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EVALUATION OF THE UV-DISINFECTION ROBOT

BLUE OCEAN ROBOTICS
- for humans

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Abstract

The Ultra Violet (UV) Disinfection Robot - also called UV-DR - is an autonomous disinfection robot for hospitals, production lines and pharmaceutical companies. The robot is designed as a supplement to the existing cleaning cycle with the aim of reducing the spread of Hospital Acquired Infections (HAIs), infectious diseases, viruses, bacteria, and other types or harmful organic microorganisms.

The robot can drive autonomously while emitting concentrated UV-C light onto pre-defined infectious hotspots in patient rooms and other hospital environments, thus disinfecting and killing bacteria and virus on all exposed surfaces. The robot has been tested at one of the largest hospitals in Denmark, and the results showed that an exposure time of ten minutes can kill up to 99,9% of common bacteria found at hospitals.

Introduction

Hospital Acquired Infections (HAIs) and Healthcare Associated Infections are a major and growing problem for the healthcare system and give rise to significant costs for hospitals, primarily because of extra days in bed, readmissions, deaths, etc. (Klevens et al, 2007; Fletcher et al, 2004).

The infections typically occur in connection with the admission, examination, treatment, care or rehabilitation. The source of infection can be other patients, staff, visitors or even equipment and environments. In general, the infection rates can be prevented if the chain of infection is broken (Rutala, 2012; Greene, 2012; SSI, 2012), and studies find that UV-light can be used for disinfection (Rutala et al, 2010)

The UV-DR is developed by Blue Ocean Robotics in collaboration with leading university hospitals in Scandinavia. The robot is designed to ensure a cost-efficient and reliable measure and removal of the overall level of bacteria and viruses, and thereby increasing the operation time of the hospital, limiting the number of patient complaints and securing high quality service, better patient experience and higher success rate. The UV-DR can also be used in manufacturing production lines where a high level of compliance in disinfection is required.

The UV-DR was developed based on a tender from the Hospital Partnership with the enquiry to solve one of hospitals' biggest problems - the spread of HAIs (Sygehuspartnerskabet, 2015). Each year, approximately 50,000 Danes catch an HAI, while an estimated 3,000 people die from HAI related complications (Pedersen & Kolmos, 2007). The source of the infections can be difficult to identify, as patients, visitors, and physical objects can be transfer agents. Therefore, a comprehensive disinfection is necessary to minimize the risk of transmission and infection.

A recent study made by the World Health Organization (WHO), shows that out of every 100 hospitalized patients at any given time, on average 7 in developed and 10 in developing countries will acquire at least one HAI (WHO, 2013.) At any given time, the prevalence of HAIs in developed countries varies between 3.5% and 12%. The European Centre for Disease Prevention and Control reports an average prevalence of 7.1% in European countries. The estimated incidence rate in the United States of America (USA) was according to the same source 8.5% in 2013, corresponding to 18.2 infections per 1000 patient-days and 3.14 million affected patients.

"*The UV-Disinfection-Robot will improve and simplify the way we currently disinfect patient rooms. And by letting the robot support the cleaning, we aim to reduce the number of hospital-acquired infections, sick leave and - not least - the number of deaths due to infections acquired during hospitalization. OUH and the Clinical Microbiology Department by Hans Jørn Kolmos has all along participated in and supported the development process of UV-Disinfection-Robot, and will continue to assist Blue Ocean Robotics and the partnership Sygehuspartnerskabet with clinical expertise*" says Peder Jest, Director of Odense University Hospital.

Current Solutions vs. the UV-Disinfection Robot

There are various existing solutions, primarily in the US market, however, all are limited by a lack of flexibility, mobility and ability to autonomously position themselves in relation to its surroundings. Several of these solutions have already gained American recognition, which confirms the potential of disinfection solutions for hospitals. Therefore there is a huge unexplored potential for handling disinfection via a mobile robot solution with a UV light system that is designed specifically for disinfection of hospitals.

