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Small Robot Vehicle Developed for Multi-purpose Industrial Use

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Abstract

The small robotic vehicle presented in this article is a special, multifunctional vehicle that can perform diagnostic tasks in several different areas. Examination of heat release and heat losses, which characterizes the efficiency of processes in many technical areas. A device that penetrates into small spaces may be needed. In this area, an important task is to navigate the device to the right place under trucks and cars to perform thermal camera diagnostics. The examination of excessive heat emission is extremely important to filter out faulty transmission systems, faulty engines, and to detect excessively hot brake drums, which are unfortunately also responsible for causing many serious accidents and fires.

The remote-controlled navigation robot with a camera presented in the article is perfectly suited for the above task, as it can also transmit the image of the thermal camera to a remote display. In addition to automotive applications, the device can also be used for other industrial purposes and machine diagnostic tasks. I According to the current European Union building energy regulations, new buildings must have almost zero energy requirements. The so-called thermal bridges must be calculated for both old and new buildings under construction.

A useful solution to this problem can be the quick and cost-effective energetic measurement and classification of thermal bridges, factors, and structural elements that cause heat loss. The Heat Spotter robotic vehicle presented and built in the article is suitable for the above tasks, ready to be manufactured and quickly paying for itself.

Keywords

small remote-controlled robot vehicle, energy, heat technology, diagnostics

1 Introduction

The goal of the development of a small robot vehicle is to create a (technical or building) energy metering device that reduces the time and human resources required for the thermal energy assessment process, while at the same time achieving the necessary accuracy and detail in a cost-effective manner (Lakatos, 2021, 2022a, 2022b , 2022c , 2023). The implemented device is a remote-controlled robotic platform with a target sensor. The development was preceded by research on thermal energy measurements.

The buildings to be used in the future will have to comply with the latest requirements of national and EU building energy legislation, i.e., they will have to be nearly zero energy (Potter, 2018).

In Hungary, buildings account for about 40 percent of total energy use and 70% of dwellings do not meet modern thermal and technical requirements. This represents a huge potential for energy savings. One of the relevant energy requirements relates to the maximum heat transfer coefficient (heat loss) of the boundary structures. This determines the heat transfer coefficient of walls, ceilings, windows and glazing that are used to enclose heated cooled spaces. The main objective is to reduce the energy demand for heating (cooling in summer). This will also reduce heating/cooling costs. The comparison of the thermal camera image with the reference image can be the basis for assessment and diagnostic tests. A servomotor-driven thermal camera mounted on a robot vehicle can quickly show exactly where the problems are, or where there is a loss of energy or electrical problems.

Here is an example of a building energy problem. The problem affects both old and new buildings under construction:

- In most cases, the heat transfer coefficients of walls, bridges, slabs, and windows are not known for old buildings. This is a serious problem before renovation.

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- In new buildings, however, it is worth checking the quality of the materials and construction technology used and their impact on the thermal insulation properties during the construction phase.
- Any necessary repairs can be carried out during the process at a much lower cost than after handover or possibly under warranty.

However, this does not yet require costly official energy certification, which can be carried out by contractors with a cheap, easy-to-use measuring device. A good alternative is a quick and inexpensive energy survey by a target robot, listing and rating thermal bridges as well as heat loss factors and structural elements. This is an essential tool for planning and budgeting for construction and renovation. The equipment can be used in a variety of applications, including vehicle diagnostics, e.g., battery diagnostics (Vantuch et al., 2018) shown in Fig. 1 and Fig. 2. In addition to building energy, air quality is also an important quality parameter, which I intend to incorporate as a further development of the robot. (Wall et al., 2021; Christopher Lawson et al., 2022; Pipal and Taneja, 2023) These images can be used for immediate diagnosis, or processed through special software (this may be a later development phase) for further evaluation, accuracy and report output. Some more technical application examples are presented below (Figs. 3 to 5).

