GOCE DELCEV UNIVERSITY, STIP, NORTH MACEDONIA
FACULTY OF ELECTRICAL ENGINEERING

ETIMA 2023

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27-29 SEPTEMBER, 2023

TECHNICAL SCIENCES APPLIED IN ECONOMY, EDUCATION AND INDUSTRY

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УНИВЕРЗИТЕТ „ГОЦЕ ДЕЛЧЕВ", ШТИП, СЕВЕРНА МАКЕДОНИЈА

FACULTY OF ELECTRICAL ENGINEERING,
GOCE DELCEV UNIVERSITY, STIP, NORTH MACEDONIA

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PREFACE

The Faculty of Electrical Engineering at University Goce Delcev (UGD), has organized the Second International Conference ***Electrical Engineering, Informatics, Machinery and Automation - Technical Sciences applied in Economy, Education and Industry-ETIMA*.**

ETIMA has a goal to gather the scientists, professors, experts, and professionals from the field of technical sciences in one place as a forum for exchanging the ideas, strengthening the multidisciplinary research and cooperation, and promoting the achievements of technology and its impact on every aspect of living. We hope that this conference will continue to be a venue for presenting the latest research results and developments on the field of technology.

Conference ETIMA was held as online conference. More than sixty colleagues contributed to this event, from five different countries with more than thirty papers.

We would like to express our gratitude to all the colleagues, who contributed to the success of ETIMA'23 by presenting the results of their current research and by launching the new ideas through many fruitful discussions.

We invite you and your colleague to attend ETIMA Conference in the future as well. One should believe that next time we will have opportunity to meet each other and exchange ideas, scientific knowledge and useful information as well as to involve as much as possible the young researchers into this scientific event.

The Organizing Committee of the Conference

ПРЕДГОВОР

Меѓународната конференција ***Електротехника, Технологија, Информатика, Машинство и Автоматика-технички науки во служба на економија, образование и индустрија-ЕТИМА*** е организирана од страна на Електротехничкиот факултет при Универзитетот „Гоце Делчев".

ЕТИМА има за цел да ги собере на едно место научниците, професорите, експертите и професионалците од полето на техничките науки и да претставува форум за размена на идеи, да го зајканува мултидисциплинарното истражување и соработка и да ги промовира технолошките достигнувања и нивното влијание врз секој аспект од живеењето. Се надеваме дека оваа конференција ќе продолжи да биде настан на кој ќе се презентираат најновите резултати од истражувањата и развојот на полето на технологијата.

Конференцијата ЕТИМА се одржа online и на неа дадоа свој придонес повеќе од шеесет автори од пет различни земји со повеќе од триесет труда.

Сакаме да ја искажеме нашата благодарност до сите колеги кои придонесоа за успехот на ЕТИМА'23 со презентирање на резултати од нивните тековни истражувања и со лансирање на нови идеи преку многу плодни дискусии.

Организационен одбор на конференцијата

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AUTONOMOUS ROBOTIC VACUUM CLEANER

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Abstract

In today's world, technology surrounds us, and its impact on our daily lives is undeniable. The use of advanced gadgets and software has made our lives easier, thanks to the automation happening around us. The vacuum cleaner has been the last to receive a significant upgrade among the many household appliances. However, the autonomous robotic vacuum cleaner market has seen great success in recent years. This paper aims to explore the complex algorithms powering autonomous robotic vacuum cleaners and make them more understandable. By doing so, this technology will help us to finish our daily tasks more efficiently and with minimal involvement.

Keywords

Robotic vacuum cleaner, Arduino, Printed circuit board, Algorithm.

