Implementation of a UVC ligths desinfection system for a diferential robot applying security methods in indoor*

Ronald Velez Burgos[1], Andres Paredes Ruiz[1], Steven Silva Mendoza[1], Dennys Paillacho Chiluiza[2], and Jonathan Paillacho Corredores[2]

ESPOL Polytechnic University, Escuela Superior Politécnica del Litoral, ESPOL, Campus Gustavo Galindo P.O. Box 09-01-5863, Guayaquil, Ecuador
[1]Facultad de Ingeniería en Mecánica y Ciencias de la Producción - FIMCP
[2]Facultad de Ingeniería en Electricidad y Computación - FIEC, CIDIS
{rdvelez,aeparede,sasilva,dpaillac,jspailla}@espol.edu.ec

Abstract. Implementing methods that allow trajectory tracing for an autonomous robotic system is a topic that covers several fields of study since different parameters must be taken into account to locate obstacles to ensure proper navigation in environments where there is a moderate traffic of people. For this purpose, different methods of trajectory tracing will be implemented, which take as a reference the distance at which people are located. In addition, there are added human image recognition for avoid exposing people to UVC light. As a result, it can be observed that the methods implemented for the trajectory tracing give quite acceptable "pathing" results, since the main criterion to determine the efficiency is the SII, and thanks to the T265 and D435i sensors, it was possible to determine the presence of people in terms of image processing.

Keywords: Autonomous mobile robots · Robotics operating system · Social navigation · Disinfection areas · UVC Light

1 Introduction

Autonomous robots have gained a lot of popularity in the last years and not only in the industrial area, also in the different imaginable areas including the disinfection. There are some methods for disinfection like using chemicals or irradiation like UV light [15], these lights, being capable of inactivating agents at the cellular and molecular level, can inactivate viruses and bacteria, but also cause damage to cellular tissue, since UVC light according to the ISO-21348 standard is between the ranges of 100 to 280 nm[6] which is dangerous because it is in the ionizing light range, this radiation can cause damage mainly in the vision and skin, additionally this generates ozone which is considered a toxic substance for humans, so the devices that work with this type of light must

* CIDIS-ESPOL

carry the corresponding signage and must be operated by trained and aware of the dangers that may result from exposure to light and ozone generated[1].

For implementing this function there was considered some security factors because there will be an interaction between pedestrians. To guarantee that a system works correctly, the cooperation between physical systems and computer systems, the synergy between the physical system with the information network system and finally the synergy between the computer system with the information network system in order to have a correct interaction in real time[19]. Using internet as a medium of data transmission it has to be considered that it still takes a long time to take it as a reliable method since there may be problems with bandwidth, random delay times and data loss which causes poor performance in our application, the problems that can be generated when using the internet as a data transmission medium cannot be easily determined, but mainly depend on the network load[7].

Most accidents are related to failures in the recognition sensors or data loss during the operation causing collisions, a personal assistance robot does not have the strength to push a person but if there have been cases where they caused bruises, the risk is greater if it were to collide with a child[18], most of the accidents are associated with the movement of the robot either by not stopping before the minimum distance or by having sensors at a height that do not allow the detection of objects under it[8].

In this work, mechanisms are implemented to avoid exposing people to the different risks involved in implementing an AMR[1] with UVC[2] light system, during navigation to the point to disinfect a SFM[3] is implemented, once reached the goal, a trajectory planner is implemented and at the same time the image is processed to detect people in order to stop the disinfection process. Subsequently, an analysis of the effectiveness of these mechanisms is carried out by means of the SII[4], surveys and interpretation of the robot's behavior.

2 State Of Art

Nowadays exists some systems adapted to autonomous robots, for example robots that prepare samples for detection of SARS-CoV-2 [12], robots used in pharmaceutical vaccines production, robots used to disinfect areas with UV light, etc. Robots with UV system has a 99% effectiveness, due this the use of these robots will growth the 400% - 600% [17].