2 Design and construction of the robot vehicle

Design and construction of the robot vehicle is easy and cheap to manufacture, but robust enough to withstand

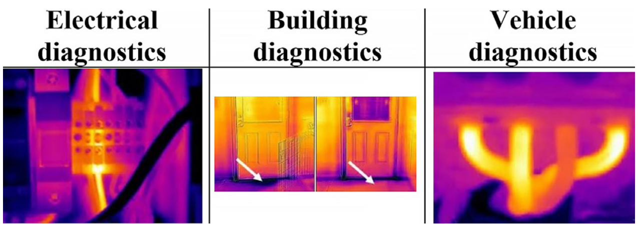

Fig. 1 Thermal camera field of application samples (Snap-on Diagnostic Thermal Imager EETH300)

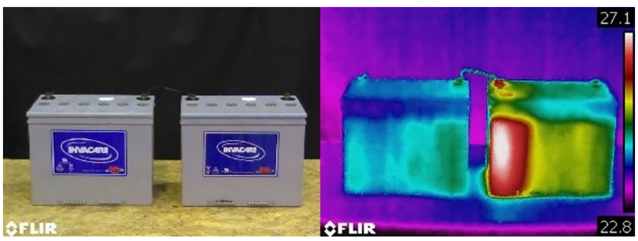

Fig. 2 Thermogram of damaged and undamaged battery (Vantuch et al., 2018)

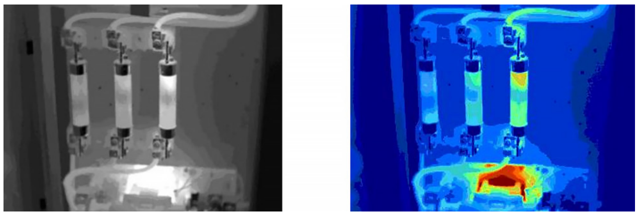

Fig. 3 Fuse diagnostics (electricity), (Vantuch et al., 2018)

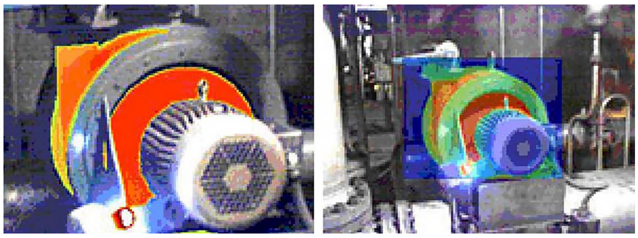

Fig. 4 Electric motor and assembled machine diagnostics (maverickinspection thermography)

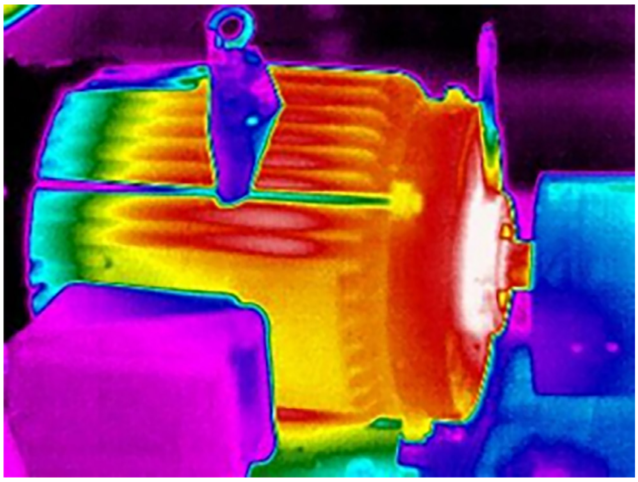

Fig. 5 Overheating Inboard Bearing (maverickinspection thermography)

the stresses of use. It is made of aesthetically pleasing *anodized aluminum* sheet for low weight and corrosion resistance, as shown in Fig. 6. The machine is remote-controlled, six-wheel, differential-driven. This type of drive facilitates *maneuverability* in confined spaces, with the possibility of stepping if required (Fig. 7). Each wheel is driven by an electric motor with a separate speed-reducing gearbox, which ensures a simple design.

Inside the device is an embedded computer (Raspberry Pi 4) responsible for on-board image processing. I have separated the teleoperation from the image transmission.