1. Introduction

Today, we are surrounded by advanced technology from various aspects. From cutting-edge devices to sophisticated software, our lives are made easier thanks to the automation that surrounds us [1]. The use of autonomous devices, such as domestic robots, allows us to perform tasks without direct involvement or wasting time on things that can be easily and efficiently done by robots [2]. The need for automation, especially when we are overwhelmed with tasks and responsibilities, provides us with relief in our work and greater efficiency in accomplishing what we want to achieve [3]. Over the past decade, robot vacuum cleaners have become increasingly popular automated household appliances. They are designed to save time and effort while providing a thorough cleaning of floors. The rapid evolution of these vacuum cleaners means new features and technologies are added every year to better fulfill consumer needs [4]. The market for robotic vacuum cleaners was valued at $4 billion in 2022 and is expected to rise even more by the end of 2023. This tremendous market growth is attributed to the development of industrial robots, as well as the prevalence of smart homes and IoT technology [5]. The latest robotic vacuum cleaner developed by Samsung even features artificial intelligence software, sophisticated 3D sensors and cameras for spatial mapping [6].
We will try to develop a robotic autonomous vacuum cleaner that will help us in our everyday lives. Based on the Arduino microcontroller and some commonly sourced electronic components, we will design a model of a robotic vacuum cleaner. We will design an appropriate circuit, as well as a rudimentary algorithm that will power the robot. Finally, we will test the robot in the real world and study its behavior with obstacles. Previous work in this field will provide us with experience in the design process [7] – [9].

2. Design of the autonomous robotic vacuum cleaner

We will begin our research with the design of the autonomous robotic vacuum cleaner. Firstly, we will design the electronic circuit. Using the AutoCAD Eagle software and other CAD tools, we designed a rudimentary circuit. It consists of:

➢ Microcontroller – 1 x Arduino Uno – a microcontroller board based on the ATmega328P microprocessor chip [10]. It has 14 digital input/output pins (of which six can be used as PWM outputs), six analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection for programming and serial monitoring, a power jack, an ICSP header, and a reset button. The board contains everything needed to support the microcontroller, and there is an extensive library of functions and qualified support from the manufacturer, as well as the community of users around the world.

Features of the ATMega328P Processor [11]:

- Memory:
- AVR CPU at up to 16 MHz
- 32KB Flash
- 2KB SRAM
- 1KB EEPROM
- Security
- Power On Reset (POR)
- Brown Out Detection (BOD)
- Peripherals
- 2x 8-bit Timer/Counter with a dedicated period register and compare channels;
- 1x 16-bit Timer/Counter with a dedicated period register, input capture, and compare channels;
- 1x USART with fractional baud rate generator and start-of-frame detection;
- 1x controller/peripheral Serial Peripheral Interface (SPI);
- 1x Dual mode controller/peripheral I^2C;
- 1x Analog Comparator (AC) with a scalable reference input;
- Watchdog Timer with separate on-chip oscillator;
- Six PWM channels;
- Interrupt and wake-up on pin change.

➢ Drive train – 2 x 28BYJ-48 – unipolar stepper motor with incorporated gear reduction, internally converted to the bipolar stepper motor schematic.

Features of the 28BYJ-48 stepper motor [12]:

- Rated voltage: 5 V DC;
- Number of phases: 4;
- Speed reduction ratio: 1/64;
- Step angle: 5.625° /64;
- Frequency: 100 Hz;
- DC resistance: 50 Ω ± 7 % (25 °C);
- Idle in-traction frequency: 600 Hz;
- Idle out-traction frequency: 1000 Hz;
- In-traction torque: 34.3 mNm(120 Hz);
- Self-positioning torque: 34.3 mNm;
- Friction torque: 600-1200 gf*cm;
- Pull-in torque: 300 gf*cm;
- Insulation resistance: > 10 MΩ (500 V);
- Insulation grade: A;
- Rise in temperature: < 40 K (120 Hz);
- Noise: < 35 dB (120 Hz, No load, 10 cm);

➢ Motor controller – 2 x HW-134 – bipolar stepper motor controller driven with the A4988 integrated motor driver circuit, included with DIR, STEP, and ENABLE inputs.

