Measuring Robot Development

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Motto:

"Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world."
Albert Einstein

Abstract: *Last year, my self-developed energy robot, HEAT SPOTTER, won high commendation at the 30th INTERNATIONAL SCIENTIFIC AND INNOVATION COMPETITION. The robot is patent pending, as recommended by the jury.*
In the meantime, I have improved the robot in many ways. The main aspects of this process have been to improve technical sophistication and usability.
In this article, I present the results of this process.

Keywords: *Energetics, robot, remote control, thermal camera*

1. Introduction

Energy plays a prominent role in the world. Energy losses are a sign of inefficiency, a disruption of operations. In certain cases, we can identify these processes and diagnose the points of failure by means of heat loss.
A good tool for this can be a thermal imaging camera. In many cases, however, it can be useful to use a mobile, remote-controlled robot to introduce the analysis tool into hard-to-reach places. It can also be important to store the results for several analysis points and evaluate them later.
Remote control can also mean not having a direct view of the instrument. This problem also needs to be technically addressed.
HEAT SPOTTER, as the first development version, solved the above-mentioned tasks with simplified technical solutions.
Its main advantages are that it:

- is labour-saving,
- is simple and efficient to use, not only by energy and air chemistry specialists,
- It provides objective and documentable measurement results.

In this article, I describe the subject, the tools, and the results of the nearly one-year development process that has taken place since then.

2. Improving the basic and energy operation of HEAT SPOTTER

I have also upgraded the basic and energy operation in the following areas:

- improved image transmission technology,
- enhanced thermal imaging camera with higher resolution,
- improved on-board electronics (design of printed circuit boards instead of the previous prototype electronics)
- reducing the robot's risk of collision with front and rear ultrasonic distance sensors,
- making the mechanical structure suitable for the new functions (design and construction of new supports and structural elements),
- LIDAR-based environmental detection (in this case, the first phase of development is currently under way).

The above listed objectives were achieved by carrying out the following professional tasks.

- Mechanical design (Autodesk Inventor) and construction, 3D printing (Anycubic Chiron 3D printer),
- Programming (image transfer, teleoperation, LIDAR, data acquisition, processing),
- Electronic design (new camera and thermal camera, improved image transmission and teleoperation, LIDAR-based environmental assessment, ultrasonic range finders).

3. How it is implemented

3.1. The initial design (HEAT SPOTTER 1.0)

Main features of version 1.0:

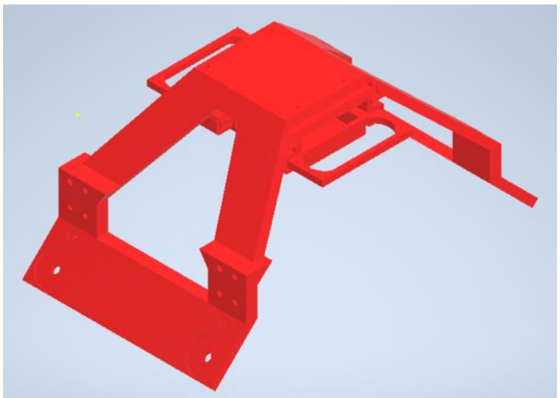
- The structure of the robot is easy and cheap to manufacture, but at the same time robust and aesthetically pleasing anodised aluminium sheet to withstand the stresses of use.
- The equipment is remote-controlled, six-wheeled, differential-driven. This type of drive facilitates manoeuvrability in tight spaces.
- Basic IT architecture:
    - An embedded computer (Raspberry Pi 4) is located inside the device and is responsible for on-board image processing.
    - Teleoperation is separated from image transmission:
        - The speed and direction are determined by a 2.4 GHz radio signal.
        - The thermal camera and the camera image are displayed on a display tablet (Archos Oxygen 70).

