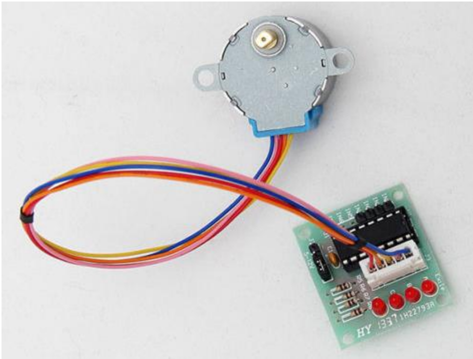


Figure 6. *Stepper motor with a driver*

4.2. Controller of hovercraft

The ZYBO (**ZY**nq **BO**ard) is a low-level embedded system development platform board, with the Z-7010 type circuit, the smallest member of the Zynq-7000 family, as its central component. The Z-7010 is based on the Xilinx All Programmable System-on-Chip (AP SoC) architecture, which includes two ARM Cortex-A9 processor cores and a Xilinx 7. series programmable logic core (FPGA) on one integrated circuit board.

Figure 7. *ZYBO board*

The ZYBO board is the main component of the hovercraft.

5. Summary

The article introduced the robot created for the 9th “Hungarians on Mars” competition, a hovercraft that benefits from the installation of a crane to manipulate objects. The literature review of scientific articles revealed that the robot designed by the A-Team is not a conventional hovercraft. The article describes the hovercraft, including the robot model, its electrical components and design features. The ZYBO card, which contains a system chip (FPGA + processor), is used for controlling the robot.

The next figure shows the finished hovercraft.

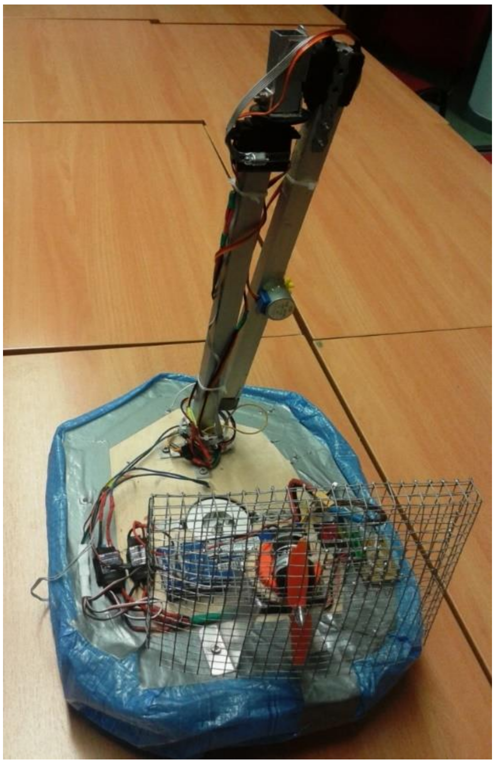


Figure 8. *Hovercraft*

This was built in 2014 when the author was in the second year of BSc studies. Nowadays, this robot is used in Embedded systems and Control labs. The challenge was rewarding for the author, as he had the opportunity to study different types of controllable motors.

6. Acknowledgments

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