As mentioned there are several different disinfection solutions using light radiation, including solutions for

the healthcare sector. Nevertheless, all of the existing solutions rely on being carried around and are in no way autonomous in their use, meaning they disrupt the workflow of the cleaning staff. Also using a non-autonomous solution (for example passive robots), there is a significant waste time setting up and transporting the unit per disinfection, that must be considered as well.
The functional difference between the UV-Disinfection Robot and its main competitors is its ability to autonomously drive around and position itself optimally in relation to the infection hotspots, for example, on a bed. Because of these technological improvements, the UV-Disinfection Robot can achieve a higher disinfection efficiency and at the same time, it has a lower impact on the cleaning staff's workflow compared to existing solutions.

Figure 1 illustrates the benefits of an autonomous robot solution that can drive around in a room to avoid shadows, thereby achieving optimal disinfection.

Test & Results

The UV-DR was tested in September 2016 over a 3-week period. The test protocol was made by one of the leading and most respected microbiology groups in Europe. The test was performed at OUH (Odense University Hospital) in Odense, Denmark, and it was performed at one of the most complicated departments at the hospital: The Children's Department of Contagious Infectious Diseases. The test was divided into:

- **Disinfection test**: the disinfection test was designed for testing the efficiency of the UV-DR in the disinfection task. Various settings and cases were tested, recorded and analyzed, and more than 100 samples were used in the test.
- **User interaction test**: the user interaction test aimed to test the web interface where the user/manager managed and interacted with the robot and server. This test needed users to understand the system, test the fitness of the interaction flow, and leave suggestions and future improvement as feedback
- **AGV test**: the AGV (Automatic Guided Vehicle) test aimed at testing the existing function of mapping, path planning, and automatic movement of the UVDR to assess if the UVDR works in a hospital environment. In this test, several empty rooms were used.

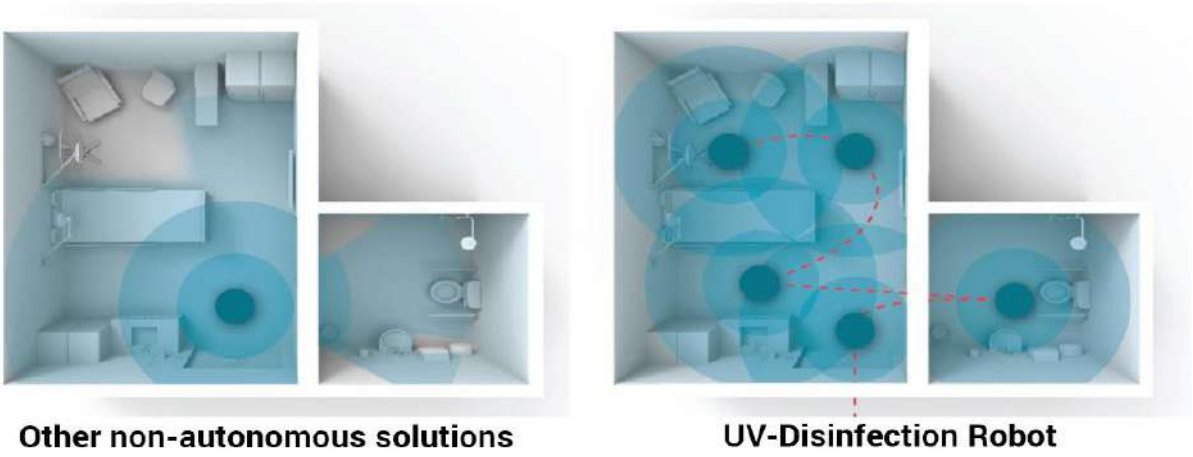

Figure 1: Passive Robots vs. the UV-DR

The staff only has to "call" the UV-Disinfection Robot (e.g. via a smartphone / tablet app) prior to cleaning, and choose which room the robot should disinfect. While the cleaning staff is doing the regular cleaning, the robot drives from its base to the ordered room. When ready the cleaning staff can let it in when they finish the regular cleaning routine. In connection to the future hospitals the UV-Disinfection Robot can use an open / close door system, which will save the cleaning staff additional time.

