Autonomous Ground Vehicle (COR-AGV) Disinfectant System Using Far-UVC Light Exposure

Muhammad Farris Khyasudeen and Norlida Buniyamin*

***Abstract*—In this Covid -19 pandemic era, where the negative impact of the virus is felt worldwide, it is crucial to reduce the rate of infection. This paper presents the development of a vehicle to minimize the spread of the disease. The Coronavirus-Autonomous Ground Vehicle (COR-AGV) uses Ultraviolet Light (UV) rather than liquid sanitiser. The use of UV light as a disinfectant is proven in the medical field, where many medical appliances were disinfected using UV light without the need for alcohol substances. Previous research showed thatsimilarCoronavirus such as SARS and MERS lost their ability to infect when exposed to the UV for a particular durationasthe exposure causeddamageto the virus's DNA sequence. The COR-AGV presented herewith uses UV Light to carry out the disinfection task autonomously. The COR-AGV, equipped with a far-UVC light array, navigates autonomously within the targeted areas to sweep systematically, scan and disinfect. The COR-AGV is equipped with camera and sonar sensors to enable path planning and obstacle avoidance in confined spaces and outdoor environments. A GPS is included to assist the COR-AGV navigation system. Simulation test runs were performed to check the adequacy of the rover in performing disinfection. The COR-AGV perform disinfection on the wall surface with more than 50% of the wall surface were covered for disinfection in various floor layouts, while being able to perform obstacle avoidance within the test area. Thus, COR-AGV can be adapted prior to the actual pandemic event to enhance its level of performance. The performance of COR-AGV can be improved with additional sensors such as Computer Vision or LiDAR sensor.**

Keywords—Autonomous System, Ultraviolet, Ground Rover, Navigation, Coronavirus, Disinfection.

I. INTRODUCTION

THE recent development in the cases of infection from Coronavirus has become worrying that it affects not only the health system to a pandemic level but also the economy and social activities.

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As of 2020, number of cases recorded fatality rate of 1.9 million just within the period of not more than two years[1]. The surge in the numbers of cases worldwide has lead researchers to help to reduce the risk or effect of the virus in any way possible. To address the issue, different approaches can be implemented such as prevention, treatment, education, and policy, to categorize a few. In a situation where the virus outbreak is imminent that leads to a pandemic level of disaster, any possible approach is to be taken in reducing the risk of infection. The risk is higher when considering a populated area scenario. In this scenario, it is necessary to manage and assist in the pandemic operation management to avoid sporadic infection and mitigate the economic consequences [2]. The most effective approach in reducing the risk of infection is to perform prevention towards spreading the virus. Coronavirus attacks and spreads within the community through human to human transmission via air, droplets and surface that contain the virus [3], [4]. Face mask can significantly reduce the human to human transmission, and most of the country worldwide makes it compulsory for the community to wear it in public. But it is not applicable in places such as restaurants and diners as people often take it off when consuming foods. A face mask is not 100% effective as it is not a foolproof method for prevention and did not cover the risky area, i.e. mouth and nose, perfectly, as shown in Figure 1. The virus can also enter human body through the eyes opening, which the face mask did not cover [5]. Virus that is airborne either from an infected human or surface containing the virus can transmit easily within 1 metre to another healthy person[6].

In this paper, a preventive measure to help to reduce the risk of infectionis proposed using COR-AGVequipped with Far-UVC Light that is efficient in performing sanitization that will reduce the volume of active Coronavirus in the environment, with the goal to reduce infection rate. Far-UVC is a visible light that ranges between 207 to 222nm in wavelength. Far-UVC has been proven to effectively deactivate and kill the viruses' cell, preventing them from regeneration, thus negating their ability to spread [7], [8]. It can be used as a disinfectant agent against harmful viruses such as H1N1 and Coronavirus as it can penetrate the cell and damage the DNA sequence of viruses' cell. Conventional UV light has proven to be very effective. Still, it can be very hazardous to human being, both cataractogenic and carcinogenic, as it can penetrate mammal skinsand damage the healthy cells and DNA [9].

Fig. 1.The appropriate and inappropriate wear of the face mask to avoid the risk of infection through the mouth and nose

The advantages of using FAR-UVC light as a disinfectant is that the wavelength used cannot penetrate mammals skin but can penetrate and traverse inside smaller dimension virus such as Coronavirus, thus it is not hazardous to humans or animals. This has a similar effect with the widely used alcohol-based substance. However, the alcohol-based substance is limited commodities and may cause skin rashes for some.Moreover, it is limited and can't be reused or renewed, making it costly and unfriendly to the environment. The alcohol-based substance is being placed in public areas as an immediate disinfectant to be used on hands, as the hands perform contacts with the surroundings the most. Bacteria or virus can enter the human body when the same hands touch the human mouth, nose or eyes; thus, sanitizing your hands regularly with alcohol is a suitable prevention method. For a surface with a large area of coverage, this might not be the best method for disinfection as it will require a considerable volume of alcohol substance to be used and require a lot oflabour work to be done. It is not an effective cost solution, especially for a surface disinfection process.

