Study for Autonomous Robot Control Using Different Sensors for Implementing Disinfection Robots

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Abstract. This paper investigates the integration of advanced sensing into an autonomous robot prototype with control, focusing on the development of an efficient and safe disinfection system. The study examines how various sensor technologies, such as ultrasonic sensors, vision cameras and PIR sensors, are implemented and coordinated to enable the robot to navigate complex environments and identify areas that require disinfection. Autonomous control will be achieved in the future through advanced algorithms, allowing the robot to adjust movements and interact effectively with the environment. The results of the experiments and the analysis of the obtained data underline the performance and effectiveness of the proposed system. This research makes significant contributions to the field of mechatronics and mobile robots, providing valuable insights for future applications of robotic disinfection technologies.

1. Introduction

In a world marked by rapid technological developments and the need to respond effectively to sanitary challenges, the development of an autonomous robot with an advanced sensor system for disinfection is an essential step. This paper addresses this urgent requirement by proposing a comprehensive investigation into the integration of state-of-the-art sensing in an autonomous robot prototype. The goal of this research is to develop and evaluate a robotic system that not only navigates autonomously and identifies high-risk areas, but also performs disinfection procedures in an efficient and accurate manner. This investigation explores the technological possibilities for the development of future robotic disinfection solutions and provides crucial insight into the significant potential these innovations can bring to public health and environmental security.[1][2][3]

2. Components and integrated systems for operation in hospital environments

Conventional disinfection systems and robotic systems represent two different approaches to the process of cleaning and disinfecting environments, be they hospitals, medical facilities or other hygiene-critical spaces. These two types of methods have distinct advantages and disadvantages, and their comparison can help to understand the benefits that autonomous robots bring to the field of disinfection.[4]

Conventional disinfection systems mostly use manual or semi-automatic processes to clean and disinfect premises. These often involve the use of cleaning chemicals as well as personal protective equipment for operators. Although effective in most cases, traditional methods are painstaking and may require considerable time to ensure proper hygiene. There is also the risk of operator contamination and non-conformances can occur due to human error.

3. The theoretical foundantion for the development of an autonomous disinfection robot

Ultrasonic sensors measure distances using ultrasound, allowing the robot to detect obstacles and avoid collisions in various environments.[5]

Cameras and image sensors are the robot's intelligent eyes, responsible for identifying objects and surfaces that require disinfection. Through machine vision algorithms, the robot can recognize shapes, textures and colors, facilitating the identification of work areas and the application of appropriate disinfection procedures.[6][7]

Gas and air quality sensors are critical in industrial and medical environments where they detect levels of noxious gases or other hazardous chemicals in the environment.[8] These sensors provide protection against exposure to hazardous substances, which are crucial for the health of workers and users. Temperature and humidity sensors also monitor environmental conditions, influencing disinfection procedures according to specific conditions and ensuring that they are carried out under optimal conditions, thus increasing the effectiveness of the process.

Navigation and path planning algorithms play a key role in enabling autonomous navigation in complex environments. These algorithms, fed by data provided by sensors, identify obstacles and plan safe routes, avoiding collisions.[9] Autonomous control, the heart of the system, involves developing a system that allows the robot to make real-time decisions and adapt to the environment.[10][11] This autonomous control involves regulating the speed of the motors, adjusting the direction of travel and managing the disinfection systems, such as the distribution of cleaning substances or the use of neon lights with UV-C radiation. These intricate components and algorithms are the core of the system, ensuring an efficient and safe disinfection process in a variety of environments.[12][13][14]

4. The electrical diagram of the robot and its functionality

In this chapter, the electrical diagram of the autonomous robot prototype is presented and how it is integrated with the various sensor components, as well as with the control system, which is the platform for raspberry pi. The schematic is essential for understanding the complex connections between the sensors and the motherboard, thus providing an in-depth look at how the robot works.[15][16]

The distance sensors and the ultrasonic are connected to specific pins of the Arduino Uno R3 board, using appropriate communication protocols. These connections allow the transfer of data from the sensors to the central control system and vice versa, essential for the precise navigation of the robot in complex environments.[17][18]