Disinfection test

Type of Bacteria

In the disinfection test, samples of three known hospital bacteria were used; S.aureus (Staphylococcus aureus), E.coli (Escherichia coli) and E.faecalis respectively, as these are common bacteria found in the hospital environment.

UV Dose

Distance:

The disinfection capability was measured at 4 distances:

- 1.0 meter
- 1.5 meters
- 2.0 meters
- 3.0 meters

These were the distances from the UV-DR to the bacteria samples (see figure below.)

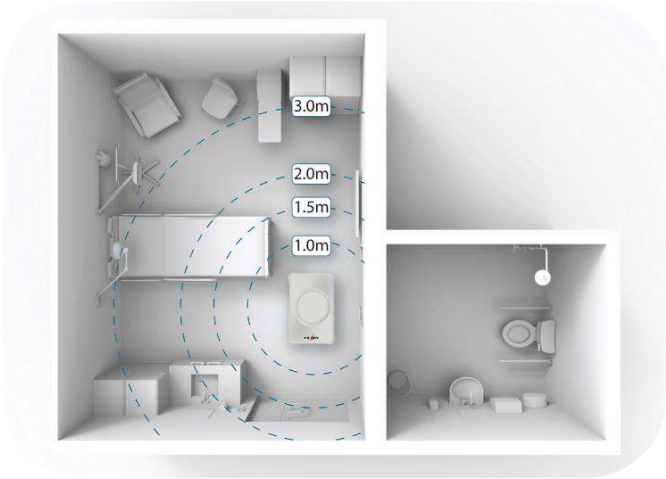

Figure 2: Test Set-Up

Radiation time:

The disinfection capability was measured at 5 time intervals:

- 20 seconds
- 40 seconds
- 75 seconds
- 150 seconds
- 300 seconds

These were the lengths of time the bacteria samples were exposed to the UV-DR's UV-light.

The Procedure

A screening of the most common types of surfaces at the hospital was performed, and Laminate was chosen since it is the most common surface in Danish hospitals. The premade bacteria suspension was inoculated on the Laminate test plates in a controlled environment. A test room at the hospital was chosen by the hospital staff, and a special door was constructed to ensure a controlled exposure with focus on credibility and repeatability.

The UV-DR was turned on in the room behind the door, so that no people were exposed to the UV-light. The test plates with the bacteria could then be placed in the custom-made door and be exposed to the UV-light using a gate and a sliding hatch, for 20, 40, 75, 150 and 300 seconds respectively.

When the distance between the robot and the test plate was changed, the robot was turned off, and placed in the new distance position, and the test was repeated. Each test setting was replicated four times to ensure reliability. This resulted in 160 measurements pr. bacteria (4 various distances X 5 various radiation times X 4 test replications x 2 (Before and After UV light exposure sample)). The Laminate plates were 10 x 20 cm and the bacteria suspension was distributed evenly over the surface. On the left side of the plate (10 x 10 cm) a swap was made before illumination and on the right side a swap was made after illumination. The swaps were then transferred to Agar plates for growth and next day evaluation was performed based on colony-forming units (cfu).

See Figure 3 for an illustration of the test procedure.

Figure 3: Test Procedure incl. active UV-DR, Laminate Test plates, and Moving of samples

All scientific experiments including counting colonies (cfu) and estimating outcome of disinfection capability was performed by the Hospital with skilled doctors and lab technicians.
The results obtained in this experiment are therefore a representation of an infected hotspot in the patient room either left with no actions taken or a surface treated with the UV-DR robot.