Most robots need techniques that allow them to navigate around a space, fortunately, today there are numerous methods that allow to efficiently plan a trajectory to be followed by a robotic system, which according to its characteristics and limitations must interact in a specific way. Some of these methods depend on factors such as the initial position of the robot, or the trajectories it

[1] Autonomous Mobile Robot
[2] Ultraviolet C
[3] Social Forces Model
[4] Social Interaction Index

traces when it moves, since the position between the initial and final points is determined based on this. All these methods are governed by a basic structure since they have to accomplish the task of moving from one point to another. Therefore, a strategy was determined that allows the development of new computational methods to be used, since they take into account the various systems that are part of a robot.

In order to reach a secure navigation there must be implemented obstacle avoidance algorithms, for a social navigation a popular model used is the SFM [9], which is based on the model proposed in [4], this is the simplest model, but the original considers effects on people, for example, attraction by another persons or objects, this generate additional potentials and also a fluctuation is added due the unpredictable behavior of an human being [5], another variation considers adding an extra force to the model in the same side of conduction convention for avoid collisions, left side for British and right side for American, this induces a force in the robot that provokes that in the major of the cases the robot pikes the defined side for pass the pedestrian [10].

In the other hand for an non social navigation there are some kinds of algorithms for obstacles avoidance, for example the "Follow The Gap Method", which constructs an array around the robot and calculates the best heading angle and at the same time considers the goal point [13], the "Dynamic Window Approach" incorporates the robot's dynamic and reduces the searching of velocities as result of having these dynamics constrains [3], the "Vector Field Histogram Method" that implements two staged of data reduction, this method identify three levels of data representation, the first one contains the description of the robot's environment, the second level construct a Polar Histogram and the last one is a representation [2].

3 Methodology

before continuing, it should be noted that this work is a continuation of [14] with the repository at `https://gitlab.com/sasilva1998/amr`.

3.1 UVC System Control Through ROS or App

To control the UVC lights system through an application, an ESP32 with micropython installed on it was used, the way to transmit the commands is through a MQTT broker, in this case there was used the shiftr.io cloud where the Publisher is the cell phone and the Subscriber is the ESP32, in the case of the Publisher, it sends the command to turn off the lights to the "stop" topic. For setting the disinfection time there was used a ROS topic that establish a connection to the MQTT broker and sends the activation time to the topic "activationTime"; it's also possible set the activation time from the App, this can be considered in case that the desired behavior of the robot not be 100% autonomous, in Fig. 1 it's represented the necessary connections for implement the system.

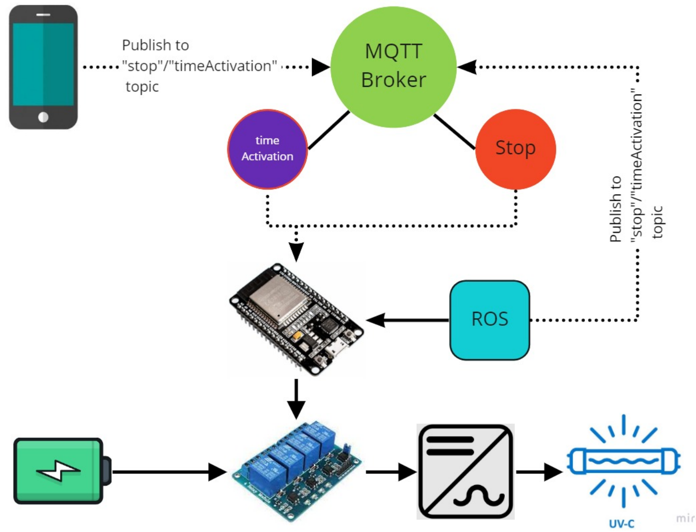

Fig. 1. Conection for the UVC lights implementation

Fig. 2. UVC System implemented in a differential robot

3.2 Navigation And Distancing From Pedestrians And Obstacles

According to the theory, four zones of social interaction are identified in human beings, intimate, personal, social and public. Other types of defined personal spaces are also mentioned, such as social distance and the peripersonal zone, but these are different concepts; it should also be mentioned that the measurement of these areas differs according to culture and age[11], as an exact value cannot be estimated, it was proposed that the The robot must not be close to the person less than 0.5m away, in order to carry out this task, a Social Force Model (SFM) is implemented which causes the point of arrival to exert an attractive force and pedestrians and obstacles generate repulsive forces while the robot is moving, this acts as an obstacle evader. To identify obstacles, the LiDAR sensor is used, with this, obstacles are identified and by means of a ROS node called `leg_detector`[5], with this the legs of pedestrians are detected and the distance they are at is estimated, also for validating human detection `darknet_ros`[6] node is used . It is worth mentioning that both people and objects are considered as obstacles and the system is established to avoid the nearest obstacle; a simple representation of the model at work is shown in Fig. 3.