Fig. 1. HEAT SPOTTER 2.0 (Source: Own development and own photo)

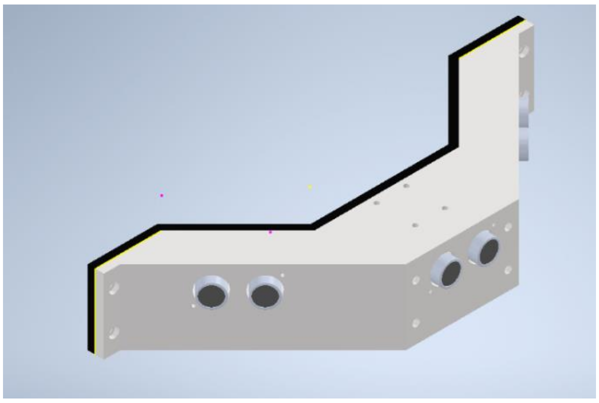
3.2 Mechanical design and implementation

3.2.1 Additions to the robot body to support new functions

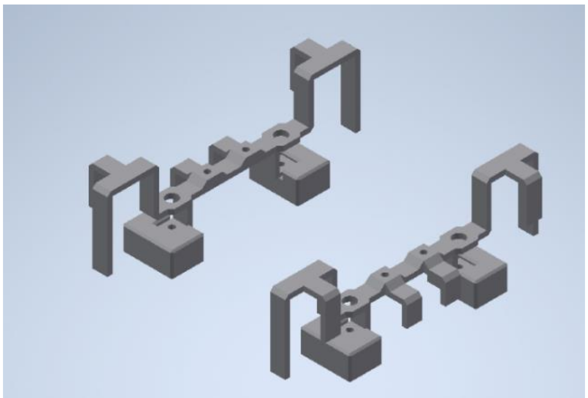
The housing (body) of the robot platform I designed was already made from aluminium sheet for the previous competition, using CNC laser cutting. I used Autodesk Inventor to design the mounting and support elements (PLA filament) and the bumper (PETG filament) of each element in the body (fig. 2), and then fabricated them on my 3D printer (Anycubic Chiron 3D). In this respect, version 2.0 (fig. 1) includes a number of newly designed and manufactured elements that improve quality.



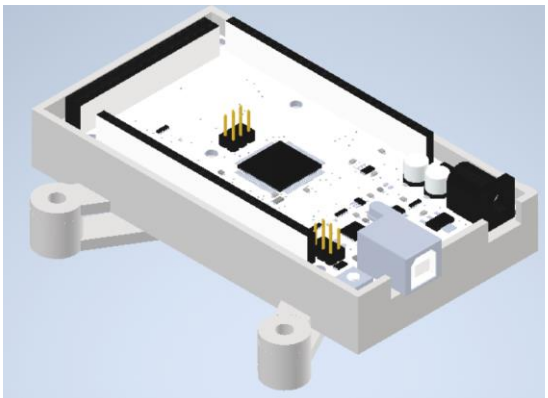
LIDAR and air quality sensor holder (PLA)



Bumper (PETG)



Battery holder (PLA)



Raspberry holder (PLA)