Results
The results shown in the results section are based on colony forming unit (cfu) conducted with and → without UV-light treatment for the variables. The test showed a significant reduction in bacteria cfu when the bacteria was exposed to the UV-light. The graphs below represent an average from each of the four replicas. A value of 0.25 cfu after treatment is a result of an average of values 0,0,0 and 1. Hospital staff did not count more than 200 in cfu due to the fact that when the number of microorganisms reach over 200 it is difficult to see and count, so a value of 200 means more than 200 (in reality it is somewhere between 200 and 500 cfu.)

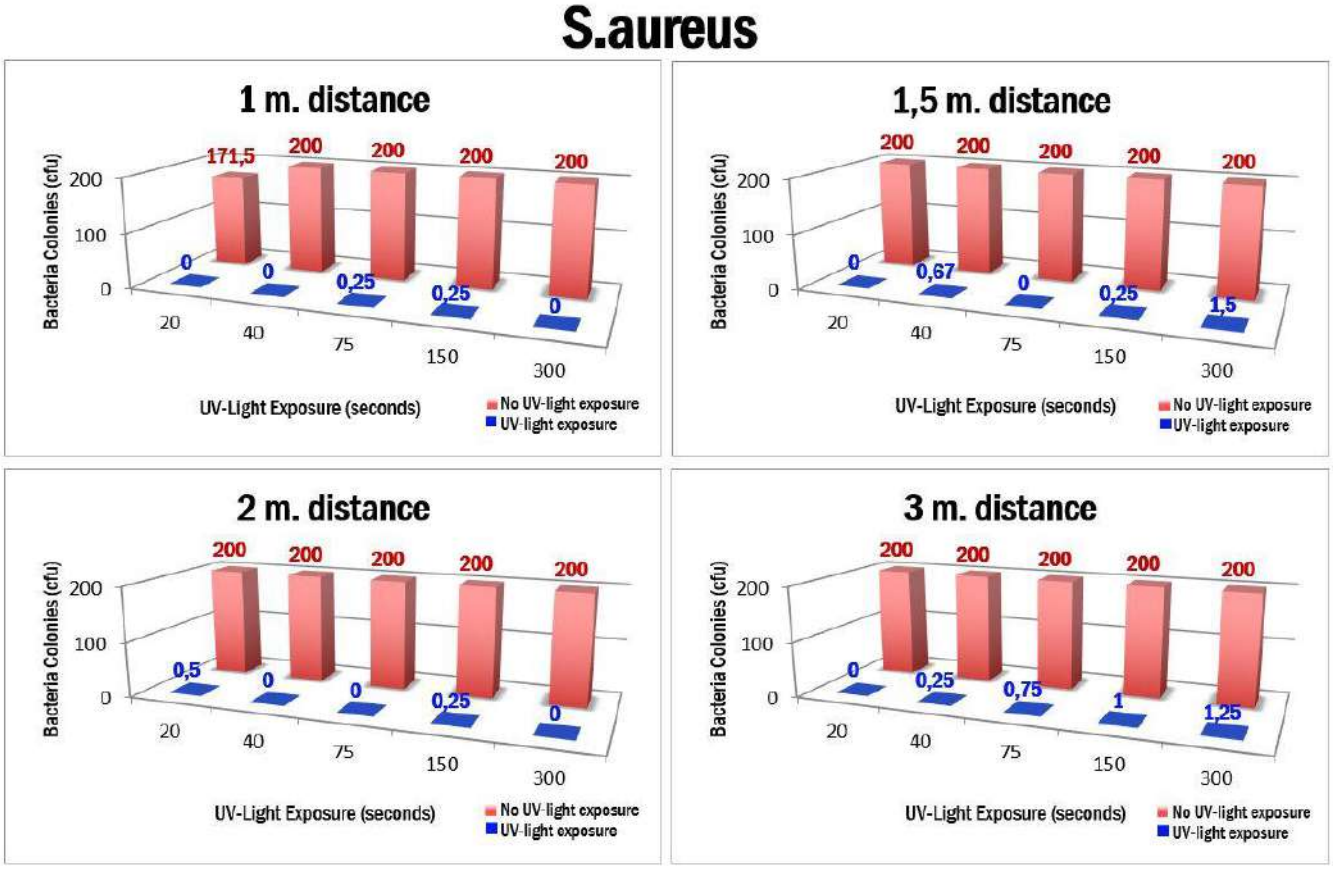

Figure 4: Results for S.aeureus bacteria level with no UV-light exposure and after UV-light exposure