Features of the A4988 stepper driver module [13]:

- Max. operating voltage: 35 V;

- Min. operating voltage: 8 V;
- Max. current per phase: 2 A;
- Micro-step resolution: Full step, ½ step, ¼ step, 1/8 and 1/16 step;
- Reverse voltage protection: No;
- Dimensions: 15.5 × 20.5 mm (0.6″ × 0.8″);
- Short-to-ground and shorted-load protection;
- Low RDS (ON) outputs;
- Thermal shutdown circuitry;

➢ Sensors – 3 x HY-SRF05 – Ultrasonic distance sensor, provides 2 cm to 400 cm non-contact measurement function, with a ranging accuracy of 3 mm.

Features of the HY-SRF05 ultrasonic sensor [14]:

- Trigger pin format: 10 uS digital pulse;
- Sound frequency: 40 kHz;
- Echo pin output: 0 – Vcc;
- Echo pin format: output is DIGITAL and directly proportional with range;
- Measurement range: 2 cm to ~ 4.5 m;
- Measurement resolution: 0.3 cm;
- Measurement angle: up to 15 deg;
- Measurement rate: 40 Hz;
- Supply voltage: 4.5 V to 5.5 V;
- Supply current: 10 to 40 mA;
- Connector: standard 5-pin male connector which can plug directly into breadboards;
- Static current: less than 2 mA;
- Detection distance: 2 cm - 450 cm;

➢ Power supply – 1 x GOLF 10 Ah Li-Ion power bank.

Features of the GOLF 10 power bank [15]:

- Capacity: 10000 mAh;
- Input: DC 5.0 V - 2.0 A;
- Output: DC 5.0 V - 1.0 A / 5.0 V - 2.1 A;
- Size: 64.5 x 14.5 x 132.5 mm;

The circuit, given in Appendix 1, consists of the Arduino UNO microcontroller, which is supplied with 5 V DC voltage from the power bank. The motor controllers and ultrasonic sensors are connected to the digital IO pins of the microcontroller, as well as to the 5 V DC voltage supply from the power bank, and the stepper motors are connected to the motor controllers.

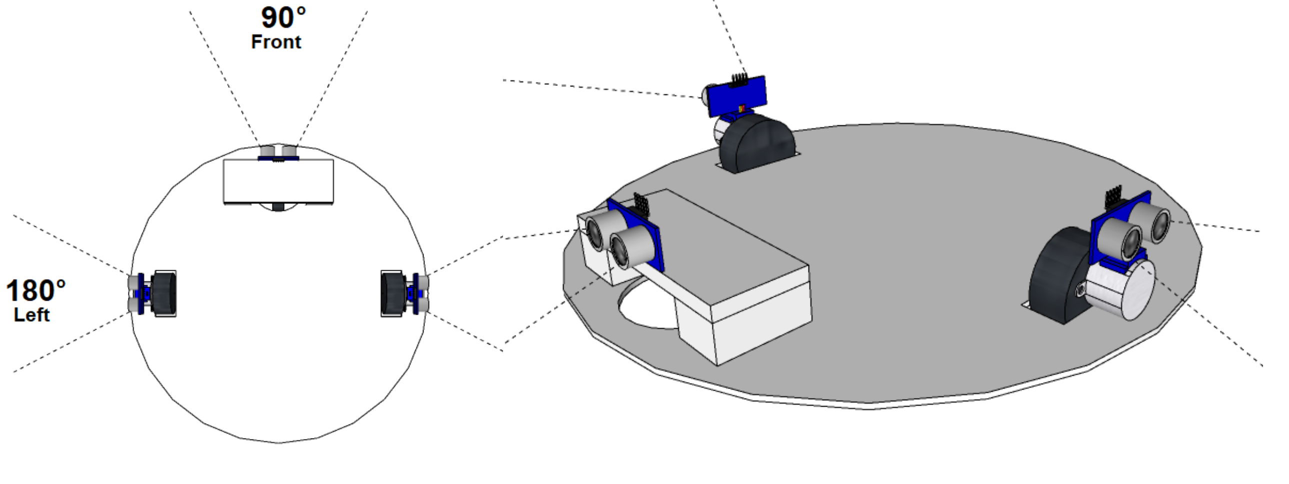

Fig. 1 (a) Top view of the robot model, (b) Side view of the robot model.