In contrast, FAR-UVC uses electricity which is rechargeable and will not cause damage to the skin, making it very suitable as a practical disinfectant system solution. FAR-UVC can achieve a similar result to the alcohol-based substance, but in its advantages, light source is relatively easy to generate and cheap to implement. Furthermore, it generate 207-222nm ultraviolet from an LED light source which is efficient in its power consumption.. To make it more effective, an autonomous system equipped with FAR-UVC LEDinstalled on a ground rover is proposed that sweeps the affected surface area and performs disinfection by exposing those areas in a certain periodand intensity to achieve virus deactivation stage.

This paper proposed a solution that can overcome two shortcomings of using alcohol substances: the vast amount of solution volume spent—secondly, the labour work to be done to prevent virus spread through disinfection. The first shortcoming was overcome by using an alternative solution that can achieve similar results as to alcohol, which is Far-UVC Light. Exposing the surface to this light for a certain period is equivalent to sanitization and disinfectant that inactivate the virus from regenerate. Details of the properties of UVC light will be discussed in detail in the next section.

The second shortcoming of using intensive and costly labour work to do disinfection can be overcome by using an Autonomous System (AS) such as machines and robots to replace the work of humans in this scenario. The use of AS in pandemic management can ease the burden of labour work and cost of the health office that can be used on other critical section, especially when the number of infected cases to be attended overshoot the number of workable personnel available. Exploiting AS such as robots for disinfection system in disaster management has become a highlight in recent years of research. The introduction of AS in disaster management reduces the cost and labour work. Still, researchers have developed AS to achieve a more effective and efficient system than the conventional method of facilitating the relief operation. At the same time reduces the exposure of the health personnel on the ground and further reducing the risk of infection among them.

The overview of this paper is as follows: Section II is an overview of autonomous systemsfor pandemic management; section IIIpresents the architecture of the autonomous system; and section IVprovides the behaviour assessment of the system.

II. Autonomous System for Pandemic Management

Recent development in robotics and control systems, caused the emergence and popularity in research in the area of Autonomous System (AS) both in the universities and the industries.AS can support health personnel teams by performing several tasks in pandemic management. Among common tasks includedetection, tracing and disinfecting.

Detection plays a vital role in early pandemic management, narrowing down and focusing on the affected areas, either macro area, i.e. city, town, country;ormicro area, i.e. chest, lung, face. Macro detection is notassessable as Coronavirus, or infected person did not show a distinct thermal signature or any other distinct radiation that is hard to recognize compared to regular flu. A human with coronavirus symptoms shows a slightly higher temperature than an average person does. One of the detection methods is by performing a temperaturecheck. This has been done primarily in public places where people must screen their temperature before they can enter any premises.However, temperature check applied only as the first stage of screening and is not sufficient to identify the presence of Coronavirus on the test subject as stated in Gandhi, M. et al. [10]. Furthermore, many shows asymptomatic cases cannot be identified via temperature check alone[11].Since the virus attacks mainly on the human respiration system, it is best to perform detection on those areas in which involves the relevant organ. It includes the nose, mouth and lungs area. The easiest detection method is by performing a swab test. The swab test consists of using a long Q-tip inserted into the cavity located between the nose and mouth of the subject and then collecting material enough to detect any presence of virus(es)[12]. This is called a nasopharyngeal swab, which gives test results almost 100% accuracy, such as the real-time polymerase chain reaction (RT-PCR) test[13].To date, the test has to be done manually by the health officerat an isolated location, with no autonomous system currently in place. Another method of detection is by using X-ray images.X-ray images have been used to analyze various health issue within the human organs. Coronavirus can be detected using X-ray images in an infected person's lungs. In [15] and [16], the authors proposed automatic detection of Coronavirus in the lung area using x-ray images.In both papers, the authors proposed using machine learning to identify the coronavirus infection automatically from the x-ray images obtained. Both show an accuracy of over 95%, which is almost as accurate as of the RT-PCR swab test. This method can be considered semi-autonomous in detection.

Another approach that can be implemented to reduce the spread of the virus is by performing tracing. The current effective method is via contact tracing. This method gives information on the infected person's whereabouts and with whom he or she had close contact. With this information, pre-emptive strike can be done such as isolation and quarantine towards their close contact. Contact tracing also helps the pandemic management teamto have a targeted and focused area for containment and, in severe cases, total lockdown on the locality. Testing and detection can be performed on a more focus group of a community instead of mass testing, especially for the management with insufficient resources of test kits. In Malaysia, the government made it compulsory for the public to check their location before entering any premises. This is done via MySejahtera apps [16]. Through the apps, the person last known location(s) will be recorded and stored. If the person has been infected, it will be easier for the pandemic management team to retrieve and trace the potential location of its source or spread from and to the person. Then, decide on any appropriate measures to contain the viruses.Although this will not give the exact contact tracing information, it narrows down thelocality and community involved. More importantly, the system autonomously populates the data obtained from the public masses and identifies the risky infection zone. Jian SW et. al. [17]proposed developing acentralized contact tracing systemthat has an organized data structure that can be analyzed automatically to assist the pandemic management team in taking action of coordination cross-referencing, follow-up cases and many more.The authors stated that in Taiwan, digital tools had been used as the assistance of contact tracing effort. The structured information obtained using various digital tools plays a crucial role in strategic planning towards the pandemic situation.