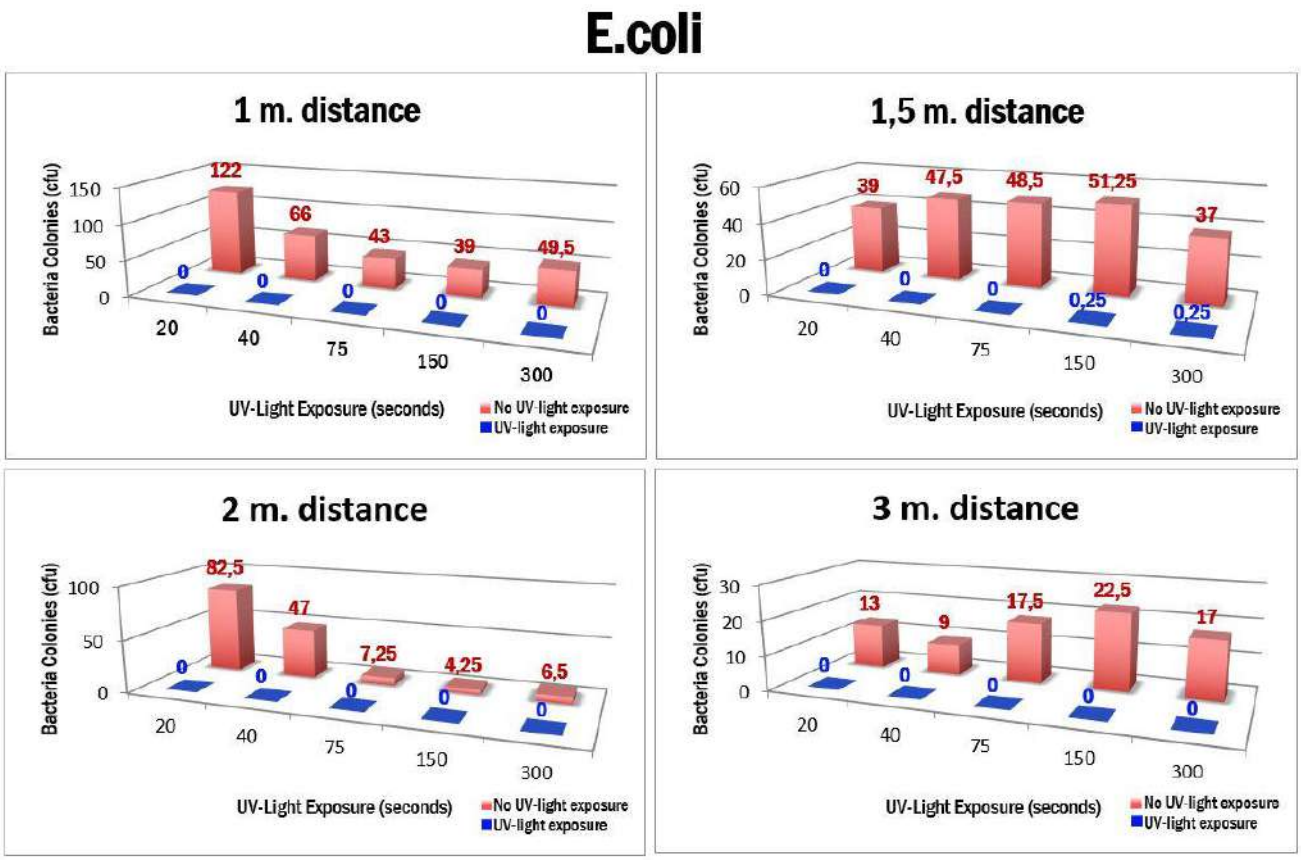

Figure 5: Results for E.coli bacteria level with no UV-light exposure and after UV-light exposure
Please note that the scales differ for this particular bacteria.