After the design of the circuit, we will design the body of the robot. Using the SketchUp 3D CAD software, we came up with the design of the robot (Fig. 1a and Fig. 1b) that consists of:

- Base – HDF (High-Density Fiberboard) with a diameter of 35 cm and 3 mm thickness. Appropriate holes are incorporated for the drive and support wheels.
- Drive wheels – two rubber model wheels with 48 mm diameter, mounted directly to the output shaft of the stepper motor. The wheels are mounted at 0° and 180° (left and right sides), which gives the robot the ability to rotate in place.
- Support wheel – one omnidirectional wheel with a diameter of 30 mm, and a turning diameter of 60 mm. This wheel is mounted at 90° (front side), thus giving the robot support from tipping over.
- Stepper motors – mounted to the drive wheels and to the base with appropriate aluminium brackets.
- Sensors – ultrasonic sensors, securely mounted above each wheel, giving the robot the ability to see in front, to the left, and to the right.

After the process of designing the robot, we can begin the programming of the robot. The Arduino Uno microcontroller is relatively simple to program with the help of online libraries and resources. The programming process will begin by creating a simple algorithm that will control the robot, which is given in Appendix 2.
The full code that controls the robot is given in Appendix 3, and snippets of the code are explained below:

```
#include "BasicStepperDriver.h"
#include "SyncDriver.h"
#include "NewPing.h"
```

With this segment of code, the appropriate libraries for using the motor controllers and ultrasonic sensors are included.

```
#define MOTOR_STEPS 4096
#define MOTOR_X_RPM 10
#define MOTOR_Y_RPM 10
#define DIR_X 8
#define STEP_X 9
#define DIR_Y 10
#define STEP_Y 11
#define MICROSTEPS 1
```

Here we are setting the parameters of the stepper motors. We are defining the steps per revolution, maximum speed, as well as the pins for controlling the stepper motors.

```
#define TRIGGER_PIN_FRONT 3
#define ECHO_PIN_FRONT 2
#define TRIGGER_PIN_LEFT 6
#define ECHO_PIN_LEFT 7
#define TRIGGER_PIN_RIGHT 5
#define ECHO_PIN_RIGHT 4
#define MAX_DISTANCE 200
```

Here we are setting the parameters of the ultrasonic sensors. We are defining the trigger and echo pins, as well as the maximum distance that can be measured by the sensors.

```
void setup() {
	stepperX.begin(MOTOR_X_RPM, MICROSTEPS); // Left motor
	stepperY.begin(MOTOR_Y_RPM, MICROSTEPS); // Right motor
}
```

In the setup function, we are defining the maximum speed and micro-stepping of the motors.

```
void loop()
{
	start:
	unsigned int distance_front = sonar_front.ping_cm();
	unsigned int distance_left = sonar_left.ping_cm();
	unsigned int distance_right = sonar_right.ping_cm();
```

In the loop function, we're defining the variables in which we are storing the distances from the appropriate sensors. The distances are measured with the function ping. The value given by this function is the distance to an obstacle that is in front of the sensor in cm. The following are the commands that are used for controlling the movement of the robot:

```
  if (distance_front >= 15)
  {
	controller.rotate(+118, +118);
	goto start;
  }
```

If the measured distance forward is more than 15 centimeters, then the motor controllers are given the command to turn 118°, which moves the robot 10 cm forwards.

```
	else if (distance_front <= 5 && distance_left >= 15 && distance_right >= 15)
	{
		controller.rotate(+241, -241);
		goto start;
	}
```