The next step to be taken in a typical pandemic situation is disinfection.The transmission of the virus from the affected surface to the human respiratory system can best be done through disinfection. Disinfection is a process of killing or inactivate on an inert surface [18]. Disinfection kills or damages the structure of the virus protein. It cannot regenerate and replicate, which can cause severe damage to its host and, in the case of Coronavirus, to the point of a fatality where the host respiratory system is failing and disfunction. With the disinfection in place, if the virusesmanage to enter the human lungs, they will lose their ability to regenerate and duplicate. Eventually, it will die, make it not harmful due to its inactive state. Disinfection process that can be done autonomously during pandemic situation will be helpful and reduce the burden on the pandemic management team. Not only that, AS worksefficient consistently. With proper optimization, disinfectionon the intended areas can be covered entirely without human intervention; furthermore, AS will not deter in its task, unlike human where they may get tired and inefficient. Autonomous disinfection can be done chemically or mechanically. For example, in [19], the authors proposed a hybrid system that generates H_2O_2disinfectant autonomously via the chemical reaction of Mg-ZnO/Auto kill bacteria such as E. Coli.While authors like in [20] and [21] use a mechanical system to perform disinfection autonomously. In [20], the concerned area of disinfection is attheendoscope used by the patients and health staff to replace the current method of using the washing machine.The authors proposedan auto-disinfector system namely KeyMed that cleans and disinfect endoscope thoroughly using three separate reservoir systemin avoidance of glutaraldehyde exposure that the current practice produces.In [21], the authors use autonomous mobile robot to perform disinfection using Programmable Logic Circuit (PLC) that substitute the involvement of humans. This will significantly help the pandemic management in planning and allocating their workforce.In [22], the author proposed almost similar approach in performing disinfection using UV Light. But the autonomous system uses UV Light for floor disinfection instead while for wall surface, it uses germicide fogging method. The system, namely Autonomous Disinfectant Robot (ADR), can be also voice-controlled for navigation. However, in ADR, wall surface sanitization using the fogging method differ in this research objectives which is to reduce the usage of the limited chemical solution commodities. Another example is in [23], where a robot is use for a routine cleaning process in a specific hospital. Similarly, it uses UV light, which is anUVC-typeto perform disinfection. The robot navigates autonomously within the hospital building while radiating UVC light on the target contaminated surface to kill pathogens. However, the method only applicable to a specific layout. This is because the path that the robot takesare required to be pre-programmedbeforehand to reach the target area.

Detection, tracing and disinfecting are not the only task that can be done autonomously in pandemic management. There are several other approaches, such as prevention by using vaccines, educating, through awareness in public media or policy, such as enforcing the Standard Operating Procedure (SOP). To approach the situationin this paper, the focus will be on development of autonomoussystem towards performing disinfection.

III. The Architecture of the Autonomous System

In this section, hardware and software architecture of the proposed AS will be discussed. The overall architecture of the system is shown in Figure 2. Basically, the system is a disinfectant system using ground rover, thus named Corona-Autonomous Ground Rover (COR-AGV) Disinfectant System.

A. Hardware Architecture

Figure 2 shows the system hardware architecture of COR-AGV. Note that the companion PC governs the centre of the autonomous system while the rover controller controls the movement and speed of COR-AGV. The rover controller receives instructions from the companion computer that generates trajectory commandsvia protocol named MAVLink.MAVLinkis a communication protocol used for communicating between drones and onboard or offboard computer. It is a very lightweight message encapsulated in a tiny packet using XML format.

Attached to the Companion PC is a Rangefinder. The Rangefinder is used to detect obstacle using a sonar sensor. It determines the distance of the obstacle it is pointed to by calculating the time taken to receive the echo of the acoustic generates by the Rangefinder. However, the distance obtained is not as accurate, and it has a slow response time to update the current distance.

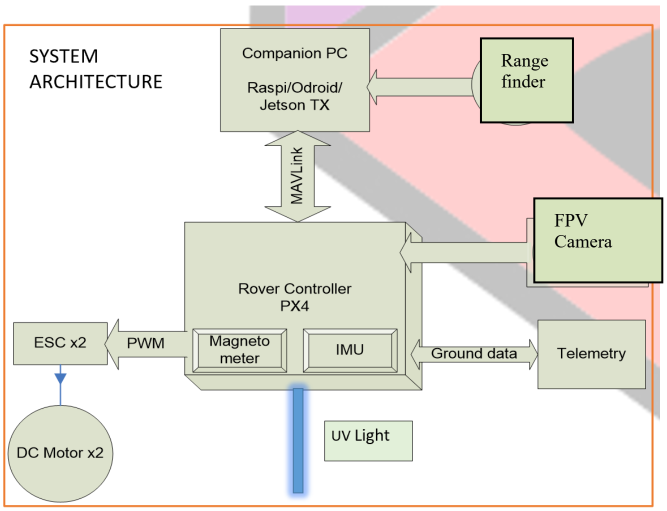


Fig. 2.Overall system architecture of COR-AGV Disinfectant System.