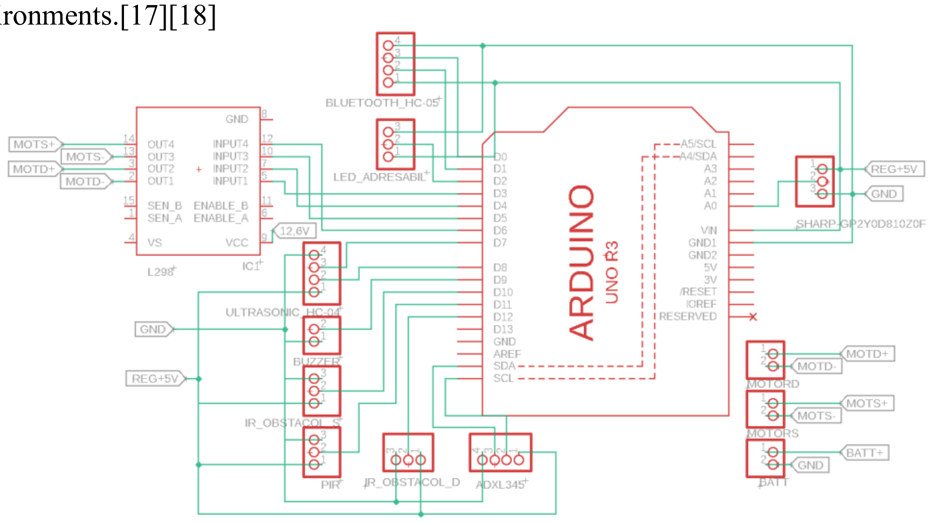

Figure 1. The electrical diagram of the prototype with the implementation of the sensors used, the motor driver and the motors used

Powering the sensors and motors is handled by the L298N control driver, which can fully power the sensors through its 5V regulator, ensuring proper and stable power for each to function optimally.[19]

The motor control driver is connected to the Arduino Uno R3 board through the pins of IN1,2,3,4 they receive from the microcontroller allow to adjust the speed and direction of rotation of the motors, coordinating the movement of the robot according to the data received from the sensors.[20]

The navigation and route planning algorithms as well as the autonomous control algorithms are loaded and executed on the Arduino Uno R3 board. These algorithms interpret the data from the sensors and coordinate the actions of the robot, ensuring safe navigation and effective disinfection of complex environments.