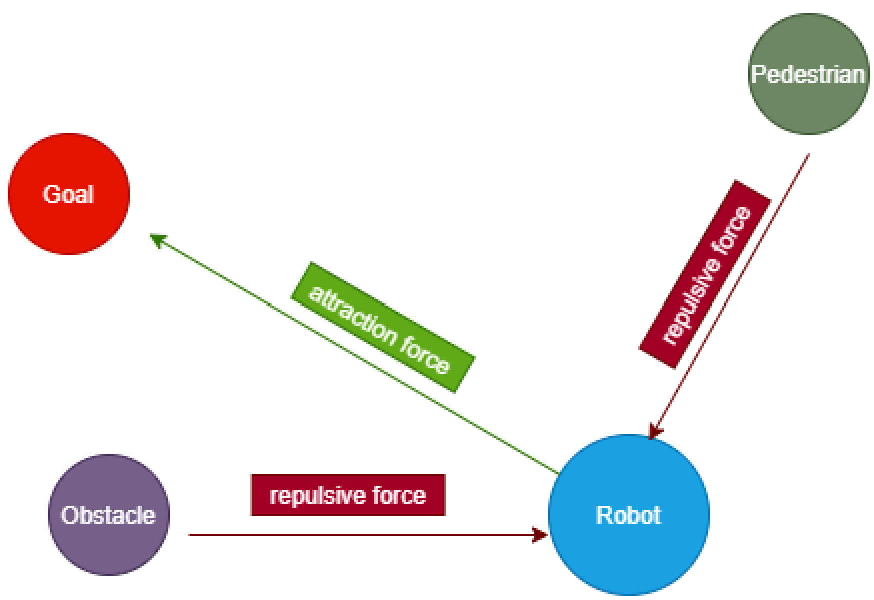

Fig. 3. Representation of the SFM at work

The model implemented is shown a continuation:

[5] *http : //wiki.ros.org/leg_detector*
[6] *http : //wiki.ros.org/darknet_ros*

$$f^{a}(t) = m \cdot \frac{1}{\tau} \cdot \left(v^{0} \cdot \hat{e} - v(t)\right) \tag{1}$$

Where m is the robot's mass, τ is the relaxation time, v^0 is the desired speed, $\hat{e}$ is the unit vector and v is the actual velocity. In other hand, the repulsion force is defined as:

$$f^{r}_{ij}(t) = \sum_{j \epsilon Q_0}^{Q_0} A_0 \cdot e^{-d_{ij}/B_0} \cdot \widehat{d_{ij}} \tag{2}$$

Taking A_0 as the intensity of the interaction, B_0 as the range of the interaction and d_{ij} is the normalized vector of the distance between the entities.

3.3 Analysis of the SII

To determine if the social navigation was successful, there was used the SII used in [16], this Social Individual Index evaluates if the robot generates uncomfortably and exposes to danger to the pedestrians, for this evaluation it's necessary determine a radius that represents the personal area of a human, in a few words this area must no be invaded by the robot, the area selected to carry on this experiment was a circle of 0.5m radius from the center of the person. The expression for the SII is shown in Eq.3:

$$SII = \max_{i=1:N}(e^{-(\frac{x_r - x_i^p}{\sqrt{2}\sigma_0^p})^2 + (\frac{y_r - y_i^p}{\sqrt{2}\sigma_0^p})^2}) \tag{3}$$

$$\sigma_0^p = \frac{d_c}{2} \tag{4}$$

Where (x_i^p, y_i^p) represents the human's position and (x_r, y_r) the robot's, σ_0^p is the d_c half, this last is a value major that the distance between the human and the robot, this value varies across cultures. Another technique used to avoid obstacles is the "Dynamic Window Approach", which evade obstacles during the disinfection process.Trajectory planning is done through a ROS node called `global_planner`[7], this computes the trajectory between the start and end point, in Fig. 4, describes the functioning of the system.