But the implementation is relatively easy and low cost, and the data obtained is adequate for the COR-AGV to navigate itself to perform obstacle avoidance as required.

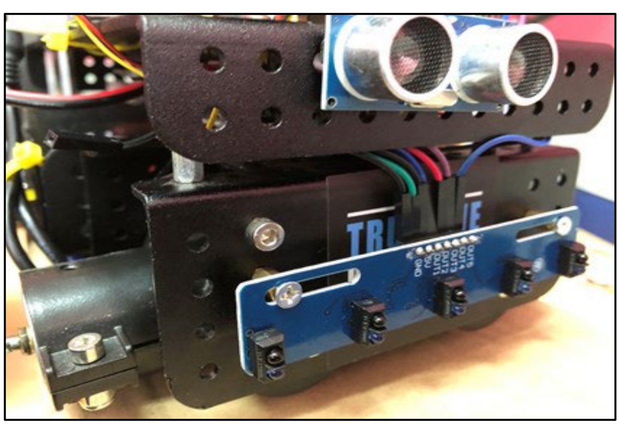


Fig. 3.Rangefinder placed in front of the COR-AGV.

Connected to the rover controller is the FPV camera, which is optional for the system to be operated. FPV Camera is a small, lightweight camera, usually in a low-resolution setup used for transmission to Ground Control Station(GCS). GCS is an application to configure and monitor an autopilot vehicle runs by a remote user. FPV Camera captures and transmits the video feed from COR-AGV wirelessly for the remote system operators to monitor the vehicle's whereabouts. It can be transmitted over a short distance, i.e. 1 km and up to 100 km, depending on the technology used. For this implementation, a small scale FPV that can go up to 10 km of transmission distance is used, which is enough to cover the area of disinfection.

Similarly, connected to the rover controller is a telemetry system that transmits the status of COR-AGVto the remote operator. The status of the COR-AGV includes its ground speed, battery health, elevation, GPS location and any abnormalities detected within the system. Telemetry data is crucial for the operatorto monitor system stability while COR-AGV autonomously performs disinfection. It uses 915Mhz wireless communication that can cover enough distance (depends on hardware parameter)for this application.

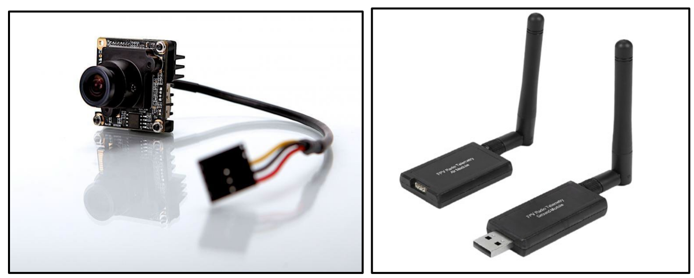


Fig. 4. a) Left: FPV Camera b) Right: Telemetry Air and Ground Module

A rover controller is connected with but independent of aUVClight which is the source of disinfection for the system, and it ispowered by a DC supply. The UVC is an LED light strip with a length of around 2 metres that uses more than 50 small LEDs along the strip.The effective wavelength of UVC LED used is between 210 nm to 222 nm. An independent 12V DC power supply is used to light up the LED strip to get the optimum power required. Theoretically, it is best to have a monochromatic UVC light in the system to be highly effective. Still, such hardware is expensiveand is not suitable for mobile rover application with limited power supply. To reach the height where humans are most vulnerable towards the virus, which is the mouth and nose area, the LED strip is attached to a lineraactuatorthat can be extended verticallyto attain that height as well as to maximize the UVC light intensity on the focus area – which is the wall surface at human face level. The linear actuatoris a motorized extender that receives Pulse Width Modulation (PWM) signals to either retract or extend its metal rod. This enables the system to utilize the input of the line actuator to be able to control it remotely using the telemetry communication medium. PWM signals are distinct in their pulse width representation, giving different instructions based on pulse width duration. In thissystem,three different instructions in regards to the linear actuator are being determined. PWM signal less than 1400 ms will send a rod to retract instruction, while a signal above 1600ms will sends a rod to extend instruction.

Between the duration, that is 1401 ms to 1599 ms, the rod will maintain in its place. Thus, when reaching areas where a particular height needs to be achieved, the COR-AGV operator can control its height of which disinfection is optimum.

Other peripherals hardware required to complement the systemare the Magnetometer and IMU, giving the vehiclecompass and vehicle orientation direction. The DC motors for front and back wheelsare controlled by Electronic Speed Controller(ESC) which receives PWM signals from Rover Controller.