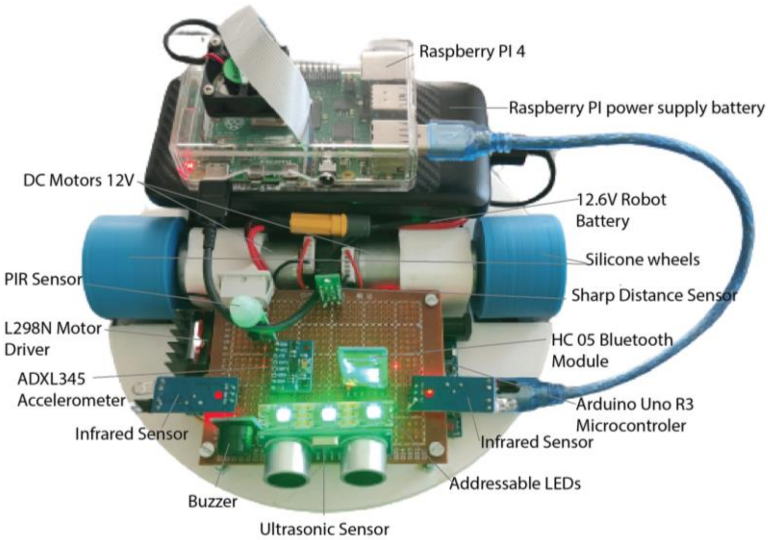

Figure 2. Electrical diagram of the prototype with sensor implementation

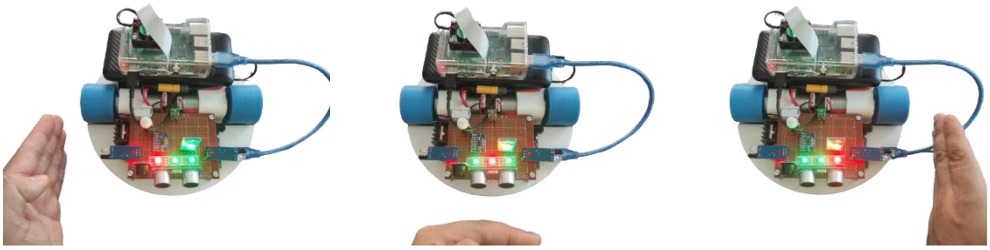

Figure 3. Checking the main sensors to avoid obstacles

5. Sensors used on the robot prototype

Ultrasonic sensors measure distances using ultrasound, allowing robots to detect obstacles and avoid collisions in spaces with unplanned or crowded obstacles. In parallel, image sensors and machine vision technology are fundamental to ensure accurate disinfection. These sensors allow robots to accurately and reliably identify contaminated surfaces, including those areas invisible to the human eye. This accurate detection is essential to achieve complete and effective disinfection.

```
#include <FastLED.h>
#include <Wire.h>
int ADXL345 = 0x53;
float X_out, Y_out, Z_out;
#define LED_PIN 2
#define ECHO_PIN 7
#define TRIG_PIN 8
#define BUZZER_PIN 9
#define IRSensor1 10
#define PIR_PIN 11
#define IRSensor2 12
const int motorSPWM = 5;
const int motorSDir = 6;
const int dir=random(100);
const int moveDelay=random(250,400);
const int rotateDelay=random(100,300);
#define NUM_LEDS 3
CRGB leds[NUM_LEDS];
long duration;
int distance;
Wire.endTransmission();
delay(100);
pinMode(TRIG_PIN, OUTPUT);
pinMode(ECHO_PIN, INPUT);
pinMode(BUZZER_PIN, OUTPUT);
pinMode(IRSensor1, INPUT);
pinMode(IRSensor2, INPUT);
pinMode(PIR_PIN, INPUT);
pinMode(motorDPWM, OUTPUT);
pinMode(motorDDir, OUTPUT);
pinMode(motorSPWM, OUTPUT);
```

```
#define SHARP_PIN A0
#define SpdMax 255
#define SpdStop 0
#define SpdBase 100
const int motorDPWM = 3;
const int motorDDir = 4;
int sharpValue;
void setup() {
  Serial.begin(9600);
Wire.write(8);
pinMode(motorSDir, OUTPUT);
Serial.begin(9600);
FastLED.addLeds<NEOPIXEL, LED_PIN>(leds, NUM_LEDS);
FastLED.show();}
```

This code snippet represents the main architecture of the robot control program. The program starts by including the FastLED and Wire libraries Defines the communication address for the ADXL345 sensor and variables for acceleration values on the X, Y and Z axes Defines pins for various robot components such as the addressable LEDs (LED_PIN), the sensor ultrasonic (ECHO_PIN and TRIG_PIN), the buzzer (BUZZER_PIN), and the infrared sensors (IRSensor1 and IRSensor2). Also defined is the pin for the Sharp sensor (SHARP_PIN). Constants for controlling the motors are defined, including maximum speed (SpdMax), stop (SpdStop), and a base speed (SpdBase). Pins are also defined to control the motors on the robot. In the setup() function, serial communication is initialized to display data on the Serial Monitor. The ADXL345 sensor is configured to start measuring acceleration. The pins for the ultrasonic sensor, buzzer, infrared sensors and motors are also initialized. The FastLED library is used to manage addressable LEDs. The LEDs are added to an object called "leds" and the "FastLED.show()" function is used to display any specific light patterns or colors on these LEDs.

Overall, this part of the program establishes the hardware configuration of the robot and initializes all components necessary for its proper operation. He also prepares the initial connections and settings for communication with the robot's sensors and motors.

The next step for the robot is to read the values for the ADXL345 accelerometer and the IR and Sharp sensor readings. Reading data from the accelerometer (ADXL345) the code starts by initiating communication with the ADXL345 sensor. It then sends a request to read the acceleration data from the three axes (X, Y and Z). This data is stored in six consecutive registers and is read in a correct format. The read values are then corrected to obtain the appropriate units of measurement (in this case, g) and are displayed on the Serial Monitor.