[7] *https://wiki.ros.org/global_planner*

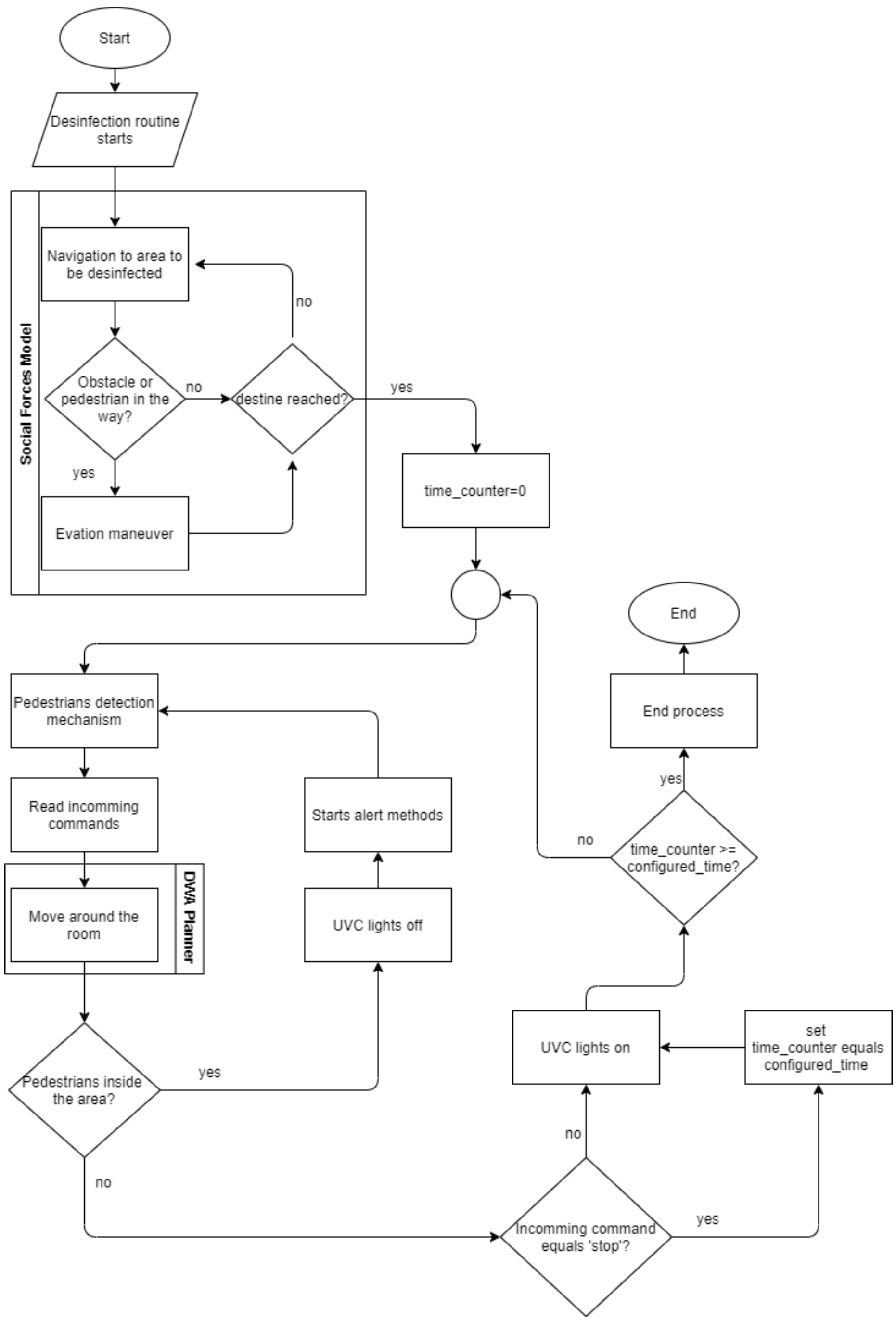

Fig. 4. Block diagram where the operation of the system is detailed

4 Results And Discussion

4.1 SII results

SII applying teleoperated method This graph (Fig.5) is the representation obtained when performing a movement controlled by an operator, in which it can be observed that the trajectory followed by the robot is linear, that is to say, it does not present abrupt changes in its movement. In addition, the "map" of the place is not disturbed due to the movements. And in the figure of the SII (Fig. 6) it can be determined that the robot does not invade the personal space of the people since it does not exceed the value of 0.5.