Fig. 2. Mechanical design and construction

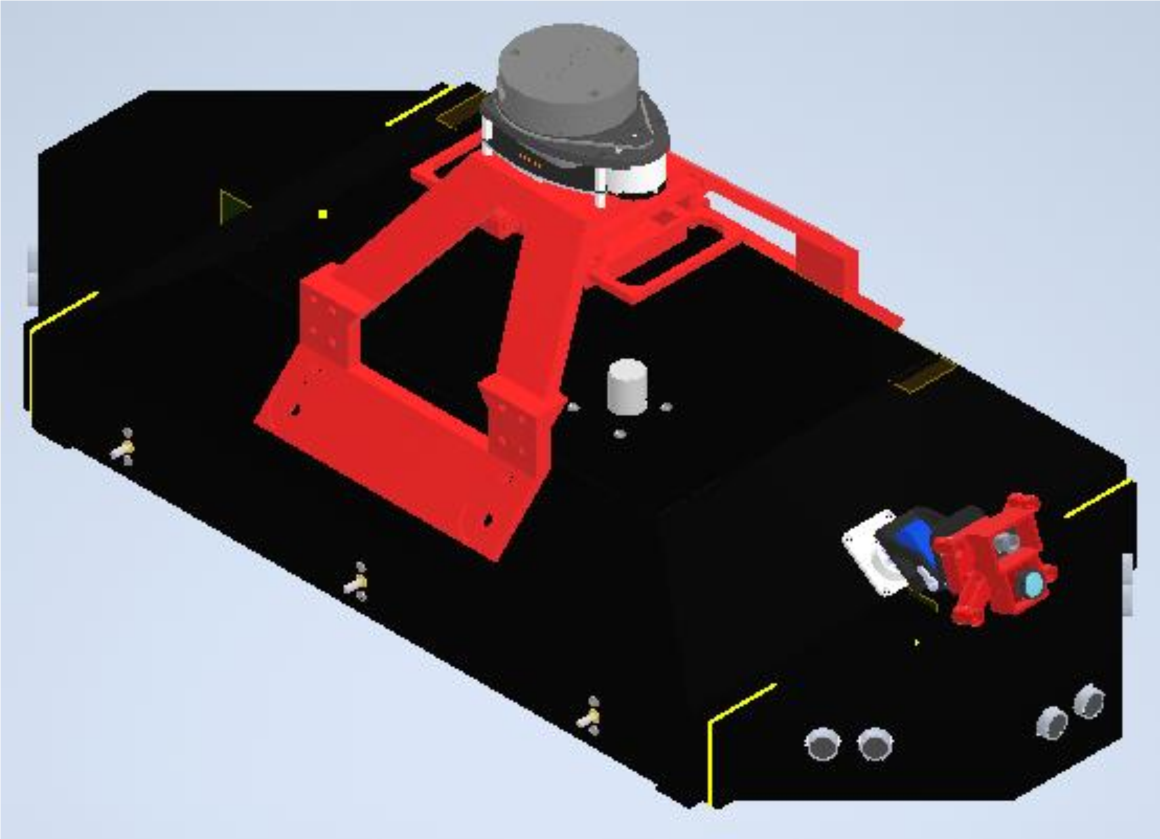


Fig. 3. The robot body with the new LIDAR and camera mounts designed from scratch, the air quality sensor drawer and the bumpers (3D design and printing, PLA material)

3.2.2. Drive

Differentially driven robots are capable of a high degree of mobility with mechanical simplicity. The drive mode makes the robot very manoeuvrable, even when turning in one position, and therefore easy to manoeuvre in confined spaces.

Speed control is achieved by pulse width modulation (PWM) in proportion to the stick positions set by the teleoperator.

As my future plans include the ability to enable the robot to autonomously navigate in the field, which may require odometry, I have equipped the motors with Hall-effect quadratic rotary encoders

3.3 Electronic design and implementation (fig. 4)

The on-board electronics were developed using printed circuit boards of my own design. The printed circuit boards were created using Autodesk Eagle software.