The speed and direction of the robot is given by a radio signal with a frequency of 2.4 GHz. The image transmission is done by a Wi-Fi connection. This is how the thermal camera and the camera image are transmitted to the display tablet (Archos Oxygen 70).

Fig. 6 The finished HEAT SPOTTER robot

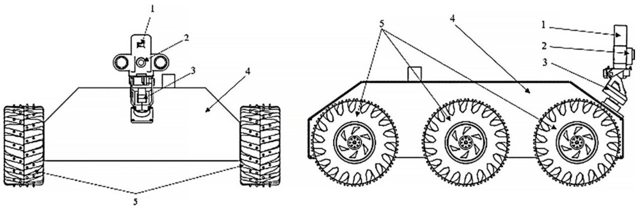

Fig. 7 HEAT SPOTTER robot (1 - thermal camera, 2 - wide angle camera, 3 - adjustable angle bracket, 4 - robot platform, 5 - wheels)

3 Mechanical design and implementation

3.1 The robot vehicle chassis

The robot platform housing (body) is made of aluminium sheet, CNC laser cut. I made the design myself using Autodesk Inventor 3D design software (Fig. 8). The aim was to design a robust, durable and lightweight housing, which after being bent to the finished shape, was anodised.

I designed the mounting and supporting elements (PLA filament) and the bumper (PETG filament) of the body also with Autodesk Inventor and then produced them on my own 3D printer (Anycubic Chiron 3D), shown Figs. 9 to 11.

An important consideration was to make it fit for the job, but also to produce an aesthetically pleasing and easy to assemble solution.

3.2 Drive

Differentially driven robots can move without major geometric constraints. The idea is that the turning is caused by the difference in angular velocity of the wheels on opposite sides, i.e., if the left wheel is turning faster, it will turn to the right, and if the right wheel has a higher angular velocity, it will turn to the left. The drive mode makes the robot very maneuverable in tight spaces, as it can turn in a single turn. The robot is driven by 6 electric motors (Fig. 12), each pair controlled by a dual-channel motor controller. The control is done via an Arduino MEGA2560 panel, which is radio frequency signal controlled. This panel is also responsible for controlling the servo motors that move the cameras. The programming was done in C++ based Arduino programming language.

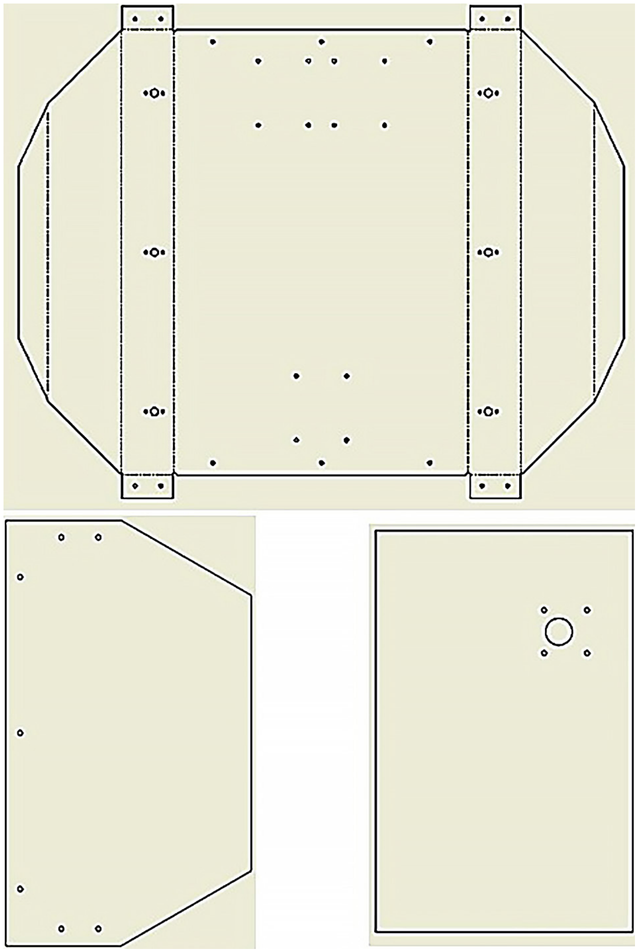

Fig. 8 The parts of the robot vehicle frame, 1.5 mm thick aluminum plate CNC laser cutting based on 3D design