The serial display of sensor values is an essential component in the development and debugging of the autonomous disinfection robot. Through serial communication with the computer or other control platform, the values read by the sensors can be transmitted and analyzed in real time. This functionality allows operators to monitor sensor performance, identify potential problems, and adjust settings for optimal operation. By serially displaying the data, valuable information can be obtained about the environment and how the robot reacts to this data. The next section in the code is the main loop (loop()) of the program and is responsible for reading data from the robot's sensors and updating this data in real time. The program continues by measuring the distance using the ultrasonic sensor, which works by sending a sound signal and recording the time it takes for the signal to return. The measured duration is converted to distance in centimeters and stored in the variable "distance". This allows the robot to estimate how close it is to an object. Next is reading the status of the infrared (IR) sensors placed on the right and left side of the robot. These sensors are used to detect nearby objects. The read results are stored in the variables "sensorStatus1" and "sensorStatus2" and can indicate the presence or absence of objects in front or behind the robot. Reading the value of the sharp sensor provides information about the distance at which objects are in front of the robot. The read value is stored in the "sharpValue" variable. This main loop is essential for constantly collecting data from the robot's sensors, including acceleration data, distance to obstacles, and infrared sensor status. This data is later used to control and navigate the robot in its environment. To monitor the functionality of the sensors through the addressable LEDs, a visual approach is used that can be extremely useful in various scenarios. These LEDs can be programmed to indicate the status of the sensors in real time. For example, a green color could indicate that the sensors are working properly, while a red color could signal a problem or obstacle detected. This functionality makes monitoring fast and intuitive, allowing operators to obtain important information easily and intervene if necessary.

```
void loop() {
digitalWrite(TRIG_PIN, HIGH);
  delayMicroseconds(10);
else {
  leds[0] = CRGB::Green;
```

```
Wire.beginTransmission(ADXL345);
      Wire.write(0x32);
      Wire.endTransmission(false);
      Wire.requestFrom(ADXL345,       6,
true);
      X_out = ( Wire.read()| Wire.read()
<< 8);
      X_out = X_out/256;
      Y_out = ( Wire.read()| Wire.read()
<< 8);
      Y_out = Y_out/256;
      Z_out = ( Wire.read()| Wire.read()
<< 8);
      Z_out = Z_out/256;
      Serial.print("Xa= ");
      Serial.print(X_out);
      Serial.print("   Ya= ");
      Serial.print(Y_out);
      Serial.print("   Za= ");
      Serial.println(Z_out);
      Serial.println();
digitalWrite(TRIG_PIN, LOW);
delayMicroseconds(2);
      digitalWrite(TRIG_PIN, LOW);
      duration = pulseIn(ECHO_PIN,
HIGH);
      distance = duration * 0.034 / 2;
      int          sensorStatus1          =
digitalRead(IRSensor1);
      int          sensorStatus2          =
digitalRead(IRSensor2);
      int          pirStatus              =
digitalRead(PIR_PIN);
      sharpValue                          =
analogRead(SHARP_PIN);
      Serial.print("Distanta Ultrasonic:
");
      Serial.print(distance);
      Serial.println(" cm");
      Serial.print("Valoare Sharp: ");
      Serial.println(sharpValue);
      if (sensorStatus2 == LOW) {
        leds[0] = CRGB::Red;
  }
      }
      if (distance >= 20) {
        leds[1] = CRGB::Green;
      } else {
        leds[1] = CRGB::Red;
        evitaObstacol();

digitalWrite(BUZZER_PIN,
HIGH);
      delay(100);

digitalWrite(BUZZER_PIN,
LOW);
      }
      if (sensorStatus1 == LOW)
{
        leds[2] = CRGB::Red;
      } else {
        leds[2] = CRGB::Green;
      }
      FastLED.show();
}
```

The final implementation of the code for this robot will be presented in a later paper. In that paper, we aim to include the details of motor control, Lidar communication, and video image processing.

6. Conclusions

In this paper, a robot prototype was presented, in the future it will be implemented with the Raspberry Pi 4 system and will become an autonomous robot for testing algorithms for disinfection in complex environments, using a wide range of sensors and advanced technologies. By implementing the Raspberry Pi system as a central control unit, we would manage to integrate and coordinate complex sensors, including ultrasonic sensors, infrared sensors, PIR sensors, Sharp sensors, motor control, and in the future Lidar technology and video camera system will be used but also image sensors are to be tested, gas and air quality sensors, as well as temperature and humidity sensors.

This study demonstrated that the developed autonomous robot will be able to perform efficient and accurate disinfection procedures, adapting in real time to environmental changes and intelligently avoiding obstacles. The integration of artificial vision and autonomous navigation algorithms will allow the robot to identify and locate work areas, thus increasing the effectiveness of the disinfection process.

Through our tests and experiments, we have validated the effectiveness of this prototype, including in medical and industrial environments. Also, integration with state-of-the-art technologies such as Lidar and machine vision will open new horizons in the development of autonomous disinfection robots.

In conclusion, this work represents a significant step forward in the field of autonomous disinfection, highlighting the enormous potential of this technology in providing a clean and safe environment in various contexts. Further development and optimization of this prototype could lead to its widespread implementation, thereby helping to improve safety and health in our communities.