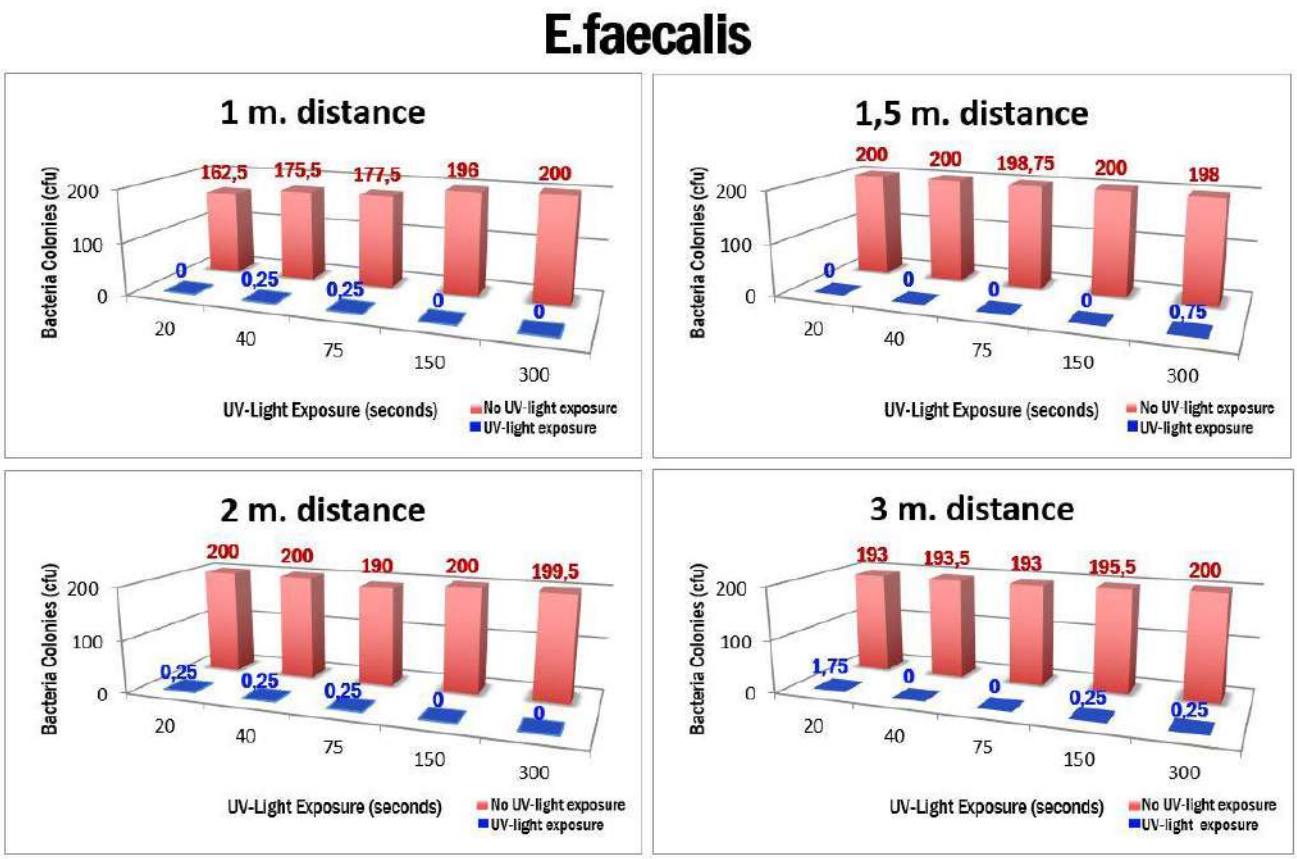

Figure 6: Results for E.faecalis bacteria level with no UV-light exposure and after UV-light exposure