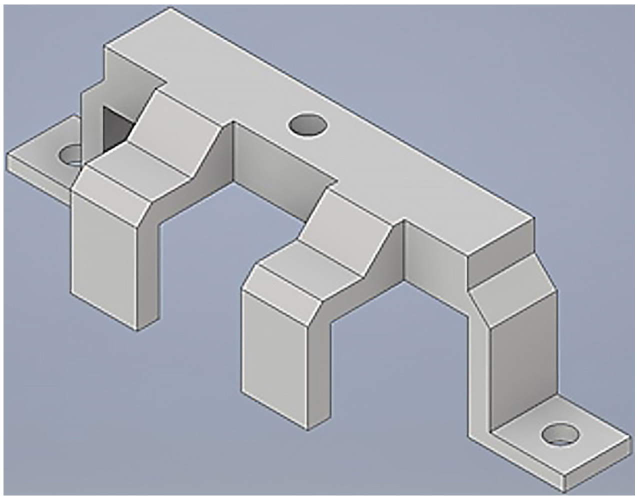

Fig. 9 Battery holder (easy to mount) - 3D design and printing, PLA material

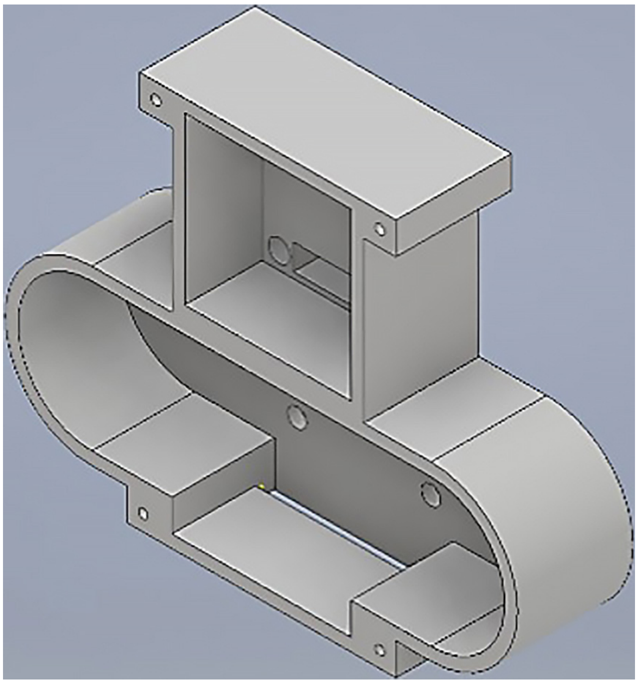

Fig. 10 Camera and thermal camera holder - 3D design and printing, PLA material

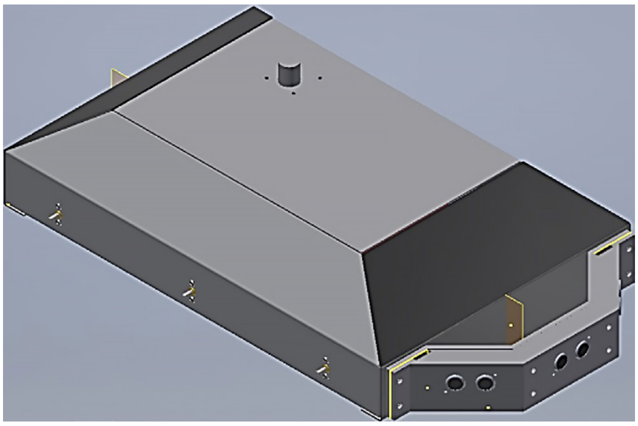

Fig. 11 Robot front and rear bumper, for 3-3 ultrasonic range sensors and LEDs - 3D design and printing, PLA material

Fig. 12 Wheel and electric motor (Machifit 25GA370 DC 12V, Speed: 190 rpm, Torque 5,0 kgf.cm)

4 Electronic design and implementation

The two central elements of the electronic design are the Arduino Mega development platform and the Raspberry Pi 4 embedded computer.

