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Clean-AR: Using Augmented Reality for Reducing the Risk of Contamination from Airborne Disease Agents on Surfaces

Abstract: A core principle of modern health care is the compliance of hygienic and aseptic techniques in areas that are sensitive to contamination through bacteria, dust, aerosols, and fallout, primarily in operating theatres or around patients with contagious diseases. Keeping track of potentially contaminated surfaces in an environment is a major concern, especially when protecting from COVID-19. This work proposes a novel concept in using 3D sensing technology to track human movement within an indoor area and identifying high-risk contaminated surfaces in real-time. It combines recent Augmented Reality display technology, which allows keeping track of decontaminated surfaces during the cleaning process using an interactive visualization method. The proposed concept of *Clean-AR* is implemented in a clinical environment used for observation in COVID-19 scenarios. We discuss key challenges and outline further research direction in effectively reducing the risk of contamination using the proposed concept.

Keywords: head-mounted displays, augmented reality

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1 Introduction

Airborne diseases and contagious viruses are often transmitted via frequently used fomites, e.g. furniture, in indoor environments, and therefore, surface decontamination is an essential process for reducing the risk of contracting infections [1-3]. However, common sources of errors are overlooked surfaces or surfaces infrequently cleaned due to human error or negligence [4]. To tackle this problem, a visual feedback system would improve awareness of contaminated surfaces and direct focus during a manual disinfection process. A similar suggestion has been made in the domain of asepsis [5], a field that specializes in preventing infections caused by bacteria and viruses. Medical practices have improved dramatically in recent decades, but aseptic techniques are rarely investigated for improvement. Healthcare-associated infections occur when the rules of asepsis are violated during invasive procedures, diagnosis, or treatment of a patient and can result in health-threatening consequences for both the patient and the medical staff. For instance, the strict rules of asepsis require constant awareness of one's actions within a clean or sterile area, which even experienced nurses may unintentionally violate [6]. The principles of asepsis can be applied to facilities that handle infectious diseases. Similar to airborne and touch transmission, a person can transfer infectious agents to nearby surfaces, which then can cause secondary infections.

In this work, we propose a concept that monitors patients and generates visual indicators based on their movements and suggested airflow from breathing within an indoor environment using 3D sensing technologies. The indicators can be seen using an Augmented Reality (AR) head-mounted display (HMD) to identify and allows a user to sterilize areas that are contaminated by potentially contagious patients. We present our implementation, calling it *Clean-AR*, and deploy the system in a research laboratory for diagnosing potentially infectious COVID-19 patients [7].

2 Related Work

The number of works in digital hazard monitoring combining AR visualization is limited. For instance, Grayston et al. [8] identified common errors in aseptic techniques observed in medical students and developed *ARSterileSim* for tracking

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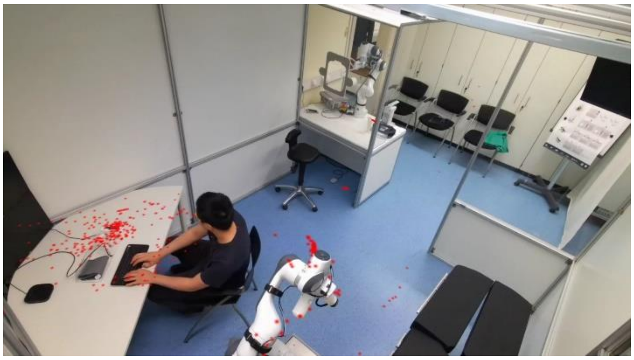

Figure 1: Phase 1 of *Clean-AR*: Contamination. A potentially infectious patient enters a disinfected environment for a medical examination. *Clean-AR* monitors the patient's movements and uses a real-time particle simulation to indicate contaminated areas with virtual red dots. A cleaning staff then enters the room and sterilizes contaminated areas.