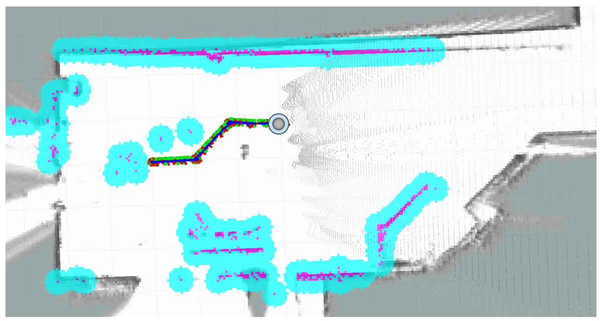

Fig. 5. Trajectory of the teleoperated method

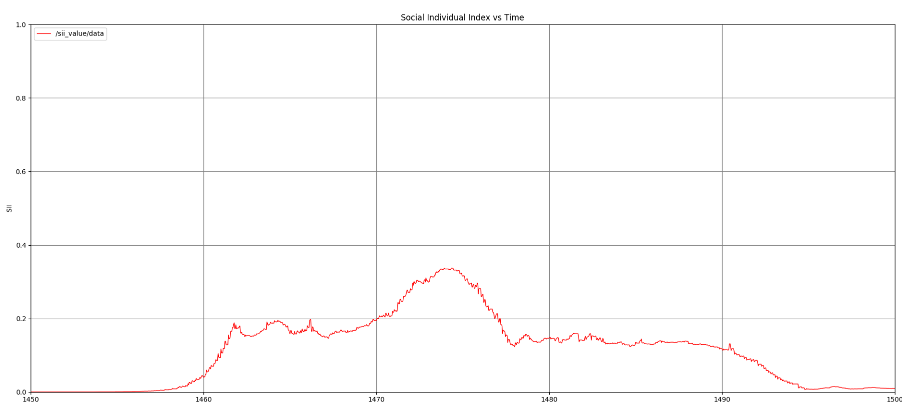

Fig. 6. SII of the teleoperated method

SII applying a planner When performing the proposed movement, the robot is able to detect the "obstacles" that may arise, which allows it to redirect its path and determine the best route taking into account the minimum safety distance, see in Fig. 7, in the graph it's observed a smooth movement. But when analyzing the SII graph it can be concluded that the robot invades the safety zone in a small space of time, see Fig. 8.