I have designed and built the division of the implemented tasks and functions as follows (Figs. 13 and 14):

- Arduino Mega: teleoperation (communication with the remote control using a 2.4 GHz radio signal)
  - set the speed and direction of the robot
    - motor controllers (3 piece, for 6 motors)
  - moving the camera servo motors
    - 2 servo motors
  - Rapberry Pi 4: on-board image processing (wireless connection to display tablet)
  - night vision (infra) camera
  - thermal camera

The digital ports of the Arduino Mega (Fig. 15) (the numbering in the list refers to the port designation in the 0s) are as follows (for the motors, there is a separate port for the forward and backward direction):

- 2. Right rear motor
- 3. Right rear motor
- 4. Right center motor
- 5. Right center motor
- 6. Left front motor
- 7. Left front motor
- 8. Right front motor
- 9. Right front motor
- 10. Left center motor

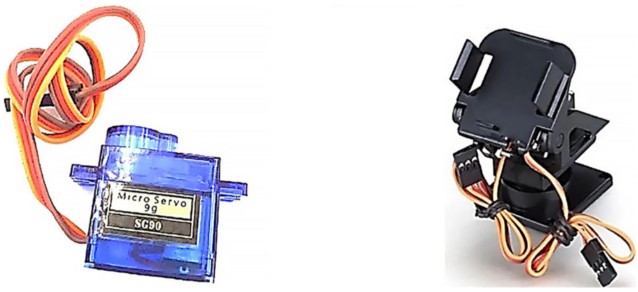

Fig. 13 Camera moving mini servo, camera holder

Fig. 14 Raspberry PI Night Vision Fisheye Camera 5MP, IR thermal camera (Panasonic, Temperature range: 0–80 °C, 8x8 sensor matrix)

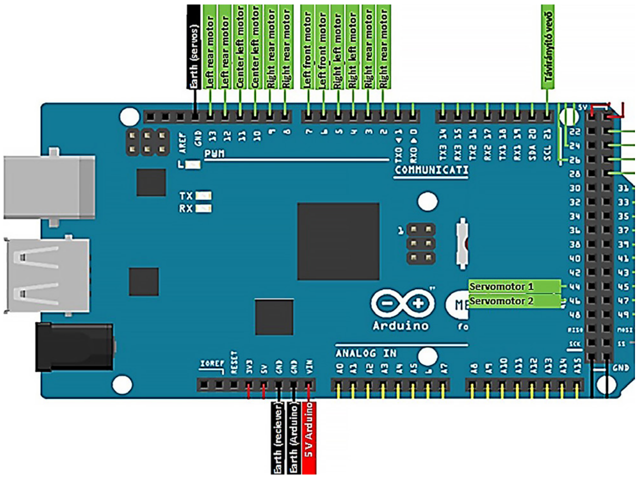

Fig. 15 Connecting Arduino Mega 2560

- 11. Left center motor
- 12. Left rear motor
- 13. Left rear motor
- 21. Remote control receiver
- 44. Servo motor 1
- 46. Servo motor 2

The motors are controlled via the motor controllers. I used three motor controllers.

The front wheels are connected in pairs, with the center wheel on one side and the rear wheel on the same side connected to a motor controller. The wiring arrangement was justified by practical wiring.

For the Raspberry Pi 4 (Fig 16), the 4 wires of the thermal camera were connected to the GPIO (general-purpose input/output pins) inputs (Kölling, 2016).

The fisheye camera, which also has a night vision function, is connected to the SCI input via a ribbon cable.