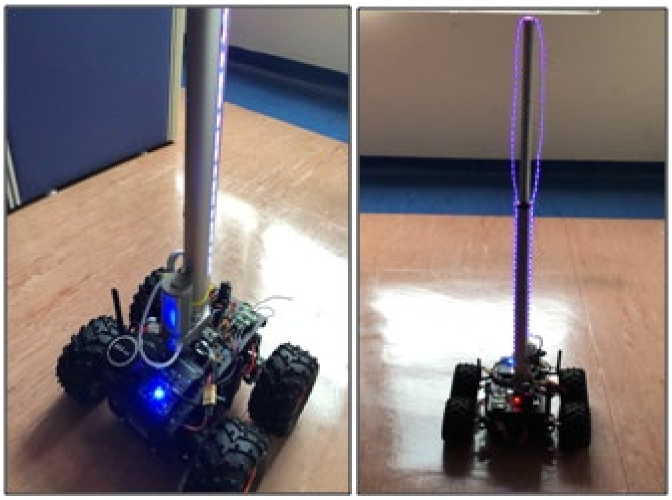


Fig. 5.COR-AGV chassis and UVC LED Strip with linear actuator extender.

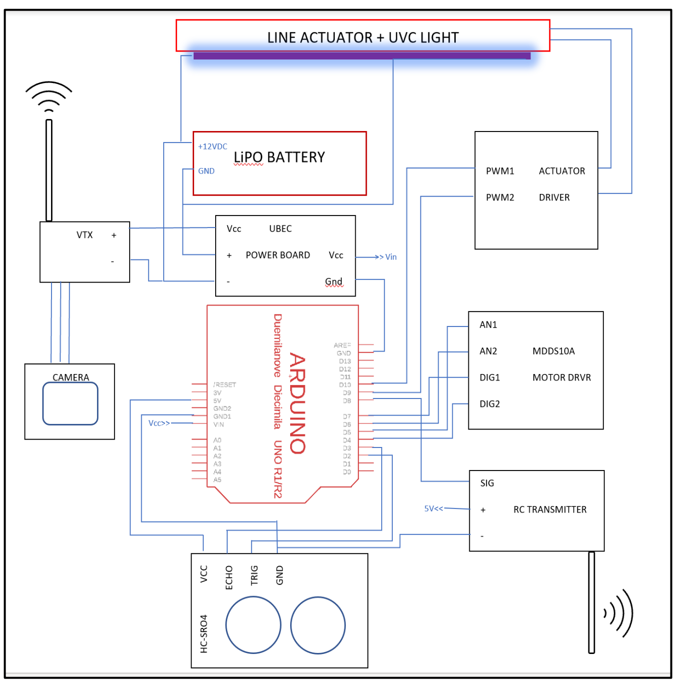


Fig. 6. Schematic diagram of the COR-AGV system

The configuration used for COR-AGV to move is a skid steering type that uses the differential movement of the left and right wheels to change the COR-AGV direction towards the left or right without moving forward or reverse. The wheels are attached to a rectangular-shaped steel body chassis of 4x4 Wild Thumper from Pololu. Figure 6 shows the schematic diagram of COR-AGV system and Table I shows the detail specification of COR-AGV.

TABLE I
COR-AGV SPECIFICATION DETAILS

Dimension(cm)	31(w) x 31(l) x 122(h)
Chasis	Pololu 4x4 Wild Thumper
Steering	Skid Steering
Motor	Brushless DC 45:1
Motor Driver	Cytron MDD10a
Companion CPU	Arduino Uno
Disinfection	UVC Light
UVC Wavelength	205 -222nm
Battery Duration	~45 mins

B. *Software Architecture*

The general software system architecture can be summarized as shown in Figure 7. The system uses various protocols to communicate with each other but mainly, it uses UDP communication.

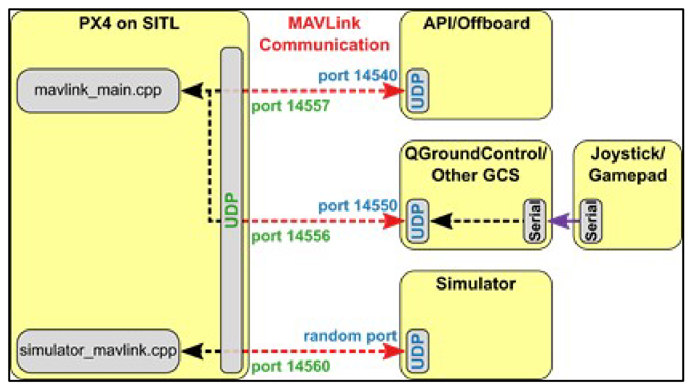


Fig. 7. Software architecture of the COR-AGVcommunication and system

Communication between companion PC or also known as Offboard, with the COR-AGV controller wasdone throughMAVLink protocol using UDP port 14540, as shown in the figure above. Other connection required, such as wireless communication between COR-AGV and GCSisvia UDP:14550 port. Both communications provide instructions to COR-AGV, particularly onthrottle and roll commands that define the movement of COR-AGVwith regards to the disinfection process. For Companion PC/Offboard, two types of CPU were tested: the Raspberry Pi 3 Model B and Arduino Uno. Both give similar accurate result. The difference is in the programming language used in the source code. The former use Python and the latter use C++ . The system using Arduino Uno as Companion PCwill be discussed for ease of implementation and explanation. Arduino Uno is simple to set up and configure, easy to program, and readily available on the shelf. To compare, it cost much less than the Raspberry Pi, and it does not require the user's high-level programming skill. However, the significant difference between those two is the processing power which, in this case, Raspberry Pi have a better processing unit than Arduino. But in this application, Arduino Uno is adequate to achieve the objectives. The following is the process flowchart as programmed in the companion PC.