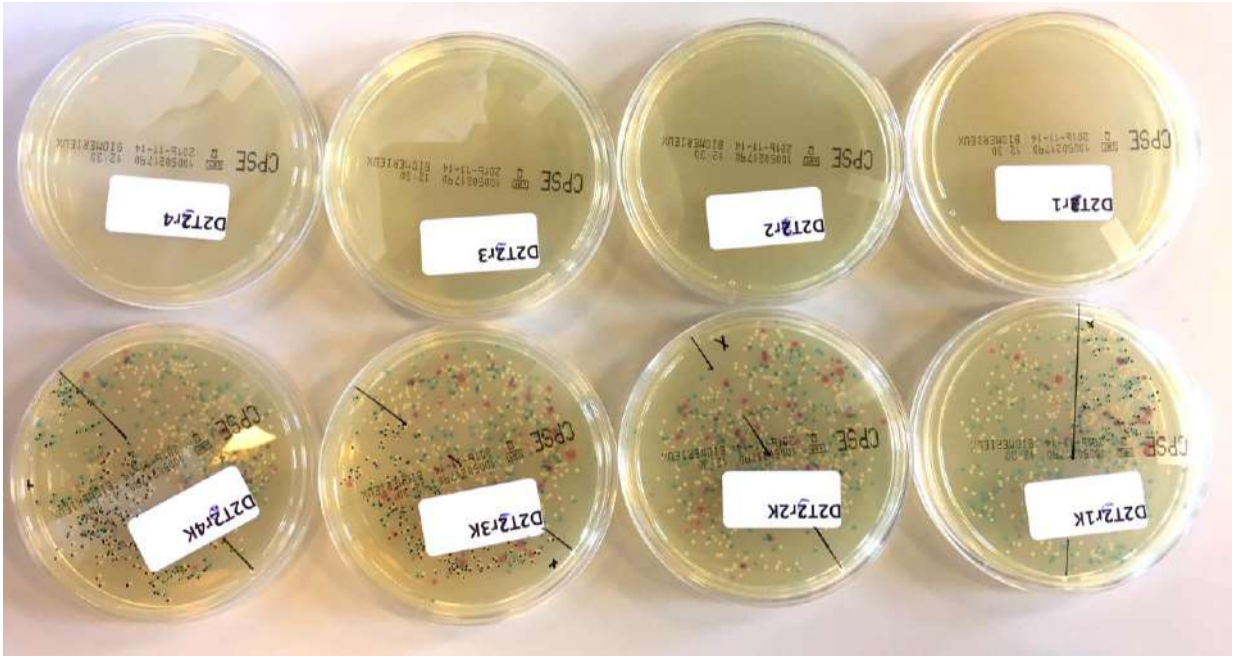

Figure 7: Four samples showing bacteria with no UV-light exposure and after UV-light exposure from a 1,5 m. distance for 75 sec. Yellow dots = S.aureus. Red dots = E.coli. Green dots = E.faecalis.

Figure 7 is an example of one test with 4 replications. The sample shows the bacteria level **prior to** UV-light exposure (bottom rows) and **after** UV-light exposure (upper rows) from a distance of 1,5 m for 75 seconds. Taking the sample second from the right, it shows a "before UV-light exposure" (bottom row) level of 200 cfu S.aureus (yellow), 72 cfu E.coli (red) and 200 cfu E.faecalis (green). It shows an "after UV-light exposure" (upper row) level of 0, 0, and 0 cfu of each bacteria respectively.
On average, this sample shows a "before UV-light exposure" (bottom rows) level of 200 cfu S.aureus, 48,5 cfu E.coli, and 198,75 E.faecalis, and an "after UV-light exposure" (upper rows) level of 0, 0, and 0 cfu of each bacteria respectively. These averages are as mentioned, illustrated in Figure 4, 5 and 6.