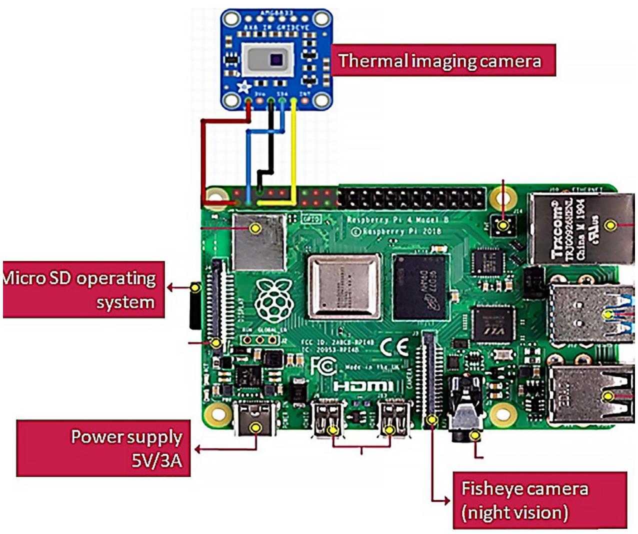

Fig. 16 Connecting Raspberry PI 4

The Raspberry's Linux-based operating system is contained on a Micro SD card.

The Raspberry display is shared on a remote tablet. Wireless signal transmission is handled by a router built into the robot. The power supply of the robot is dual:

- drive, Arduino power, remote control receiver, camera servo motor motion: LRP 3600 mAh 7.2 V NiMH battery,
- Raspberry power supply: with Power bank (4000 mAh, 5 V).

The Raspberry power supply is provided by a separate power source for operational safety reasons, thus eliminating possible problems due to load fluctuations. This solution was justified by the testing experience.

5 Programming

The programming was done in two interfaces and programming languages Keim (2019a; 2019b) Arduino: C++ based programming on Ardunio interface:

Raspberry Pi 4: Python programming language.

The following tasks (modules) were programmed on the Arduino interface (Algorithms 1 to 3):

- Control of traction motors by the left joystick signal on the remote control:
  - drive both side motors forward;
  - drive both side motors to the rear;
  - drive one side of the motor forwards and simultaneously drive the other side of the motor backwards (intensive turning, stationary) – in both directions;
  - driving one side of the motor forward, simultaneously driving the other side of the motor forward at a lower speed (turning) - in both directions.
- Moving servomotors by right joystick signal
  - servo motor that rotates the cameras horizontally;
  - a servo motor that rotates the cameras vertically.

The programming of Raspberry Pi 4 in Python included:

- Fisheye camera;
- Thermal camera.

Algorithm 1 Servo management

```
unsigned long servo1Raw = ppm.latestValidChannelValue(1, 0);
unsigned long servo2Raw = ppm.latestValidChannelValue(2, 0);
int servo2 = map (servo2Raw, 1000, 2000, 0, 180);
int servo1 = map (servo1Raw, 1000, 2000, 0, 180);
servo_1.write(servo1);
servo_2.write(servo2);
```

Algorithm 2 Different drive implementation

```
unsigned long val = ppm.latestValidChannelValue(3, 0);
unsigned long diffRaw = ppm.latestValidChannelValue(4, 0);
short diff = map (diffRaw, 1000, 2000, –255, 255);
short sp = map (val, 1000, 2000, –255, 255);
    if (diff >= –10 && diff <= 10)
    {
    sp_j = sp;
    sp_b = sp;
    }
    else if (sp >= –10 && sp <= 10)
    {
    sp_j = (sp-diff);
    sp_b = (sp+diff);
    }
    else
    {
    sp_j = (sp-diff)/2;
    sp_b = (sp+diff)/2;
    }
drive(jhm_IN1, jhm_IN2, sp_j);
drive(jkm_IN1, jkm_IN2, sp_j);
drive(jem_IN1, jem_IN2, sp_j);
drive(bem_IN1, bem_IN2, sp_b);
drive(bkm_IN1, bkm_IN2, sp_b);
drive(bhm_IN1, bhm_IN2, sp_b);
```