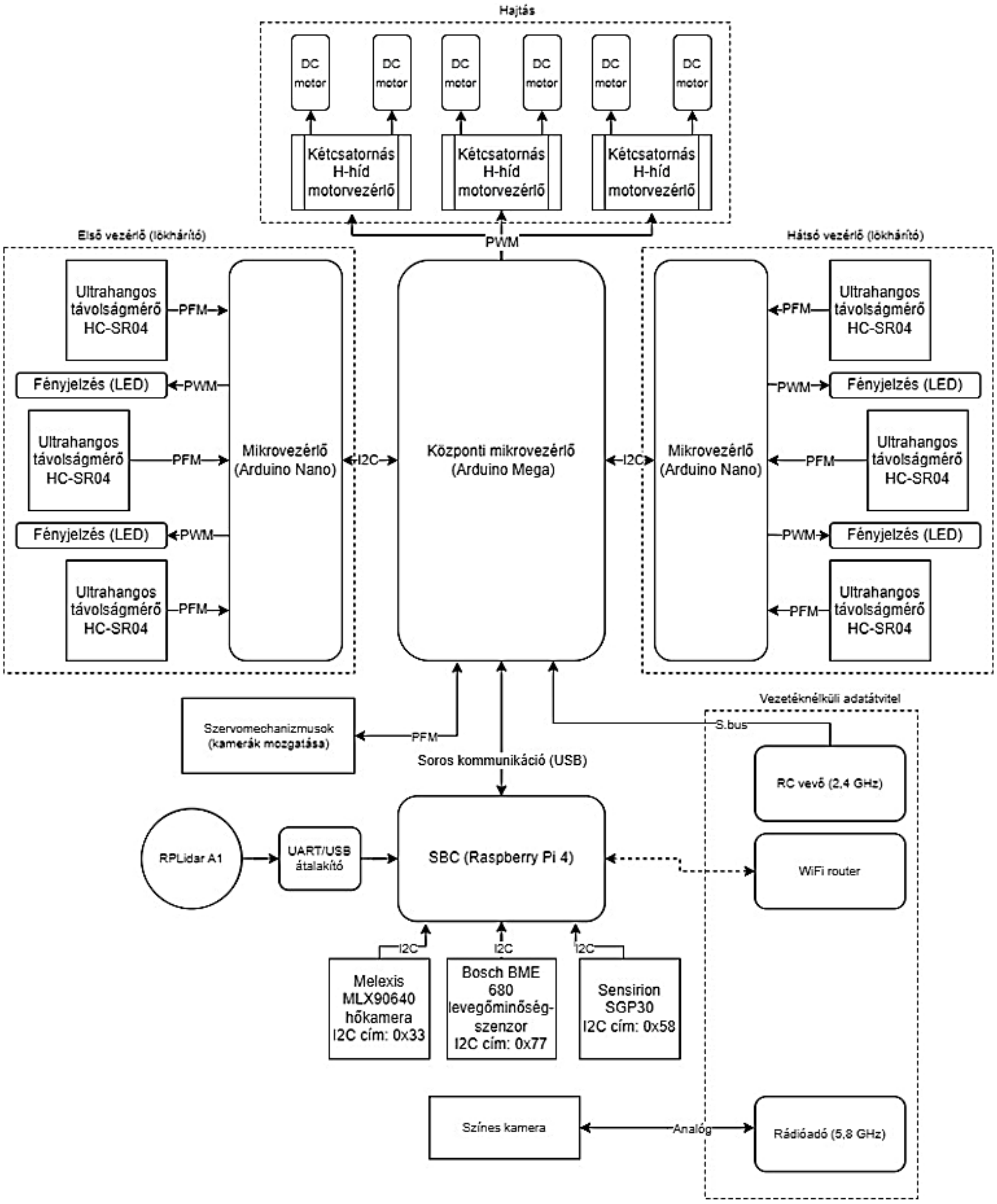


Fig. 4. Block diagram of the robot's electronic architecture (Own picture)

Components of the on-board electronics of the robot:

- **High-level control - Raspberry Pi 4**
    - Processing and transmission of sensor data,
    - Later: environment sensing, route planning for autonomous/semi-autonomous operation,
- **Low-level control - Arduino Mega**
    - Real-time guarantee,
    - Motor actuation,
    - Custom PCB.
- **Control of distance sensors on the front and rear of the robot (in the bumpers)**
    - Arduino Nano, custom PCB,
    - I2C communication between front and rear controllers and central low level,
    - Improved reliability, avoiding problems with wiring, analog signal transmission.