As shown in Figure 8, the program flowchart programmed into the companion PC can be described as follows: First, the program will initialize the hardware that triggers the COR-AGV system and UVC light disinfectant. Then, it receives the linear actuator as well as IMU and Compass current reading to make sure that the crucial autonomous part is working correctly. Then, the operator will control the COR-AGV manually to reach the target area using RC transmitter by the operator. When it reaches the target area, extend or retract instruction will be sent to the linear actuator to reach the intended height of disinfection. Once the setup and placement of the COR-AGV have been satisfied, the operator will initiate an autonomous disinfection program by triggering a PWM signal that has been pre-assigned in the RC.

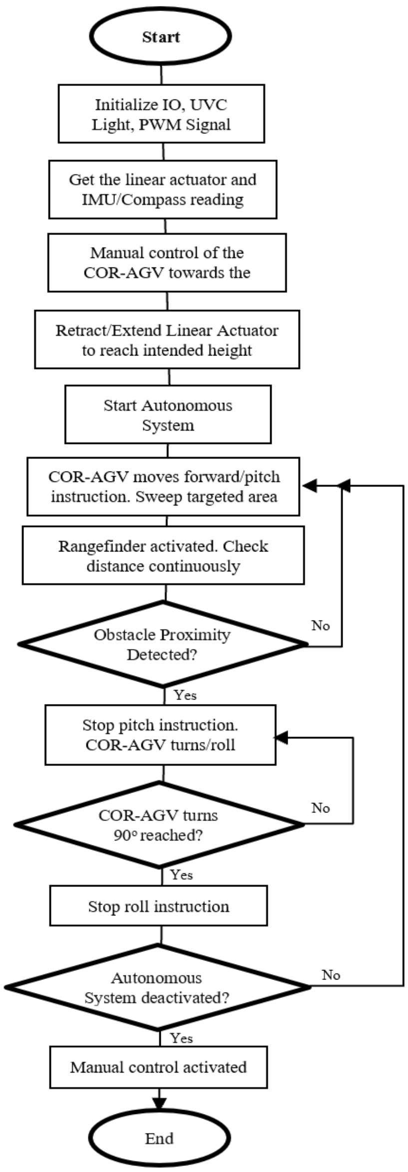


Fig. 8. Flowchartprocess of the COR-AGV Autonomous Disinfectant System

The autonomous system routine starts by sending MAVLink messages that instruct the COR-AGV to perform pitch operation, translating toforward movement. The speed of the rover is adjusted depending on the sweeping resolution and disinfection intensity level. The basic principle is that the longer any surface is exposed to the UVC light, the more effective the disinfection process is. However, a longer duration is required, especially for a large area. While the thorough disinfection process is ongoing, the Rangefinder sensor collects and check the distance towardsthe obstacle from theCOR-AGV. When COR-AGV reaches distance proximity in a certain threshold from the obstacle, triggered by the Rangefinder, it will send a stop command to avoid collision with the obstacle, usually a wall surface. Since there is no way forward, the program sends roll instruction via MAVLink, which translate to vehicle turns and changes its heading using skid steering configuration. When the COR-AGVperform turns, IMU and compass feedback their reading to the Companion PC and triggers a stop turn instruction once the heading reaches 90° turns. A right angle in triggering stop instruction is chosen as most of the walls are perpendicular to each other in their perimeters which is 90°angle. Until it reaches the angle, the COR-AGV will continue to turn. Then, it will continue to move and sweep the areas by moving forward againwhile maintaining a constant distance between the wall and UVC light source, until the autonomous system deactivated by the operators, before it will be manually controlled, which mark the end of the disinfection process on that area. As such, using the mentioned approaches, wall surface perimeters of the targeted area can be disinfected autonomously and efficiently.

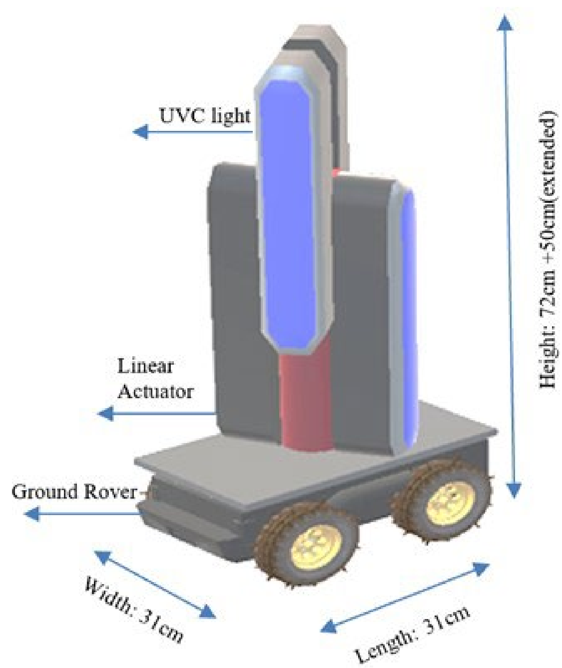


Fig. 9. 3D model view of COR-AGVand its dimensioning

Figure 9 shows a 3D model view of COR-AGV, which is composed of three modules. First, the rover chassis is a Wild Thumper with an independent motor driver of 75:1 torque ratio and its dimension, as shown in Figure 9. Such a dimension allows the rover to navigate through small or narrow areas that may be inaccessible but necessary to be disinfected. Second is the rover's brain, which is the companion CPU as explained in the previous section, placed on top of the chassis as well as sensors placed accordingly around the vehicle. Lastly is the disinfectant of UVC light source and its holder, a linear actuator placed in the middle of the vehicle to get a 360º of light dispersion around the COR-AGV focus area.