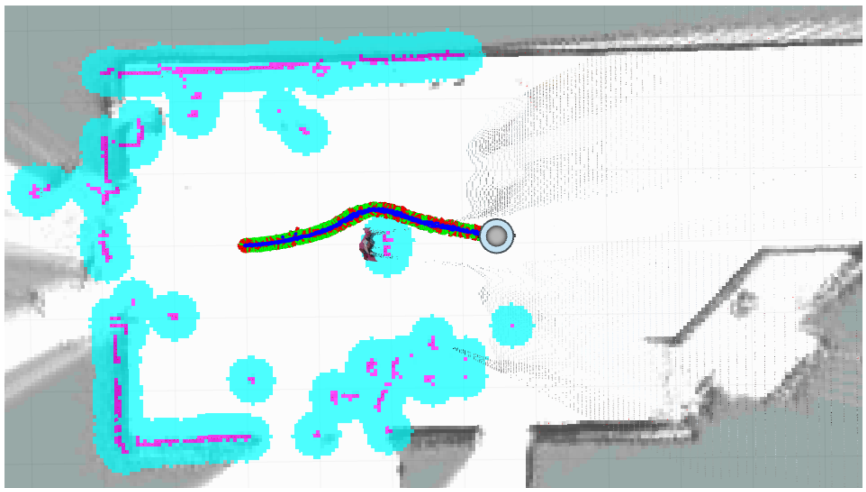

Fig. 7. Trajectory of the planner

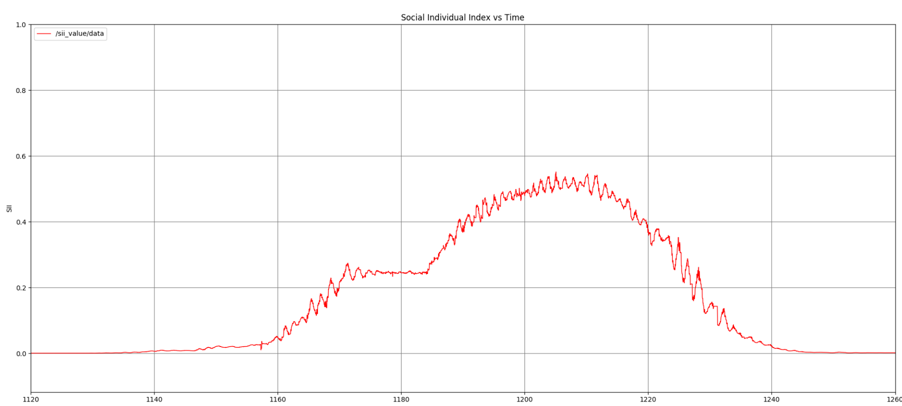

Fig. 8. SII using a planner

SII applying the SFM The results of the experimentation using the SFM are visible in Fig. 9 and 10, the first thing to take in account is that the trajectory isn't perfect a possible reason is that during the experimentation other persons were transiting the area near the robot and this may have induced another forces to the robot, the second thing to take in account is that the map is not aligned with the simulated one, the main reason is that the robot during evasion maneuvers it gets disoriented. In the other hand the SII result in Fig. 10 shows that the model worked good, there's no moment where the robot invaded the personal area of the testing agent.

