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Prototype of a Public Computer System with Fast Automatic Touchscreen Disinfection by Integrated UVC LEDs and Total Reflection †

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Abstract: Public touchscreens, such as those used in automated teller machines or ticket payment systems, which are accessed by different people in a short period of time, could transmit pathogens and thus spread infections. Therefore, the aim of this study was to develop and test a prototype of a touchscreen system for the public sector that disinfects itself quickly and automatically between two users without harming any humans. A quartz pane was installed in front of a commercial 19″ monitor, into which 120 UVC LEDs emitted laterally. The quartz plate acted as a light guide and irradiated microorganisms on its surface, but—due to total reflection—not the user in front of the screen. A near-infrared commercial touch frame was installed to recognize touch. The antibacterial effect was tested through intentional staphylococcus contamination. The prototype, composed of a Raspberry Pi microcomputer with a display, a touchscreen, and a touch frame, was developed, and a simple game was programmed that briefly switched on the UVC LEDs between two users. The antimicrobial effect was so strong that 1% of the maximum UVC LED current was sufficient for a 99.9% staphylococcus reduction within 25 s. At 17.5% of the maximum current, no bacteria were observed after 5 s. The residual UVC irradiance at a distance of 100 mm in front of the screen was only 0.18 and 2.8 $\mu W/cm^2$ for the two currents, respectively. This would allow users to stay in front of the system for 287 or 18 min, even if the LEDs were to emit UVC continuously and not be turned off after a few seconds as in the presented device. Therefore, fast, automatic touchscreen disinfection with UVC LEDs is already possible today, and with higher currents, disinfection durations below 1 s seems to be feasible, while the light guide approach virtually prevents the direct irradiation of the human user.

Keywords: touchscreen; UVC LED; radiation disinfection; staphylococci; user protection; Raspberry Pi; game

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1. Introduction

Touchscreens are already very common in our everyday lives. They can be found in smartphones, tablets, notebooks, ATMs (automated teller machines), ticket machines, and vending machines in fast food restaurants. It is expected that the importance of touchscreens will increase even further in the future, or at least that the market volume associated with them will continue to grow [1–3].

When touching touchscreens, pathogens can be transferred from the user's fingers to the display and vice versa. This makes public touchscreens or devices used by different people in particular potential carriers of infectious diseases. For example, staphylococci, which include MRSA (methicillin resistant *Staphylococcus aureus*), have been found in every scientific study to date that has examined touchscreens, alongside many microorganisms, including other known nosocomial pathogens and fecal germs [4].

The relevant microorganisms are sensitive to radiation, especially UVC, i.e., radiation in the spectral range below 280 nm [5,6]. The radiation is absorbed by the DNA and RNA of the microorganisms and thus leads to their inactivation. However, radiation with a longer wavelength, such as UVA or visible light, can also exhibit an antimicrobial impact, whereby the mechanism works via the formation of reactive oxygen species, which can destroy various structures in the cell [7,8].

In the past, it has been investigated whether the blue light emitted by a display is already sufficient for automatic radiation disinfection, but even under favorable circumstances, a 90% staphylococcal reduction took an impractical 15 h [9]. In another approach with additional lateral UVA LEDs on a glass pane, which represented a simplified touchscreen model, a 90% reduction still took more than 1 h [10]. In a technically similar setup with four 236 nm Far-UVC LEDs and a very small quartz pane, a 90% staphylococcus reduction was even achieved in 10 s [11], but Far-UVC LEDs currently cost several hundred Euros each and have a service life of only a few hundred hours. Therefore, Far-UVC LEDs are not yet suitable for realistic large-scale use for automatic touchscreen disinfection.