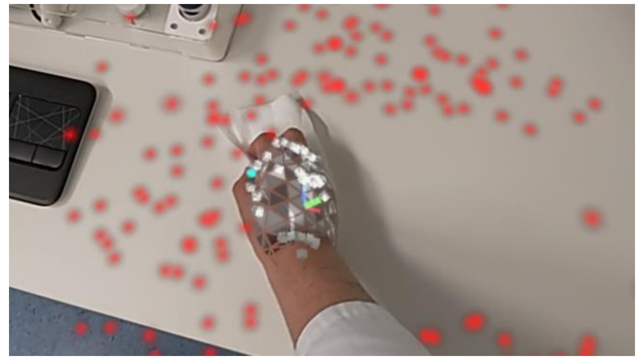

Figure 2: Phase 2 of *Clean-AR*: Cleaning. Computer-generated red dots as seen by the user wearing the head-mounted display. They indicate contaminated areas that can be removed in real-time by cleaning the area by hand. The visual feedback provides cleaning personnel with information about areas at higher risk of contamination.

sterile and non-sterile objects using visual feature-based markers. Furthermore, work was done on radiation sensitization in the vicinity of X-Ray devices such as a C-Arm using AR [9-11]. To our knowledge, no work has yet been published on monitoring human movement to identify potentially high-risk contaminated surfaces by infectious bacteria or viruses and combining such data for in-situ visualization in AR.

3 Method

We present a method for a non-contact and optical solution to track human movements to mark contaminated surfaces on the room geometry dynamically. As seen in Figure 4, the room is reconstructed by an RGB-D camera and the spatial map of the head-mounted display. The latter is generated by Simultaneous Localization and Mapping (SLAM) and provides a coarse 3D representation that is used for self-localization with 6 degrees of freedom.

Our *Clean-AR* system works in two phases in this particular order: (a) Patient monitoring: Human movements are translated into indicators visualized by red dots particles and represent areas which the patient potentially contaminated (see Figure 1). (b) Cleaning phase: Cleaning staff enters the room wearing an AR HMD after all patients have left the room. Staff can see the markings inside the room with in-situ AR visualizations (see Figure 2).

The cleaning staff disinfects contaminated areas with AR particles and removes them from the system at the same time. The removal algorithm tracks the cleaning staff's hands holding the disinfecting wipe and removes all contamination particles within a specified local radius. In the first phase, monitored patients are not required to wear the HMD. Therefore, the requirements for the system are functional body tracking and spatial reconstruction, even when no HMD is connected to provide tracking or spatial information. Hence, all calculations related to body tracking, particle simulation, and collision with 3D reconstruction are performed on a PC workstation. While an HMD is connected, the workstation only transmits the positions of the particles to the HMD client via the local network.

3.1 Technical Specification

We chose the Azure Kinect as the RGB-D camera because its SDK enables human body tracking consisting of 31 joints. The camera is configured to deliver a color stream (BGRA32, 1080p) and a depth stream (uint16, NFOV_Unbinned) at 30 fps. A laptop (Model: MSI GL63 85E, CPU: Intel(R) Core(TM) i7-8750H, GPU: NVIDIA GeForce RTX 2060, 16GB RAM) is connected to the Azure Kinect camera, processes the body tracking data and runs the central components of the system. The computations are performed within the Unity/C# game engine, which simultaneously manages TCP/IP server-client network communication with the HMD. For visualization of the contaminated areas, we chose the Microsoft Hololens 2 as the optically see-through AR HMD. We conceived this choice as the most appropriate device currently available, as the Hololens 2 incorporates SLAM, hand tracking, and QR marker tracking, which are also integrated in our implementation.