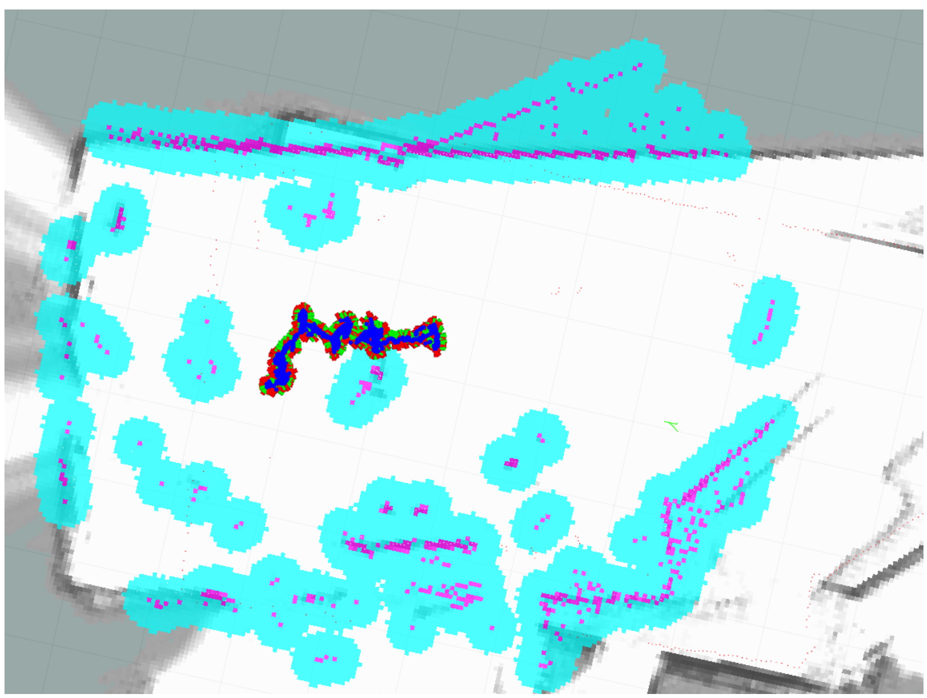

Fig. 9. Trajectory using the SMF for avoiding obstacles

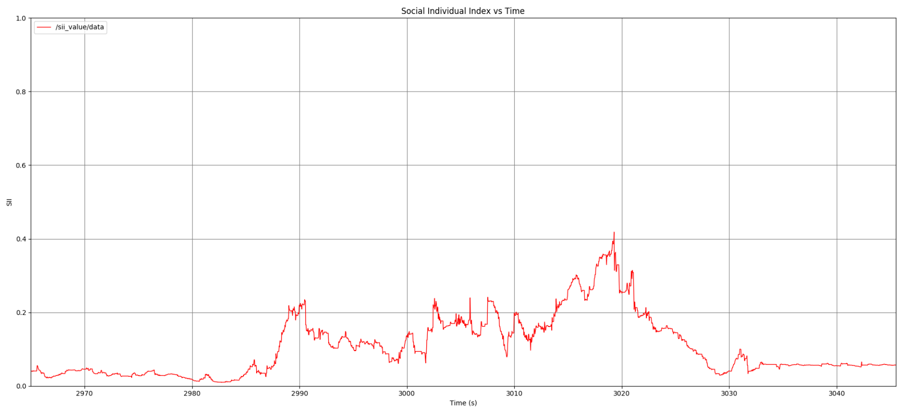

Fig. 10. SII of the SFM

4.2 Human detection during UVC disinfection

Fig. 11. Human detection during UVC disinfection

As can be seen, the 3 methods implemented allow to the robot get from an initial point to a final one, always taking into account the obstacles that may exist in the terrain, however the trajectories generated are not the same because for example in the teleoperated method the robot don't invade the human's personal area, but this can't be taken as the best option because this will always depend on human error, and there are many factors that can influence in the results, as the operator's skills, the angle of view, the mood, etc. At the planner test, it's possible to see that the trajectory is soft, this is because the planner takes the shortest path, but in this case, keep the correct distance from the human is the priority, but in this case it's supposed to work during the disinfection so it has been assumed that during this operation nobody is around the robot; and in the SFM test the robot moves in an abrupt way, but keeps the correct distance from the human. In the other hand human detection worked successfully but it's not 100 percent safer because still depends of the internet connection.

5 Conclusions

The methods implemented to determine the trajectory of the robot were able to perform the main task, which is to take the robot from one point to another, taking into account the obstacles that may occur in space. Even though the methods show different levels of efficiency as far as the SII is concerned, they still maintain the working characteristics, i.e. the map they have registered and the safety parameters. That is why the trajectories differ so much, as they have different criteria for their movement. That is why the SFM is the one that presents more changes in its trajectory, since the amount of variables to take into account is greater than the other models, it is also influenced by the model of the robot, since, being a differential robot, it presents restrictions in the movement that add more parameters that must be taken into account at the time of tracing the trajectory. Since it is used the T265 and D435i (integrated cameras) as obstacle detection methods, which allow us to obtain very accurate data in terms of mapping and detection of people, in addition to the system has a stop system which is activated when a person enters the safety space of the robot. In terms of the solutions implemented to determine the trajectories of the robot, we can determine that it is possible to trace trajectories depending on the parameters required in the movement and the assigned work space, which is obtained by mapping. Thus the robot is able to reach its final position. In the SFM the robot took several attempts to determine its trajectory, so it rotated on its own axis, this was because the space where it had to move was limited, so it was constantly redirected, this can be corrected by applying changes in the programming algorithm, taking certain assumptions that allow it to obtain more accurate movements.

References

1. Position statement on germicidal uv-c irradiation. Tech. rep., Global Light Association (May 2020)
2. Borenstein, J., Koren, Y.: Real-time obstacle avoidance for fast mobile robots in cluttered environments. In: Proceedings., IEEE International Conference on Robotics and Automation. pp. 572–577 vol.1 (1990). https://doi.org/10.1109/ROBOT.1990.126042