Algorithm 3 Control of motors

```
void drive (int IN1, int IN2, short sebesseg){
    if (sebesseg > 10){
        analogWrite(IN1, 0);
        analogWrite(IN2, abs(sebesseg));
    }
    else if (sebesseg < –10){
        analogWrite(IN1, abs(sebesseg));
        analogWrite(IN2, 0);
    }
    else {
        analogWrite(IN1, 0);
        analogWrite(IN2, 0);
```

6 Validation (building example)

The validation (Fig. 17) was carried out in our own family house. The validation was carried out with the help of Albert Csapó, a specialist of ENERGIAEXPERT Energy Engineering Office (Csorna), a qualified installation engineer, installation energy engineer, mechanical engineer, energy certification, EU energy auditor.

He measured the same structural elements with his own professional thermal camera as I did with the Heat Spotter. The thermal images of the validation are presented (Fig. 17)

I selected the following structures for validation:

- working radiator (under window)
- balcony door (external, PVC), heat transmission coefficient: 1.10 W/m^{2}K
- entrance door (external), heat transmission coefficient: 1.80 W/m^{2}K
- garage door (with 40 mm insulation).

Based on the protocol, the Heat Spotter indicates significant temperature differences with a color difference. This draws attention to e.g. insulation defects, thermal bridges.

7 General findings of the validation

The current robotic thermal camera is an 8 × 8 sensor matrix (for cost saving reasons), this is reflected in the resolution of the thermal images. The resolution of the validating professional thermal camera was 320 × 240 pixels, which gives significantly better image quality. For development purposes, I plan to purchase a 32 × 24 sensor matrix camera, which can still be purchased at a reasonable price and which gives a significantly better resolution image than the current one.

The image of the normal camera is also "weaker"on the robot than on the validation device, however the HEAT SPOTTER has night vision capability.

For diagnostic purposes, the Heat Spotter is already capable of identifying, with a clear color difference, thermal insulation defects that are also "flagged" by the Fluke thermal imaging camera.

The resolution and image quality can be improved by installing a more expensive (more professional) camera and thermal imaging camera, but value for money must be considered.

8 Possible uses

The robot vehicle has several applications. In particular, it provides construction companies with a cost-saving

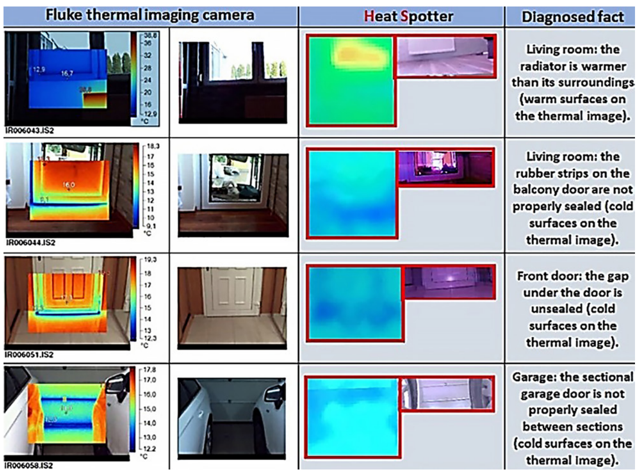

Fig. 17 Validation

opportunity to check quality before and during the construction or renovation phase, with a view to energy aspects.

Some examples of applications.

Building construction, building renovation:

- Thermal insulation
- Building construction
- Building construction
- Building services systems testing

The wide range of uses indicates that buying or renting such a robot can be a quick return on investment for construction, building services and building automation companies.

9 Practical use of the Heat Spotter

The proposed solution using the Heat Spotter is a new survey method for a more accurate, even repeated, and documentable energy survey of the surfaces bordering heated/cooled spaces. In contrast to measurements carried out by auditors, the technician using the new method does not have to walk through the building to be measured. This is due to the fact that the operator only has to guide the robot through the site.

The robot is guided by a transmitted camera image, and during the walk-through the surveyor can also see data from a thermal camera and other environmental sensors (e.g. ultrasonic distance sensor, LiDAR, etc. in case of planned upgrades). The data collected during the survey can be stored digitally.