Data transmission is an essential part of a remote-controlled robot. Its solutions are designed and developed in a modular way:

- Camera image transmission - 5.8 GHz radio frequency transceiver
- Teleoperation - 2.4 GHz radio frequency transceiver
- Other on-board sensors data transmission - WiFi, using on-board router. Two possible solutions
- Currently with screen sharing, GUI on Raspberry
- later in the form of UDP packets, GUI on the host PC,
- C# Windows Form Application.

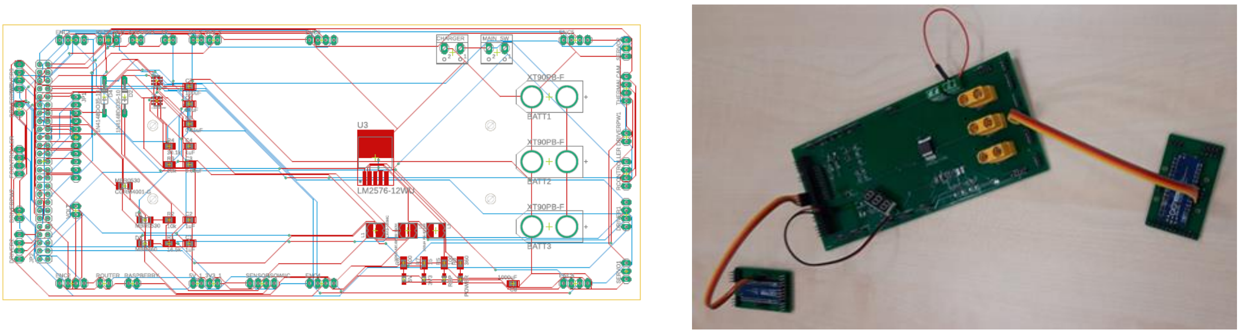


Fig. 5. Design and construction of a centralised substation (Own design)

3.4. LIDAR

I have chosen the following LIDAR for the robot, which offers the best value for money: SLAMTEC RPLIDAR A1 - 360 LASER RANGE SCANNER

This laser scanner development kit is capable of 360-degree scanning within a range of 12 m with a sampling rate of 2-10 Hz (this is for a full revolution). This LIDAR is capable of 0.2 cm range, 1-degree angular resolution and a range of 12 m.

Power supply is 5V. Via a USB cable, the data can be processed on a Raspberry Pi computer.

To hold the LIDAR and the air sensors, I designed a holder with Inventor, with the LIDAR mounted in the upper part (with a suitable robot-around-robot view) and a lower (pull-out) "drawer" to hold the air sensors. The holder also has integrated robot mounting tabs for easier handling of the robot. The design features a hinged construction for easy access to the robot's interior when needed.

3.5. Multifunctional bumpers

I wanted to keep the aluminium frame of the robot, but the redesign of the layout and the development of new functions required an extension. This is achieved by appropriately designed front and rear bumpers. I designed the main switch, the charging socket (so that the battery does not have to be removed for charging), the front and rear ultrasonic distance sensors (4-4) and the printed circuit boards designed to operate them into the front and rear bumpers.

3.6. Thermal camera

The 8x8 matrix thermal camera of the HEAT SPOTTER 1.0 was replaced by a higher resolution Adafruit MLX90640 IR thermal camera. The Adafruit MLX90640 IR consists of an array of 24x32 IR thermal sensors. When connected to the Raspberry Pi, it returns 768 individual IR temperature readings via I2C. The selected version 4469 has a wide field of view (110°x70°). The card can measure temperatures between -40°C and 300°C with an accuracy of 2°C (range 0-100°C). Thanks to the maximum frame rate of 16 Hz, it is perfectly suited to be used as a mini thermal imager.

3.7. Colour night vision camera

The Caddx Ratel, chosen to record colour images, is a low weight, compact analogue camera. 1/18"

HDR sensor, with an output signal compliant with the PAL analogue standard.