Therefore, the aim of this study is to develop a prototype of a public computer with a touchscreen that can already be used by different people to play games in a short time and that can quickly disinfect itself between two users with the help of small, inexpensive, and long-lasting UVC LEDs. The prototype presented here with lateral UVC LEDs on a front quartz plate is based on total reflection within the quartz plate, similar to the UVA and Far-UVC approaches presented above [10,11]. The user in front of the touchscreen is not irradiated directly. At the position where microorganisms are located on the quartz plate, there is no total reflection and the microorganisms absorb the UVC radiation and damage their DNA in the process. In contrast to the presented UVA approach, the UVC LED variant is expected to disinfect much faster and be cheaper and more durable than the Far-UVC approach. The antimicrobial effect is tested using *Staphylococcus carnosus*, a bacterium that has a similar UVC sensitivity to the dreaded *Staphylococcus aureus* [12].

2. Materials and Methods

2.1. Hard- and Software

The computer system selected here was a Raspberry Pi model 4B from the Raspberry Pi Foundation (Cambridge, UK) to which a 19.5-inch LED monitor type E2020H from Dell (Round Rock, TX, USA) was connected. Above this display was a quartz plate with dimensions $472 \times 300 \times 4$ mm^3 from Glas Seitz (Wertingen, Germany). The quartz plate only rested on the edge and was otherwise separated from the monitor by a small air gap. For touch recognition, an additional 19-inch commercial NIR touch frame from Touchsolutions24 (Waldems, Germany) was installed above the quartz plate and connected to the Raspberry Pi via USB.

Around the edge of the quartz plate, 120 UVC LEDs of type C3535DUVC-QB-Q5-D (Luckylight, Shenzhen, China) were mounted on a printed circuit board, with a distance of approx. 12.5 mm between neighboring UVC-LEDs. The distance between the LEDs and the quartz plate was 0.5 mm, and the LEDs emitted their UVC-radiation laterally into the quartz plate (Figure 1).

Each 275 nm LEDs emitted approx. 5 mW at an angle of ±60° under a current of 40 mA. A maximum single LED current of 50 mA was permitted by the manufacturer. (This type of LED also had a built-in UVA emitter, which was not employed in this prototype.) Electrically, three UVC LEDs were always connected in series and 40 of these three-unit arrangements were operated in parallel. The theoretically maximum possible total current was therefore 40×50 mA = 2000 mA. Most experiments were later carried out with only 1% of this maximum current, i.e., 20 mA.