If the measured distance forward is less than 5 cm, and the measured distances left and right are more than 15 centimeters, then the robot turns right 90° by default.

```
	else if (distance_front <= 5 && distance_left <= 5 && distance_right >= 15)
	{
		controller.rotate(+241, -241);
		goto start;
	}
```

If the measured distances forward and left are less than 5 cm, and the measured distance to the right is more than 15 cm, then the robot turns right 90°.

```
	 else if (distance_front <= 5 && distance_left >= 15 && distance_right <= 5)
	{
		controller.rotate(-241, +241);
		goto start;
	}
```

If the measured distances forward and right are less than 5 cm, and the measured distance to the left is more than 15 cm, then the robot turns left 90°.

```
else if (distance_front <= 5 && distance_left <= 5 && distance_right <= 5)
{
        controller.rotate(+482, -482);
        goto start;
}
```

If the measured distances forward, right, and left are less than 5 cm, then the robot turns right 180°, i.e., the robot goes back in the direction that it came.

3. Assembly of the autonomous robotic vacuum cleaner

With a completed model and schematic for the robot, as well as the appropriate program, the assembly of the robot can begin. The stepper motors with the drive wheels are mounted to the base. The support wheel is mounted in the front, utilizing an appropriate bracket. For testing purposes, special BOBs (Break Out Boards) are designed and manufactured with the purpose of easing the design process. These special PCBs (Printed Circuit Board) allow quick and secure changes in the wiring of the components. All the components are connected according to the circuit diagram using appropriate wires and connectors. The power bank is mounted in the front, and by doing so, the center of mass is moved closer to the front of the robot. After the processes of mounting and connecting the components are finished, everything is checked to make sure that the design requirements are met.

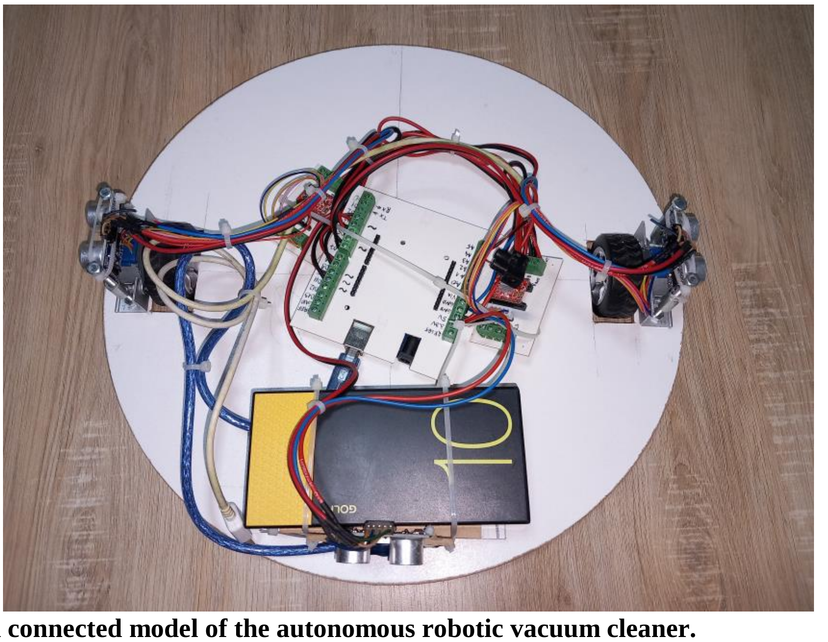

Fig. 2 Assembled and connected model of the autonomous robotic vacuum cleaner.