3.8. Data transmission, communication

To ensure reliable operation, the robot is equipped with a modular telecommunication system.

It includes the following components:

- WiFi communication with on-board wireless router
- Wireless transmission of data recorded by air quality sensors and LIDAR via WiFi connection
- The data transmitted by the LIDLAR sensors, and the LIDARs are transmitted via wireless link. Data transmission can be implemented in two ways to ensure redundancy:
    - UDP (User Datagram Protocol) - the sensor data is transmitted via the
        - The sensor data is sent in packets. The packets are sent via UDP (packets are sent in packets using the protocol "Datagram protocol").
        - The packets are received by a Windows Form application based on C# programming language.
        - The Windows Form application also acts as a graphical user interface.
    - By mirroring the screen of the Raspberry - sensor data is sent using Python code are displayed on the Raspberry desktop, this is mirrored to AnyDesk application.
        - 5.8 GHz radio communication - used to transmit the colour camera image.
        - 2.4 GHz radio communication - allows teleoperation of the robot.

4. Further development plans

In the near future (for next year's competition), I plan to implement the following improvements to achieve an even higher level of readiness:

- Semi-autonomous, autonomous scouting, surveying, data collection,
- Use of odometry and laser scanners,
- Implementation of SLAM algorithm,

- Ultrasonic distance sensors for safety stop, precise manoeuvrability application of ultrasonic remote sensing.

Preparatory operations already implemented for the above:

- Installation of the laser scanner LIDAR,
- Installation of ultrasonic distance sensors,
- Measurement of the wheel angular speed for odometry.

5. Summary

In many areas of industry and construction, a quick and inexpensive energy survey by a target robot can be a useful tool for listing and rating thermal bridges and heat loss factors and structural elements.

The Heat Spotter 2.0 robot, which I designed and implemented, is an affordable and quick payback tool for these tasks.

The Heat Spotter's design is easy and inexpensive to manufacture, yet robust enough to withstand the rigors of use.

The size and dynamic movement of the device, combined with its good maneuverability and remote control, make it an excellent tool for the job.

I spent many hours designing, building and testing the robot.

During the development phase, of course, I also had to deal with problems, which were a real development challenge. These included:

- choosing the right tools for the budget and quality requirements,
- mutual display of the camera image and the thermal image,
- adjusting the colour map of the thermal camera,
- processing the signals from the air quality sensors,
- ensuring an adequate and independent power supply to sensors and actuators and to the on-board computer,
- design and construction of additional mechanical components for the new developments (with the main focus on appropriate functional design and ease of installation)
- design of prototype-compliant, easy-to-understand PCBs and replacement of the HEAT SPOTTER 1.0 wiring with PCBs.

The robot I designed and implemented is affordable, so it is a quick return on investment for many tasks.

Acknowledgement

The research presented in this paper was partly supported by the Carpathian Basin Talent Research Foundation and Hungarian Innovation Association.

References

[1] Lakatos, Attila. "Building energy assessment robot (HEAT SPOTTER 2.0)." 31st Youth Science and Innovation Talent Competition, 2022.
[2] Chen, Min, and Gabriel A. Rincón-Mora. "Design and Planning a Printed-Circuit Board (PCB) Prototype." (2006).
[3] National Oceanic and Atmospheric Administration (NOAA), Coastal Services Center, Coastal Geospatial Services Division. *Lidar 101: An Introduction to Lidar Technology, Data, and Applications*. Coastal Remote Sensing Program, 2012.
[4] Wong, Wai Kit, Poi Ngee Tan, Loo Chu Kiong, Loo Chu Kiong, and Way-Soong Lim. „Effective Surveillance System Using Thermal Camera." Paper presented at 2009 International Conference on Signal Acquisition and Processing, ICSAP 2009, Kuala Lumpur, Malaysia, April 3-5, 2009.