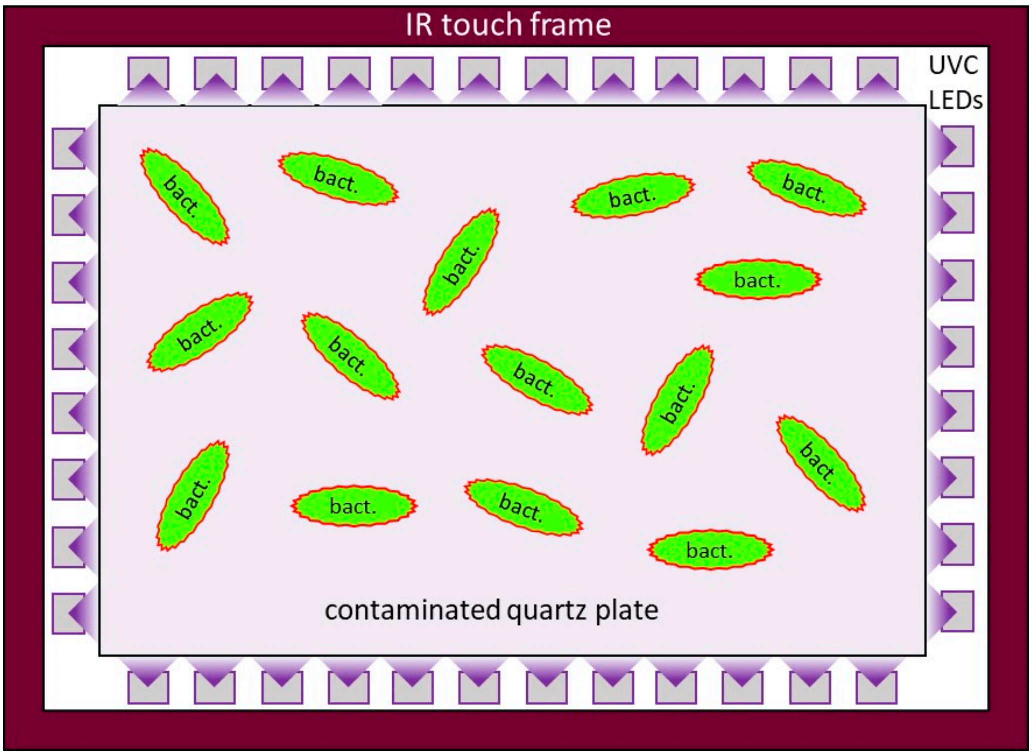

Figure 1. Schematic top view of the setup with quartz plate, touch frame, and UVC LEDs.

The quartz plate, with the medium air at the top and bottom, acted like a light guide for the LED radiation due to the total internal reflection. The radiation therefore remained in the quartz pane as long as the total reflection was not canceled out by contamination (Figure 2). The UVC radiation was switched off when a touch was recognized.

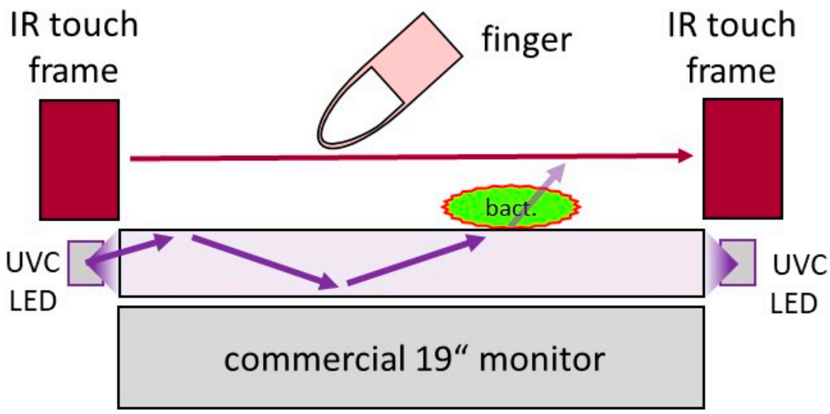

Figure 2. Schematic cross section of the setup with commercial monitor, bacterial contaminated quartz plate, touch frame, and UVC LEDs. The LEDs were switched off when a touch was recognized.

Ideally, the user in front of the display should not receive any UVC radiation because of the light guide effect, but due to the contamination and the subsequent lack of total reflection, a small proportion of the UVC radiation escaped in the direction of the user. The resulting 275 nm irradiance at a distance of 10 cm to the intentionally contaminated display was measured with an optometer type X1 from Gigahertz-Optik (Türkenfeld, Germany). The European Directive 2006/25/EC (on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents) and the American Conference of Governmental Industrial Hygienists permit a daily irradiation dose of approx. 3.1 mJ/cm^2 at 275 nm [13,14], from which it was possible to calculate the permissible duration of the user's stay in front of the touchscreen prototype.

The demonstration software running on this computer was a small game programmed in Python version 3.X (Python Software Foundation, Wilmington, DE, USA). The player was always given a choice of 4 geometric objects in 4 different colors and had to tap the correct field as quickly as possible. The game idea was developed based on ideas presented in [15]. Each time the player changed, the display was disinfected for 25 s at a current of 20 mA. If a new player touched the display before the disinfection time had elapsed, the disinfection was stopped to prevent the user from being irradiated.

2.2. Microbiology and Data Analysis

The test organism selected was *Staphylococcus carnosus* (*S. carnosus* strain DSM 20501 of the German Collection of Microorganisms and Cell Culture DSMZ, Braunschweig, Germany), a non-pathogenic relative of *Staphylococcus aureus* with a very similar UVC sensitivity [12]. It should be mentioned that many other pathogens that are frequently found on touchscreens like *Bacillus* spp., *E. coli*, *Klebsiella* spp., *Streptococcus* spp., *Corynebacterium* spp., and *Acinetobacter* spp. exhibit similar or even higher UVC sensitivities than staphylococci [4].