4. Results and Discussion

The robot is put into action. The power bank is connected to the microcontroller, and the program that drives the robot is executed. Subsequently, the robot starts to move according to the algorithm and the obstacles in the room that it is placed in. The algorithm provides the robot with the ability to avoid basic obstacles, such as walls, large furniture, and other medium to large sized objects. On the other hand, there are some drawbacks to this design of the robot and its algorithm. The robot can’t go over obstacles that are more than 1 cm tall, such as carpets, and the existence of blind spots in the front-right and front-left area limits the robot's ability to detect obstacles that are less than 10 to 15 cm wide.

5. Conclusion and Future Work

For more efficient work of the robot, we need to implement some changes. Firstly, the sensors should be positioned at better positions, therefore providing fewer blind spots. Furthermore, an infrared or ultrasonic distance sensor should be placed in the front of the robot, oriented downwards, thus providing the robot with the ability to detect obstacles that are taller than 1 cm and to avoid edges, such as stairs.
Moreover, the algorithm needs some changes. It should be able to avoid getting the robot stuck in a loop. In addition, the algorithm should be optimized to provide better coverage of the room that it operates in.
Finally, to have a completed autonomous robotic vacuum cleaner, we need the ability to collect dust. A vacuum system should be implemented, with appropriate suction motors and dust and particle filters, along with a dust reservoir that can be easily cleaned. Additionally, an upgrade is necessary to the power supply as well. Instead of a 5 V power bank, a 12 V Li-Ion battery should be installed, which will enable the robot to work for a longer time and to provide power to the vacuum system.