IV. Behaviour Assessment of The COR-AGV Disinfectant

This section covers the behaviour assessment of COR-AGV with regards to a specific mission. In this part, the aim is to assess the performance of COR-AGV in an environment.

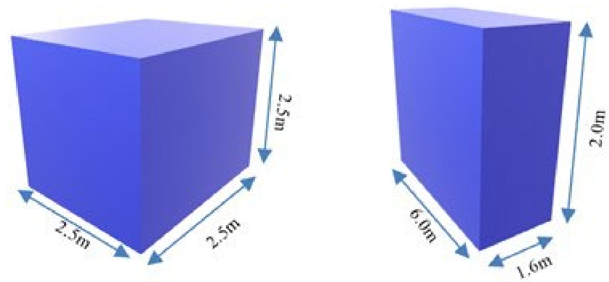
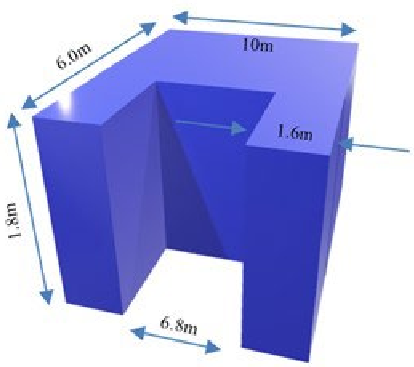


Fig. 9. a) Left: Square b) Right: Narrow



c) Middle: Segmented

Fig. 10. 3D isometric view of the target layout

The assessment of the disinfection system will cover the movement assessment of the COR-AGV with regards to the desired movement. The desired movement of the COR-AGV is to cover the perimeter of the targeted area and perform disinfectant on the perimeter wall surface. This section also aims to understand if the COR-AGVis adequate and suitable for a specific mission and accomplished a given task.To achieve this, test runs and collect data on the movement of COR-AGV were tested on two aspects; the area perimeter coverage and its autonomous obstacle avoidance system. Area perimeter coverage was measured by the distance traveled against the overall perimeter length. The efficiency of the obstacle avoidance system was observedby the behaviour of COR-AGV when approaching the obstacles, in terms of it turning and moving forward. For this experiment, three types of layout were identified which are square, narrow and segmented layout. The layout of the targeted, tested area is depicted in Figure 10. These three layouts has been chosen as it is the common type of layout thereis for an indoor environment. Furthermore, the COR-AGV efficiency can be tested to determine the most adequate setup and room for improvement that is required for each layout. The above has been tested in CSES Laboratory Faculty of Electrical Engineering, UiTM Shah Alam.

A. *Surface Area Perimeter Coverage of the COR-AGV*

To have the best disinfection process, the system must cover the area with disinfectant as much as possible. The targeted area to be covered in this method is the wall surface where the virus resides the most. As such, the COR-AGVis targeted to perform disinfectant on the wall perimeter. Different floor layout and wall height weretested to measure the coverage area in different setup and location. Testing were done in a closed controlled environment where no external or unpredicted objects in the setup. During the disinfection process, ambient light was turned off to easily observed the surfaces that had been hit by the UVC Light. Areas that were illuminated fully by the UVC Light were marked with masking tape and then measured to identify area of disinfectant. The measurements were recorded for each layout manually, to be assessed. The overall assessment as per shown in TableII.

TABLE II
COR-AGV DISINFECTION SYSTEM SURFACE AREA COVERED BY THE DISINFECTION ON A DIFFERENT LAYOUT.

Layout	Square	Narrow	Segmented
Perimeter Length(m)	10	15.2	38
Average height (m)	1.5	2	1.8
Surface Area (m^2)	15	30.4	68.4
Surface Disinfected (m^2)	12	18.24	45.6

In comparison, the perimeter of the segmented layout has the highest length than the square, and a narrow layout thus will have a bigger surface area for disinfection. During the test simulation, measurement towards the UVC light that hit the wall surface were observed and collected. In the scenario, an assumption has been made that the surface which has been exposed by UVC light has been disinfected.The surface area of which UVC light did not reach or barely hit, considered to be not yet disinfected.