S. carnosus was propagated at 37 °C in trypticase soy yeast extract medium [16] until an optical density of 0.5 at 600 nm was reached. The bacteria were then washed in PBS (phosphate-buffered saline) and sprayed onto the touchscreen, which had previously been disinfected with 70% ethanol, using a home-built device [17], resulting in bacterial concentrations of about 10^6 *S. carnosus* per square centimeter. These chosen concentrations were far above the concentration of ten to several hundred bacteria/cm^2 that were really observed on touchscreens [4], but allowed the authors to investigate the potential of this approach.

The Eswap kit from Copan (Brescia, Italy) was applied to determine the surviving staphylococci on the quartz surface [17]. The screen was first divided into 7 × 5 fields, each measuring 4 × 4 cm^2, and a random sampling sequence was determined. At the start and at each scheduled irradiation time (usually every 5 s), 3 fields were sampled with the Eswap kit. This procedure was repeated three times in three independent runs (biological replicates). For each point of time (0 s, 5 s, 10 s, 15 s, 20 s, and 25 s) and the unirradiated control, the three fields were sampled (technical replicates) and diluted at least three times, before 33 µL of each resulting bacterial solution—from the different runs and sample fields—were plated on trypticase soy yeast extract (M92) agar plates. This resulted in a total of about 200 agar plates (3 × (6 + 1) × 3 × 3). After 24 h in a 37 °C incubator, the emerging colonies were counted.

3. Results

3.1. Hard- and Software

The LEDs were operated with total currents of 20 or 350 mA. These were 1% and 17.5% of the maximum permissible current. The measured 275 nm irradiance was 0.18 and 2.8 µW/cm^2. Based on the above-mentioned standards, it was possible to calculate permissible exposure times of 287 and 18 min in front of a continuously UVC-emitting display. However, these irradiation durations were never achieved in reality, as the UVC LEDs were only ever switched on for 25 s or less.

The programmed game worked and, as intended, a 25 s disinfection took place when changing players, as illustrated in Figure 3.

Figure 3. Example screen shots from the game and the subsequent disinfection.

3.2. Microbiology and Data Analysis

At 20 mA or 1% of the maximum current, the average bacterial reduction presented in Figure 4 at 5 s intervals was observed on the screen previously contaminated with *S. carnosus*. The course was exponential, with a reduction by a factor of 10 every 7 s. After 25 s, the bacteria were reduced by more than 3 log levels or by 99.97%. In experiments with a higher current of 350 mA or 17.5% of the maximum current, no staphylococci were detectable after 5 s.