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Appendix 1

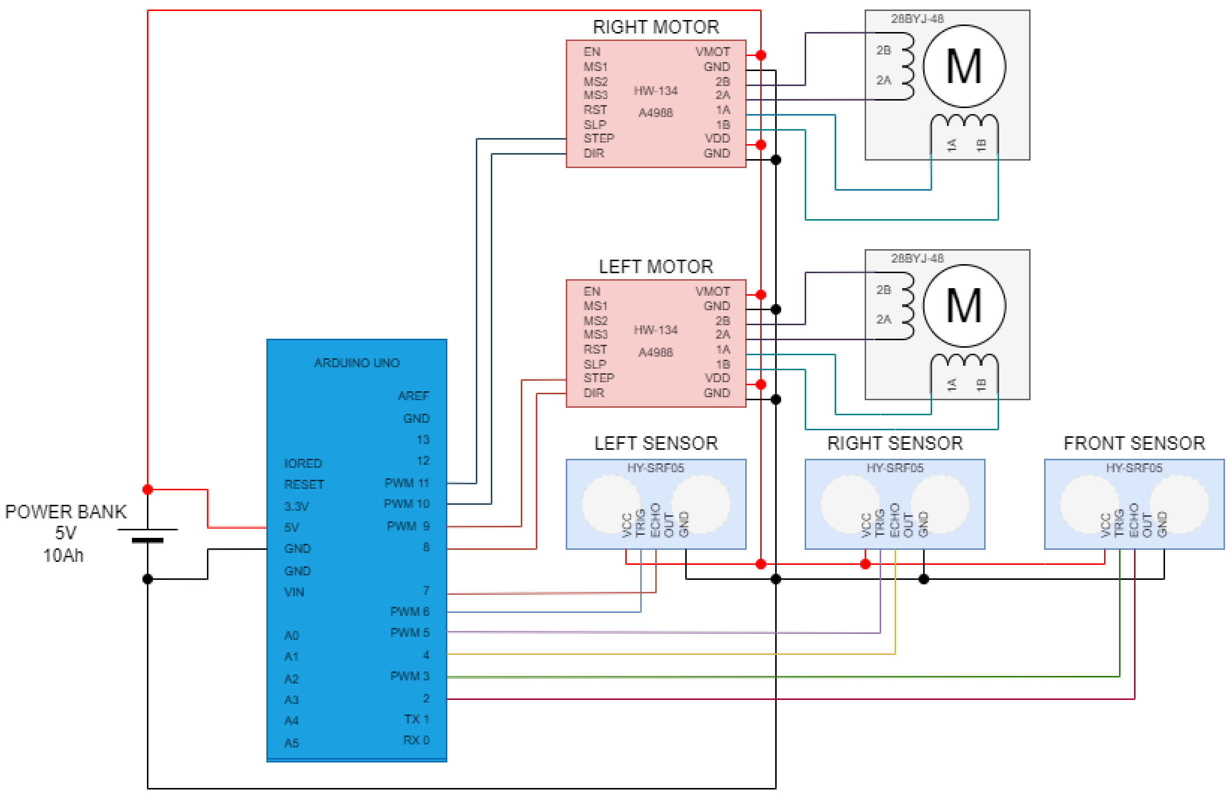

Fig. 3 Electronic circuit for the autonomous robotic vacuum cleaner

Appendix 2

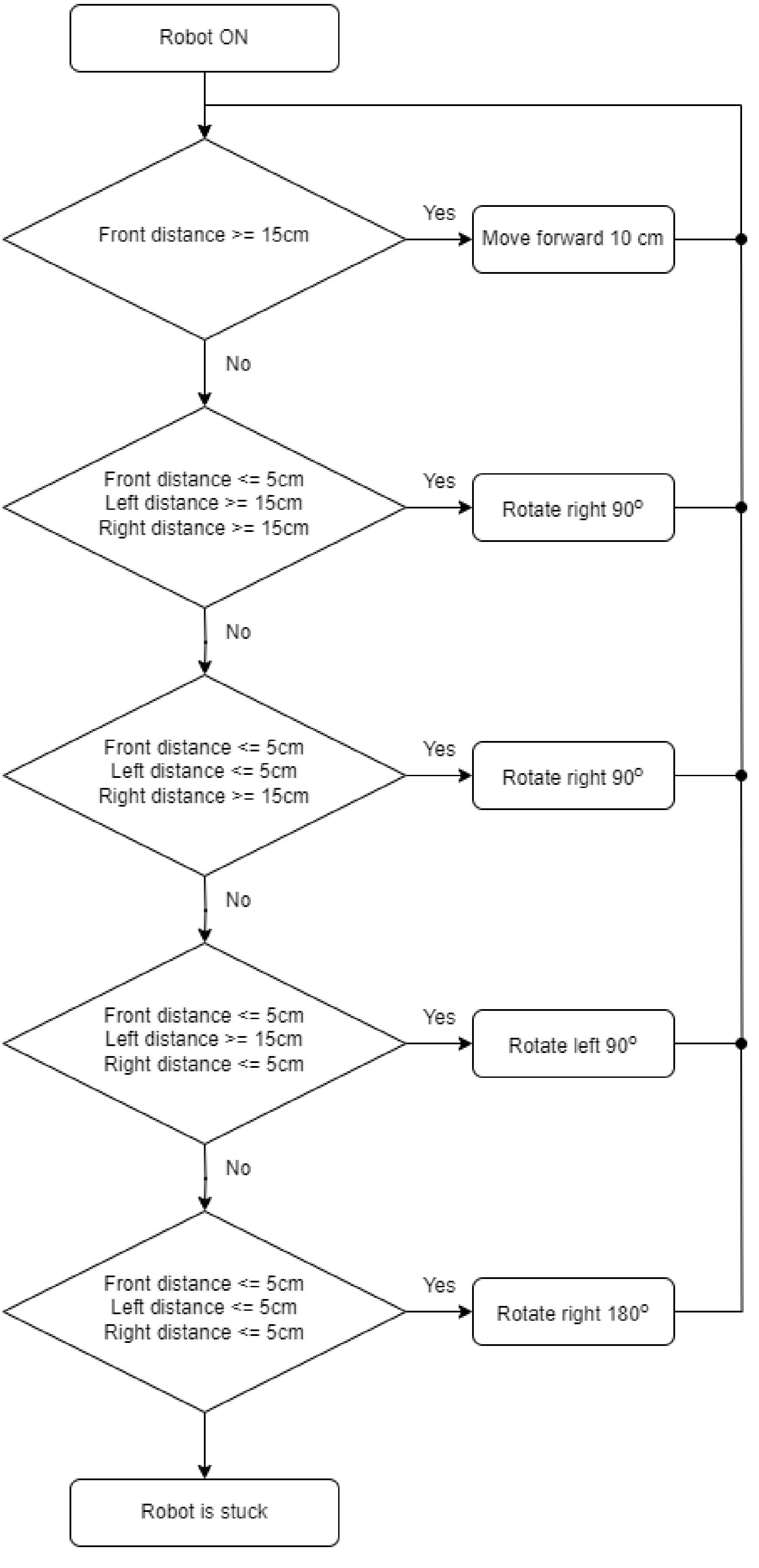

Fig. 4 Algorithm for the autonomous robotic vacuum cleaner

Appendix 3 – Full source code for the Arduino microcontroller

```
#include "BasicStepperDriver.h"
#include "SyncDriver.h"
#include "NewPing.h"
#define MOTOR_STEPS 4096 // (964,-964) - 180*; (241,-241) - 90*
#define MOTOR_X_RPM 10   // (+,+) - forward;       (-,-) - reverse
#define MOTOR_Y_RPM 10   // (+,-) - rotate right;  (-,+) - rotate left
#define DIR_X 8          // 1B - orange; 1A - pink
#define STEP_X 9         // 2A - yellow; 2B - blue
#define DIR_Y 10         // 1B - blue; 1A - yellow
#define STEP_Y 11        // 2A - pink; 2B - orange
#define MICROSTEPS 1     // 0.85mm/*; 1.176*/mm
#define TRIGGER_PIN_FRONT 3
#define ECHO_PIN_FRONT 2
#define TRIGGER_PIN_LEFT 6
#define ECHO_PIN_LEFT 7
#define TRIGGER_PIN_RIGHT 5
#define ECHO_PIN_RIGHT 4
#define MAX_DISTANCE 200
BasicStepperDriver stepperX(MOTOR_STEPS, DIR_X, STEP_X); // Left motor
BasicStepperDriver stepperY(MOTOR_STEPS, DIR_Y, STEP_Y); // Right motor
SyncDriver controller(stepperX, stepperY);