Table II shows the efficiency of COR-AGV disinfectant in terms of surface area covered for different layouts. For example, in square layout, the COR-AGV system covers almost 80% of the total surface area. The main reason that the system did not reach 100% coverage is because some of the walls have a height that is beyond the reach of the UVC light, which has a maximum height of 120cm.In a narrow layout, the system achievedonly 60% of the coverage. This is also due to the height of the area in which the COR-AGV cannot reach. Furthermore, for narrow layout with tight turns, the UVC light was barely hitting the surface in the corner due to that COR-AGVchanges direction rapidly asit avoids the obstacle. Rapid changes on turning give out turn error as the compass embedded had not been stabilized yet before the need to perform another turn, making the COR-AGV positioning a bit off in its effective angle. For the Segmented layout, which has the highest surface area, the system covers 66.67% of the total area—this due to the same issue of height coverage of the COR-AGV. Higher coverage was observed compared to the narrow layout because no tight turns performed, thus giving the system more effective surface coverage. In summary, the COR-AGV system achieves more than 50% of surface coverage, especially on the vulnerableand parallel area to the human face.

B. Obstacle Avoidance System

The second part of the assessment is on the obstacle avoidance system efficiency. In this section, COR-AGVbehaviour when encountered obstacles in its path were observed and analyzed. Efficiency of the system was measured on the vehicle's response upon detecting obstacle and the accuracy of the desired distance against the measured distance before turning. The measured value were collected from the serial port monitoringon Arduino GPIOconnected to the vehicle's Rangefinder. Table III shows the result obtained from COR-AGV test runs.

The distance were set in the avoidance system to perform a roll or turning when the obstacle is less than 10 cm as this is the effective distance for the UVC light to get the optimum disinfection distance. First, to obtain the distance, the Rangefinder will need to be triggered to generate soundwave through TRIG pin and set it to HIGH for 10ms to get the effective pulse travelling duration. Then whilesoundwave travelling through the air, the system will capture the pulse echoed when the wave hit an obstacle through the Rangefinder ECHO pin. Duration for soundwaves to travel back and forth from and to the Rangefinder was taken to calculate its distance. By using the formula below, the distance of the obstacle inwards can be calculated:

$$\text{Distance}(d) = P_d(0.034/2) \quad (1)$$

P_d is the pulse duration captured via ECHO pin; the value 0.034 is constant for the speed of sound and is divided by two as the soundwave travelled two times the obstacle distance to reach back and forth the Rangefinder.

TABLE III
RESPONSE TIME AND DISTANCE TOWARDS THE OBSTACLE BEFORE AVOIDANCE ON DIFFERENT COR-AGV SPEED.

COR-AGV speed(cm/s)	Distance to obstacle before avoidance (cm)	Response time (ms)
1	9	10ms
5	9	10ms
10	9	10ms
20	8	10ms
25	8	10ms

In the COR-AGV obstacle avoidance system, the same layout as in the previous section were performed: square, narrow and segmented floor layout, but with different COR-AGV speed to see the response and the effectiveness of the avoidance system. The speed varies from the slowest, which is 1cm/s, to its fastest, which is 25cm/s. Although the COR-AGV can move faster, this will not be effective towards performing disinfection as an optimum duration of exposure of UVC light towards the surface was needed to deactivate the virus.

Referring to Table III, it is found that theCOR-AGV obstacle avoidance system has worked effectively to almost the desired distance from the obstacle. For speed of 1,5 and 10cm/s, the COR-AGV stops and then turns at9cm distance from the obstacle, which is the desired distance of the system. For faster COR-AGV speed, 20 and 25cm/s, the COR-AGVstops and then turns slightly closer than the desired distance, which is 8cm. Nevertheless, from the data collected at the serial monitor of the Arduino board. In the various speed of the COR-AGV, the obstacle has been successfully avoided with a response time of 10ms.

V. CONCLUSION AND FUTURE WORKS

The system architecture in both software and hardware were discussed. The overall systemflowchart and the specification and the dimensioning of the COR-AGV were discussed, and then, the performance of the COR-AGVwas shownthrough its behaviour assessment. Two aspects of the system were being looked at: the disinfectant surface area covered and the obstacle avoidance system. TheCOR-AGV manages to cover most of the targeted infected area in a different floor layout setup: square, narrow, and segmented layout. In all layout, the COR-AGVUVC-Light manage to cover more than 50% of the wall surface, which was adequate as the vulnerable and risky area towards humanwas within the disinfected coverage. The obstacle avoidance system was tested and showed the intended behaviour when facing an obstacle. Before turning, the distance of the obstacle is within disinfectant range of 8cm for COR-AGV speed of 20cm/s and 25cm/s and 9cm for slower COR-AGV speeds and having a response time of 10ms.

The current implementation can be improved in many aspects, especially on the sensory system that was being used. For example, the RangeFinder sensor can be substituted with data-rich sensors that can be used to increase the accuracy ofthe systems, such as Laser Detection and Ranging (LiDAR) sensor or camera, which can generate the 2D and 3D view of the COR-AGV surroundings. This type of imaging can perform pre-path planning, which is more accurate than the obstacle avoidance system. To improve the coverage on the surface area, a longer extender can be attached to the COR-AGVsystem to reach the height required. The intensity of the UVC-Light can be increased to extend the coverage towards the surface area and reduce the time to inactivate the virus. This can be achieved using a high power supply with a larger capacity and high voltage battery, and high-powered LEDs. By improving this, the COR-AGV can perform disinfectant more effective and accurate.

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