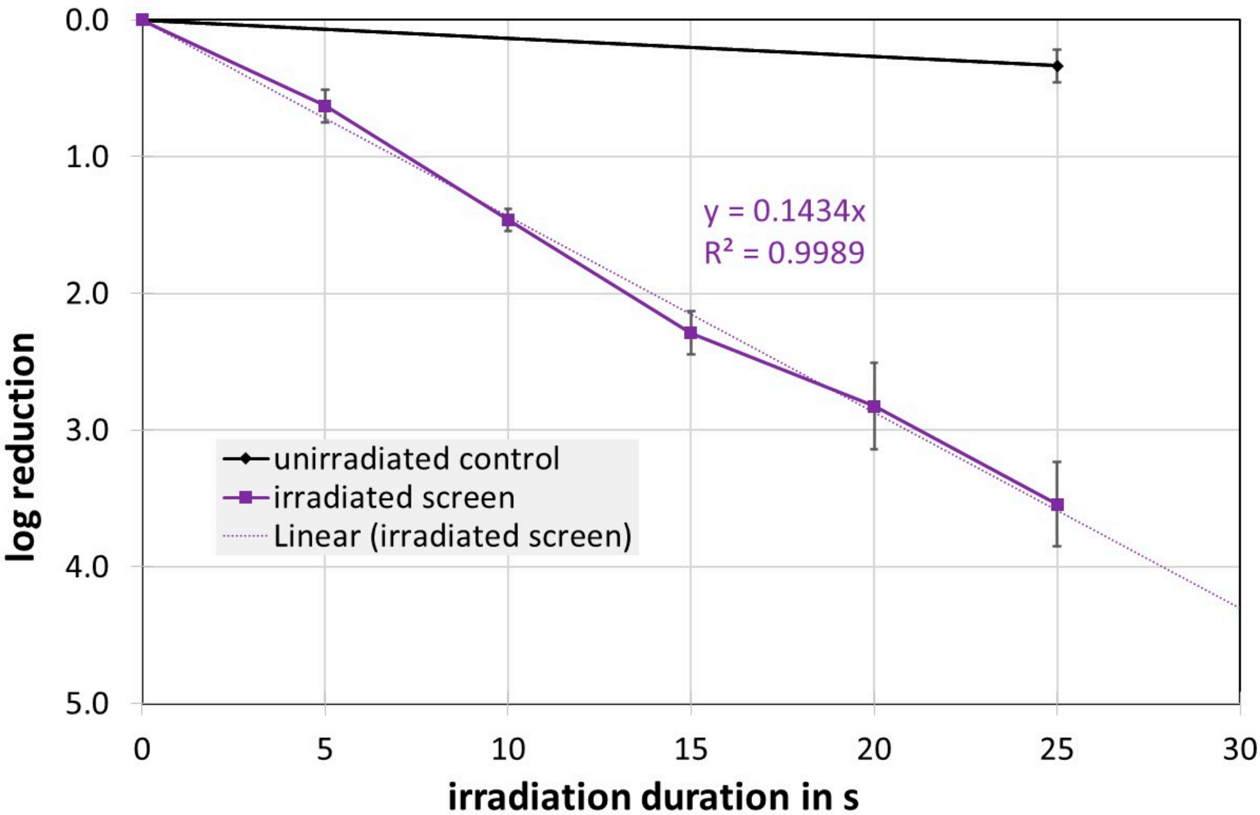

Figure 4. Average staphylococcus reduction with 20 mA LED current in half-logarithmic representation. The error bars give the standard deviation of the single runs, while the linear trend line illustrates the exponential character of the bacterial decrease.

4. Discussion

The irradiation results demonstrate a rapid reduction in *Staphylococcus carnosus* of 99.97% within 25 s at only 1% of the maximum possible LED current and thus approximately the maximum possible LED power. Since *S. carnosus* has roughly the same UVC sensitivity as the feared *S. aureus* [12], it can be assumed that this important pathogen is also significantly reduced in this short time. Similar or even higher UVC sensitivities were also observed for many other skin inhabitants and thus potential microorganisms on touchscreens [4], so that their reduction can also be assumed. In the microbial experiments, a reduction of more than 3 orders of magnitude was achieved in 25 s. For the observed bacterial concentrations on touchscreens of ten to several hundred bacteria per square centimeter [4], this would lead to a mostly sterile touchscreen after these 25 s.

These disinfection results were achieved with only a fraction of the available UVC power. This opens up two possibilities. The same disinfection success could probably be achieved with higher LED currents in less than one second or a significantly reduced number of UVC LEDs could be installed.

Despite this strong antimicrobial effect, the touchscreen operator is not endangered by the UVC radiation. This is partly due to the fact that hardly any UVC radiation is emitted from the light-conducting quartz screen, UVC radiation is only on for 25 s or less, and UVC radiation is switched off when the user touches the screen.

This proves that fast, automatic, and safe touchscreen disinfection with UVC LEDs is already possible today.

5. Study Limitations

These investigations were carried out in the laboratory with bacteria that were sprayed onto the touchscreen. In reality, contamination occurs via fingers, and not only microorganisms but also other contaminants such as dirt or grease are transferred. The effects of these contaminants are still uncertain.

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Conflicts of Interest: M. Hessling has filed a German Patent application on surface disinfection in 2020 (DE102020116262A1). Helge Moritz was employed by the company Büchner Lichtsysteme GmbH. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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