This particular sample shows a bacteria level of zero after UV-light exposure, meaning all bacteria was killed by the UV-DR's UV-light in the test.

A standard way of describing efficiency of disinfection is to use the log reduction value. There are two challenges in evaluating our results in that respect. The non-treatment with UV-light resulted in most of the samples being with a population above 200 cfu. Either a detailed count of cfu or a dilution protocol would increase our log value to a more correct value. Hospital staff evaluates our samples above 200 to be in the range of 200-500 cfu. In the other end of the scale we have killed all the bacteria in most of the samples. A logarithmic value of 0 is impossible. After discussions with the hospitals we have agreed to make an initial claim that our kill rate is close to log3 in our experiments conducted here. A recent study by Nerandzic et al (2015) showed a 3.1-3.5 log reduction for similar bacteria samples using UV-C light treatment, while a comparison of various disinfection sources done by Otter et al (2013) showed a possibility of 2-4 log reduction with UV-C light systems compared to pulsed xenon technologies only able to achieve 1-3 log reduction. We expect future studies with the UV-DR robot will result in archiving log values of more than 3 for the most common bacteria in hospitals including clostridium difficile.

AGV test

The purpose of the AGV test was to explore the AGV features of the UV-DR, and how it navigates in a real hospital environment. The following steps were carried out in the AGV test:

- Creating a map with different rooms, including an AGV charging room. The map in Figure 8 is a simulation of a real hospital, except smaller.
- Definition of room points from the corridor map. These were stored for later use in the UV-DR. As illustrated in Figure 9, the red marks are the rooms.

- Test of a user calling the robot to a specific room X.
- Definition of in-side-the-room disinfection points. This is shown in Figure 10
- Testing of the disinfection function.

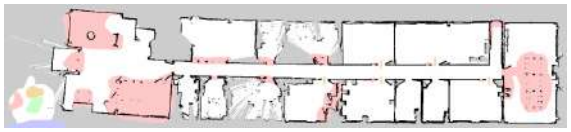

Figure 8: Map 1

Figure 9: Map 2

Figure 10: Map 3

User Interaction test

The User Interaction test aimed at testing how the UV-DR, at an early stage, performs in the given application scenario. The scenario was a single patient room with a shared bathroom. The overall interaction focused on seven areas: **1) User Experience**: collection of direct feedback from the users about their experiences with the robot system in terms of quality-of-life, user friendliness and users' questions; **2) Organization**: identification of work processes to be established in the organization in order for the robot to work effectively; **3) Competencies**: identification of knowledge gaps, where the organization's personnel needs to acquire new skills in the form of education; **4) Infrastructure**: identification of interfering factors in the building, for example technology problems such as poor Internet connection; **5) Technical Service & Support**: the setting up of appropriate training for the organization's staff and organization of the necessary services and support for the successful implementation of the robot solution; **6) Business Case**: identification and setup of parameters for a business case; and lastly **7) Hardware & Software Modifications**: identification of improvement areas on the robot on both hardware and software. Various methods were used to gather the data: the robot was tested in its natural environment and surroundings; the user interface was tested in a qualitative interview study; field research on cleaning procedures was performed, and the staff at OUH was asked about their opinions on the robot using a questionnaire. The results were discussed in three workshops.

Figure 11: Robot Navigates to the Room

Figure 12: Robot arrives to the Room

Figure 13: Check list before disinfection is started

Figure 14: Tablet Holder during disinfection

Conclusion

Both Blue Ocean Robotics and the involved hospitals in Scandinavia see a huge potential with the UV-Disinfection Robot in reducing HAIs, and providing a better hygiene standard for existing and future hospitals. The robot has been tested at one of the biggest hospitals in Denmark, Odense University Hospital (OUH) in collaboration with one of Europe's most respected microbiology groups. The test showed a significant reduction in bacteria cfu when the bacteria was exposed to the UV-Disinfection Robot's UV-light.

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