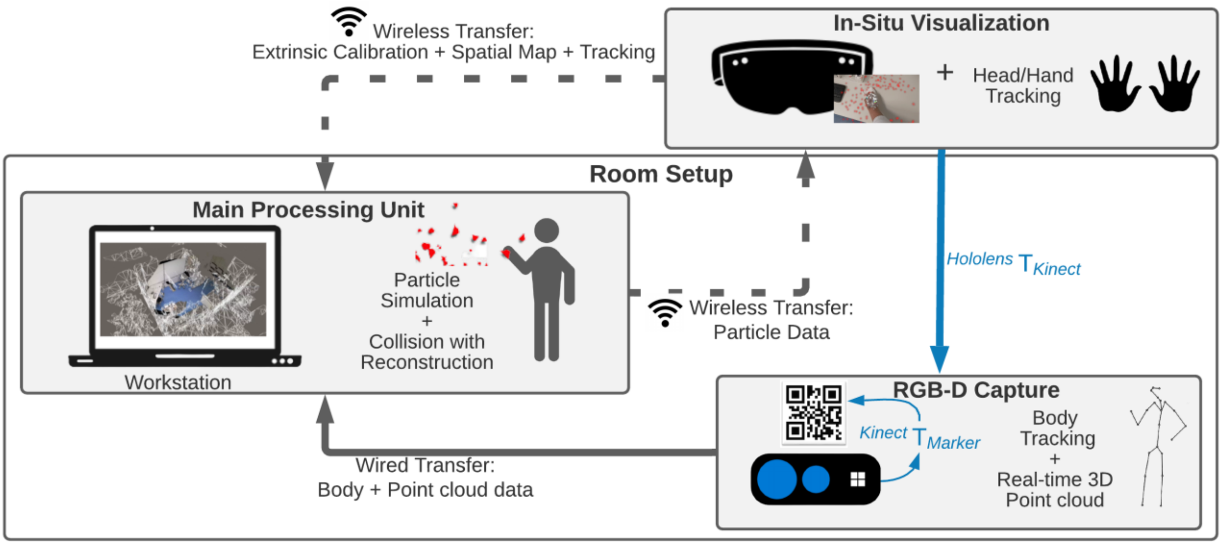

Figure 3: System Setup of *Clean-AR*: For the simulation of contaminated particles caused by a patient, Clean-AR requires at least a workstation and an Azure Kinect. The workstation takes over heavy computations such as the simulation of particles and their collision with the room reconstruction. A Hololens 2 can be connected to the system to allow more accurate hand and head tracking. For the cleaning phase, the Hololens 2 is required to visualize the contaminated fomites and the real-time cleaning feedback.

3.2 Implementation

The following paragraphs describe the four central components of *Clean-AR*. The relation between components can be seen in Figure 3.

Extrinsic Calibration

We calibrate the HMD with an optical marker that is rigidly attached to the depth camera and use the natively supported QR marker tracking of the Hololens 2. Subsequently, we apply a rigid transformation to the detected pose of the marker to estimate the pose of the camera within the world coordinate system of the Hololens 2. Figure 5 shows the detected marker alongside the final camera pose. The contents generated by the camera are positioned in the relative coordinate system of the camera.

Extrinsic Calibration

Human movements are detected by the Azure Kinect SDK, which are estimated by machine learning algorithms applied to the deep stream. When a Hololens 2 is connected to *Clean-AR*, both head and hand tracking are adopted instead of Kinect body tracking due to the higher tracking precision and the working area outside the Kinect's field of view.

Computation of Contamination

The contamination of surfaces is abstracted through simulated floating particles that can collide with the virtual reconstruction mesh of the environment. We transfer a rule of asepsis that establishes that non-sterile objects above a sterile area render the area non-sterile due to fallouts, such as dust, human skin, hair particles, or bacteria. This is represented in *Clean-AR* by marking surfaces beneath the patient's hand as contaminated due to potential fallout. Secondly, in the presence of airborne diseases, *Clean-AR* simulates the direct out-facing breath of the patient. While airborne, these particles fly into a defined direction at a constant speed. For instance, fallout particles are only flying downwards until they hit a surface, while breath simulating particles fly in the direction the head was facing and continue to be affected by gravity such that their actual flying path is curved downwards. We implemented a maximum flying distance of 50 centimetres until the particles are destroyed if they have not collided with the 3D reconstruction.

Reconstruction of the Environment

The particles representing the contamination must interact with the environment to mark surfaces as contaminated. Therefore, a virtual representation of the real environment is required to perform collision detection with such particles. In our implementation of *Clean-AR* we use real-time captured environments to perform collision detection with the particles to

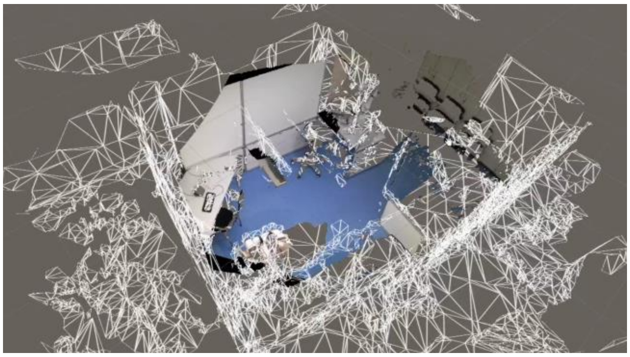

Figure 4: Combined 3D Reconstruction for Collision Handling of contamination particles. Colored areas are computed from the Azure Kinect camera. The area shown as wireframe are computed by the Spatial Map of the Hololens 2.