10 Benefits of the equipment and the technology it enables

The Heat Spotter robot is an affordable prototype of a device or even a service that can be brought to market at a later stage, with a patent application pending.

Its main advantages are:

- labor-saving,
- simple and efficient to use,
- provides objective and documentable measurement results.

Its use is expected to be most beneficial for construction companies. The robot thermal energy survey method is cheaper than currently available methods. For example, the results of the robotic survey can be used to plan the renovation technology and the required insulation materials, windows, etc., which can then be selected in the most appropriate way. The production of larger quantities of the robot will increase the efficiency of the work of the technicians.

11 Further development plans

The Heat Spotter is the first realization of a large-scale concept, capable of achieving the objectives outlined above.

In the near future, the following improvements will be implemented to achieve even higher levels of functionality and usability:

1. *Improving remote control using LiDAR (laser scanner)*
   The "A4010 SLAMTEC RPLIDAR A1 – 360 LASER RANGE SCANNER" is already under procurement. With LiDAR, the robot will be able to perform autonomous functions.
2. *Multiple UH distance sensors*
   I have already designed, 3D printed and mounted 3 bumpers with 3 ultrasonic distance sensors at the front and 3 at the back of the robot. The distance sensors will ensure the automatic collision-free maneuverability of the robot.
3. *Use of a higher resolution camera and thermal imaging*
   A cost-saving solution is currently being developed. Based on the evaluation of the test results, it will be worth replacing these devices with higher quality ones.
4. *Image processing*
   Software image processing of thermal images will make the evaluation easier and more objective.
5. *Record keeping*
   The evaluated data will be produced in a report format, which can be printed.
6. *Extending the robot's functionality to other applications*
   Examples include building electronics and vehicle diagnostics (vehicle inspection under the vehicle by robot).

12 Summary

Under current national and EU energy performance regulations, new buildings must be nearly zero energy and 70% of dwellings do not meet modern thermal and technical requirements.

There are significant heat losses in the building envelope, both in old and new buildings under construction. A quick and inexpensive energy assessment by a target robot can be a useful tool for this purpose, listing and rating thermal bridges as well as heat loss factors and structural elements.

The Heat Spotter robot I have designed and implemented is an affordable tool for this task, and therefore quickly pays for itself. The robot is a novelty with a patent application pending. The structure of the Heat Spotter is easy and cheap to manufacture, but at the same time robust enough to withstand the stresses of use. Its form is simple but aesthetic, as intended.

It is made of dark anodised aluminium sheet, which is resistant to external influences. The size and dynamic movement of the robot, together with its good maneuverability and remote control, make it an excellent tool for working.

The real image and the thermal camera image capture are based on state-of-the-art IT and therefore offer the potential for improvement.

Reliability was an important factor in the development, so the motion and image capture systems were completely separated. This applies to both the IT solution and the power supply. The wireless signal transmission is also purposefully done on two different "channels" so that the two functions do not interfere with each other. The size and resolution quality of the display is of paramount importance for remote control and thermal imaging. For this purpose, I used an Archos Oxygen 70 tablet as a cost-saving solution.

I spent many hours testing the robot. This involved two major parts:

- reliable operation and
- validation of the thermal camera diagnostics.

During the development phase, of course, I also had to deal with problems, which were a real developer 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 color map of the thermal camera,
- Ensuring an appropriate and independent power supply for sensors, actuators and the on-board computer,
- adjusting the range of movement of the servomechanisms that move the cameras,
- design of on-board wiring that is prototype-compatible, easily modifiable but fail-safe.

Based on the experience gained, I have set out the directions for further development of the Heat Spotter. At the same time, I concluded (supported by professional opinions) that the robot in its current form could be a good value for money tool for construction contractors.

The basic idea of the Heat Spotter could also provide solutions for many other applications in addition to the intended target task. The implementation of these is also in my future plans.

Acknowledgement

This project is a presentation of my work for the 30th International Scientific and Innovation Competition, which received a special commendation. I would like to thank the companies that made this project possible.

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