3. Fox, D., Burgard, W., Thrun, S.: The dynamic window approach to collision avoidance. IEEE Robotics Automation Magazine **4**(1), 23–33 (1997). https://doi.org/10.1109/100.580977
4. Helbing, D., Molnar, P.: Social force model for pedestrian dynamics. Physical review E **51**(5), 4282 (1995). https://doi.org/https://doi.org/10.1103/PhysRevE.51.4282
5. Helbing, D., Molnár, P.: Social force model for pedestrian dynamics. Phys. Rev. E **51**, 4282–4286 (May 1995). https://doi.org/10.1103/PhysRevE.51.4282, `https://link.aps.org/doi/10.1103/PhysRevE.51.4282`
6. Space environment (natural and artificial) — process for determining solar irradiances. Standard, International Organization for Standardization, Geneva, CH (May 2007)
7. Khamis, A.M., Rodríguez, F.J., Salichs, M.A.: Remote interaction with mobile robots. Autonomous Robots **15**(3), 267–281 (2003). https://doi.org/https://doi.org/10.1023/A:1026268504593
8. Kim, N., Hong, S.T., Sung, K.y., Yu, G.E., Seo, J.h.: A case study on risk assessment for personal care robot (mobile servant robot). In: 2018 18th International Conference on Control, Automation and Systems (ICCAS). pp. 343–347 (2018)
9. Kivrak, H., Cakmak, F., Kose, H., Yavuz, S.: Social navigation framework for assistive robots in human inhabited unknown environments. Engineering Science and Technology, an International Journal **24**(2), 284–298 (2021). https://doi.org/https://doi.org/10.1016/j.jestch.2020.08.008, `https://www.sciencedirect.com/science/article/pii/S2215098620308727`
10. Kumar, R.A., Vaibhav, M., Rahul, K.: Social cues in the autonomous navigation of indoor mobile robots. International Journal of Social Robotics (2020). https://doi.org/https://doi.org/10.1007/s12369-020-00721-1
11. Leichtmann, B., Nitsch, V.: How much distance do humans keep toward robots? literature review, meta-analysis, and theoretical considerations on personal space in human-robot interaction. Journal of Environmental Psychology **68**, 101386 (2020). https://doi.org/https://doi.org/10.1016/j.jenvp.2019.101386, `https://www.sciencedirect.com/science/article/pii/S0272494419303846`
12. Marais, G., Naidoo, M., Hsiao, N.y., Valley-Omar, Z., Smuts, H., Hardie, D.: The implementation of a rapid sample preparation method for the detection of sars-cov-2 in a diagnostic laboratory in south africa. PLOS ONE **15**, 1–9 (10 2020). https://doi.org/10.1371/journal.pone.0241029, `https://doi.org/10.1371/journal.pone.0241029`
13. Sezer, V., Gokasan, M.: A novel obstacle avoidance algorithm: "follow the gap method". Robotics and Autonomous Systems **60**(9), 1123–1134 (2012). https://doi.org/https://doi.org/10.1016/j.robot.2012.05.021, `https://www.sciencedirect.com/science/article/pii/S0921889012000838`
14. Silva, S., Paillacho, D., León, D., Pintado, M., Paillacho, J.: Autonomous Intelligent Navigation for Mobile Robots in Closed Environments, pp. 391–402 (04 2021). https://doi.org/10.1007/978-3-030-71503-$8_3$0
15. Tao, M., Ao, T., Mao, X., Yan, X., Javed, R., Hou, W., Wang, Y., Sun, C., Lin, S., Yu, T., Ao, Q.: Sterilization and disinfection methods for decellularized matrix materials: Review, consideration and proposal. Bioactive Materials **6**(9), 2927–2945 (2021). https://doi.org/https://doi.org/10.1016/j.bioactmat.2021.02.010, `https://www.sciencedirect.com/science/article/pii/S2452199X21000700`
16. Truong, X.T., Ngo, T.D.: Toward socially aware robot navigation in dynamic and crowded environments: A proactive social motion model. IEEE

Transactions on Automation Science and Engineering **14**(4), 1743–1760 (2017). https://doi.org/10.1109/TASE.2017.2731371

17. Wang, X.V., Wang, L.: A literature survey of the robotic technologies during the covid-19 pandemic. Journal of Manufacturing Systems (2021). https://doi.org/https://doi.org/10.1016/j.jmsy.2021.02.005, https://www.sciencedirect.com/science/article/pii/S0278612521000339
18. Yu, G.E., Hong, S.T., Sung, K.y., Seo, J.h.: A study on the risk investigation and safety of personal care robots. In: 2017 17th International Conference on Control, Automation and Systems (ICCAS). pp. 904–908 (2017). https://doi.org/10.23919/ICCAS.2017.8204353
19. Zhou, K., Liu, T., Zhou, L.: Industry 4.0: Towards future industrial opportunities and challenges. In: 2015 12th International conference on fuzzy systems and knowledge discovery (FSKD). pp. 2147–2152. IEEE (2015). https://doi.org/https://doi.org/10.1109/FSKD.2015.7382284