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References

[1] E.C. Camacho, N.I. Ospina and J.M. Calderón (2021) COVID-Bot: UV-C Based Autonomous Sanitizing Robotic Platform for COVID-19, IFAC-PapersOnLine Volume 54, Issue 13, 2021, Pages 317-322 [Science Direct]
[2] S.Wang,Y.Li,G.Ding,C.Li, Qi.Zhao,B.Sun and Q. Song, Design of UVC Surface Disinfection Robot with Coverage Path Planning Using Map-Based Approach At-The-Edge, [Google Scholar]
[3] World Health Organization. (2020). Cleaning and disinfection of environmental surfaces in the context of COVID-19: Interim guidance, 15 May 2020. World Health Organization. [WHO]
[4] D.M. Anton, R. C. Milaș, T. Țicărat, V. O. Mihalca, R. C. Ț, F. I. Biroauș , " Experimental Testing of UV-C Light Sources Used Disinfection Mobile Robots" , doi: 10.1109/EMES58375.2023.10171692. [Google Scholar]
[5] D.M. Anton, R.C. Milas, AM. Stiube, L.E. Stiube, Area mapping for autonomous disinfection robot, IOP Conference Series: Materials Science and Engineering, Volume 1169, The Annual Session Of Scientific Papers (IMT Oradea 2021) 27th-28th May 2021, Oradea, Romania [Google Scholar]
[6] J. Borenstein; Y. Koren, Obstacle avoidance with ultrasonic sensors, Journals & Magazines IEEE Journal on Robotics, Volume: 4 Issue: 2[Google Scholar]
[7] Szeliski, Richard. "Computer vision: algorithms and applications." Springer Science & Business Media, 2010. [Google Scholar]
[8] V.V. Tran, D. Park and Y.C. Lee, Indoor Air Pollution, Related Human Diseases, and Recent Trends in the Control and Improvement of Indoor Air Quality, Int. J. Environ. Res. Public Health 2020, 17(8), 2927. [Google Scholar]
[9] D.M. Anton, Ș.E. Szabo, C.A. Mociar, A.F. Iuhas , Line follower mobile robots, prototypes of robots and functional of mobile robots August 2021 IOP Conference Series Materials Science and Engineering 1169(1):012043Following DOI: 10.1088/1757-899X/1169/1/012043 LicenseCC BY 3.0 [Google Scholar]
[10] Thrun, S., Burgard, W., & Fox, D. (2005). "Probabilistic robotics." Communications of the ACM, 45(3), 52-57. [Google Scholar]
[11] M.S. Arulampalam, S. Maskell, N. Gordon, T. Clapp, A tutorial on particle filters for online nonlinear/non-Gaussian Bayesian tracking,IEEE Transactions on Signal Processing (Volume: 50, Issue: 2, February 2002) Page(s): 174 - 188[Google Scholar]
[12] Thrun, S., Burgard, W., & Fox, D. (2005). "Probabilistic robotics." The MIT Press. [Google Scholar]
[13] Bradski, Gary, and Adrian Kaehler. "Learning OpenCV: Computer vision with the OpenCV library." " O'Reilly Media, Inc.", 2008. [Google Scholar]
[14] S. Perminov et al., "UltraBot: Autonomous Mobile Robot for Indoor UV-C Disinfection," 2021 IEEE 17th International Conference on Automation Science and Engineering (CASE), Lyon, France, 2021, pp. 2147-2152, doi: 10.1109/CASE49439.2021.9551413. [IEEE]
[15] Stelian-Emilian Oltean, Mobile Robot Platform with Arduino Uno and Raspberry Pi for Autonomous Navigation, Procedia Manufacturing, Volume 32, 2019, Pages 572-577, ISSN 2351-9789. [Scince Direct]
[16] Yılmaz, E., & Tarıyan Özyer, S. (2019). Remote and autonomous controlled robotic car based on arduino with real time obstacle detection and avoidance. [Google Scholar]
[17] Pujari, S. S., Patil, M. S., & Ingleshwar, S. S. (2017, February). Remotely controlled autonomous robot using Android application. In *2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud)(I-SMAC)* (pp. 588-593). [IEEE]
[18] Sun, Y., Liu, M., & Meng, M. Q. H. (2017). Improving RGB-D SLAM in dynamic environments: A motion removal approach. *Robotics and Autonomous Systems*, *89*, 110-122. [Scince Direct]
[19] Farkh, R., Marouani, H., Al Jaloud, K., Alhuwaimel, S., Quasim, M. T., & Fouad, Y. (2021). Intelligent autonomous-robot control for medical applications. *Computers, Materials & Continua*, *68*(2), 2189-2203. [Google Scholar]
[20] Zakaria, A. H., Mustafah, Y. M., Abdullah, J., Khair, N., & Abdullah, T. (2017). Development of autonomous radiation mapping robot. *Procedia Computer Science*, *105*, 81-86. [Google Scholar]