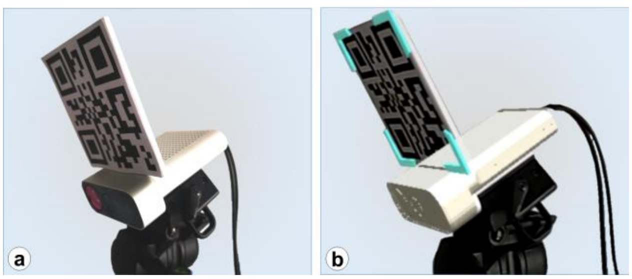

Figure 5: RGB-D Camera with Calibration Marker for extrinsic calibration with the head-mounted display. (a) Real view of the camera setup. (b) View on AR overlay of the QR marker and the camera pose. Detected and captured by the Hololens 2.

respond to dynamic changes in the scene. The implementation of the concept is not limited to the following methods, and additional options are discussed in section 4. Both presented devices, the Kinect and the Hololens provide sufficient data for 3D reconstruction independently. The difference is most notably in their geometric fidelity and update rate. The Azure Kinect captures real-time depth images, which are converted to a 3D representation using its intrinsic parameters. Additionally, the depth information of users is removed from the environment reconstruction using the provided body masks of the Kinect to prevent particle collision on the patient. For our setup, we rigidly mount the Kinect on the ceiling facing downwards such that it covers most of the environment with its field of view. The resulting point cloud inhibits holes due to occlusion for which no environmental data exists. One solution could involve the usage of multiple RGB-D cameras looking at the scene from multiple perspectives, similar to [12]. To simplify the calibration process, we instead combine the accurate reconstruction of the Kinect with the slower updating Spatial Map of the Hololens 2. The Spatial Map fills up the remaining holes to create a holistic representation of the environment. Figure 4 shows both methods combined into a shared calibrated space. For the first phase of *Clean-AR* we recommend synchronizing this spatial mesh, with only immobile furniture in the scene, at least once beforehand with the processing workstation for complementing missing surface information.

4 Discussion

The following paragraphs discuss not covered points yet but are essential for future extensions to our proposed concept.

The simulation of the contaminated particles is based on few assumptions, mainly including the heavy role of aerosol, fallout, and the direct contact responsible for transmitting contagious diseases over surfaces. We presented a simplified particle simulation model. The particles fly mostly in an initial direction, which is then affected by gravity pull and stick to the first surface they contact. Realistic particle simulations consider the spatial propagation of aerosols within the air. They will likely reveal a larger area of contamination compared to our model since the airflow would transport particles to broader areas. Sophisticated models exist, including methods using computational fluid dynamics for aerosol propagation in a closed room [13], and could replace our simulation model. Depending on the complexity of the method, calculation of contamination may have to be done post-recording of human movements rather than in real-time.

Based on our experience with the implementation, a reconstruction without holes is more desirable than geometric fidelity since holes exclude a real-world surface from being marked as contaminated. This is because simulated particles would never collide with them in virtual space. There are several approaches to 3D reconstruct environments. Geometric data can be accumulated and refined over time (e.g., SDF-based approaches [14, 15], SLAM [16, 17], LiDAR-based [18]) or generated per frame based on depth images acquired from cameras in real-time [12, 19]. The latter method is prone to holes and noise caused by occlusion and surface reflection but can represent real-time changes in the scene, therefore, being able to react to newly introduced or moved furniture. 3D reconstruction could further undergo a hole-filling algorithm [20] in trade for its real-time capability. Related is the tracking of objects to translate contamination along with the objects. For example, Tan et al. [21] present a method to track objects within a depth image generated point cloud. For full coverage of potentially contaminated surfaces, further approaches should be able to track indoor move-able objects and furniture.

5 Conclusion

We proposed the novel concept of using body tracking and 3D reconstruction to identify contaminated surfaces in an environment where patients with infectious diseases reside. Using Augmented Reality, we visualize contaminated surfaces in-situ in the real environment. Few more steps are required for our implementation to cover the behaviour of harmful particles realistically; however, we believe that AR is an immense addition for identifying contaminated surfaces in a more targeted and efficient manner. In future work, the principles of *Clean-AR* can be adapted with aseptic techniques and aiding in the identification of sterility inside an operating room.

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