NewPing sonar_front(TRIGGER_PIN_FRONT, ECHO_PIN_FRONT, MAX_DISTANCE);
NewPing sonar_left(TRIGGER_PIN_LEFT, ECHO_PIN_LEFT, MAX_DISTANCE);
NewPing sonar_right(TRIGGER_PIN_RIGHT, ECHO_PIN_RIGHT, MAX_DISTANCE);
void setup() {
	stepperX.begin(MOTOR_X_RPM, MICROSTEPS); // Left motor
	stepperY.begin(MOTOR_Y_RPM, MICROSTEPS); // Right motor
}
void loop() {
	start:
	unsigned int distance_front = sonar_front.ping_cm();
	unsigned int distance_left = sonar_left.ping_cm();
	unsigned int distance_right = sonar_right.ping_cm();
	if (distance_front >= 15) {		// move forward
		controller.rotate(+118, +118);
		goto start;
	}
	else if (distance_front <= 5 && distance_left >= 15 && distance_right >= 15) {	// rotate right
by default
		controller.rotate(+241, -241);
		goto start;
	}
	else if (distance_front <= 15 && distance_left <= 5 && distance_right >= 15) {	// rotate right
		controller.rotate(+241, -241);
		goto start;
	}
	else if (distance_front <= 15 && distance_left >= 15 && distance_right <= 15) {	// rotate left
		controller.rotate(-241, +241);
		goto start;
	}
	else if (distance_front <= 5 && distance_left <= 5 && distance_right <= 5) {  // rotate right 180
		controller.rotate(+482, -482);
		goto start;
	}
}
```