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2nd Workshop on Fail Safety in Medical Cyber-Physical Systems, Wien 2016

Evaluating Hand Disinfection with Alcohol-Based Hand Sanitizers Using Thermal Imaging

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Abstract: Thorough hand disinfection in hospitals is essential to prevent nosocomial infections. Health care workers are trained and instructed on when and how to use hand sanitizers during apprenticeship training and continuing education, but up to now there is no automatic system to give immediate feedback about the quality of a hand disinfection in daily clinical routine. We propose a method that is capable to evaluate the quality of a hand disinfection using thermal imaging. It is the first part of a medical cyber-physical system that monitors compliance and quality of hand disinfection. Our setup consists of a thermographic camera mounted in a black box. Image sets of the hands are taken before and after disinfection, so that the resulting temperature difference gives an objective measure about the quality of the disinfection. The main advantage of our system is its suitability for everyday use and its feasibility to be embedded into existing medical networks.

Keywords: hand hygiene, hand disinfection, thermal imaging, thermography, compliance

1 Introduction

The importance of hand disinfection in hospitals has been stressed in several publications [Ha85, Pi00, Pi01]. It is the most effective measure to prevent nosocomial infections, which are responsible for about 75,000 deaths solely in the US [Ma14]. Studies estimate that about one third of these infections could be prevented with better hand hygiene, meaning a higher compliance and a more thorough disinfection [Yo14, BP02]. In 2009, the WHO has defined five indications for hand hygiene in the hospital: before patient contact, before an aseptic task, after body fluid exposure risk, after patient contact, and after contact with patient surroundings [Or09b]. To raise the compliance of health care workers, it would be beneficial to convey when an indication occurred, and thus a hand disinfection is necessary. This could be visually communicated, for example in form of an LED light that is part of a badge, see [Ul14]. If the light is green, the hands are sanitized; if it is yellow, the hands need to be sanitized before the next patient contact; and if it is red, an opportunity for hand hygiene has been missed. In order to gather all needed information for this system a lot of sensors would be necessary, and indications like "after body fluid exposure risk" seem impossible to track. For this reason, up to now there is no system that covers all five indications.

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Furthermore, depending on the type of ward, the five indications result in an average of 8 to 20 opportunities for hand hygiene per patient-hour of care [PMP99]. Therefore, an inexpensive and fast method for hand disinfection and evaluation is crucial for daily use. In between patient contacts, the WHO promotes disinfection with alcohol-based hand rubs, which are accepted as the most effective antibacterial hand-washing agent [BP02, Or09a]. They are able to reduce the spread of infections including MRSA [Or09b, Pr01, Ma04]. Hand washing is only advised when there is visible dirt or grease on the hands [BP02]. We propose a method that gives the user immediate feedback about the quality of his hand disinfection with the help of an image set taken before and after disinfection.

2 Related Work

In the last years, several real-time location systems emerged with the focus on the medical sector [Ve15, So15, Ek15]. These systems are able to track patient flow, workflow, and equipment and can also be used to monitor safety and compliance. One system, developed by UltraClenz, is dedicated to give feedback to a healthcare worker when his hands need to be disinfected [Ul14]. This system consists of badges worn by healthcare workers, stationary badges in each patient zone, and modified sanitizers equipped with a badge. These badges are able to detect proximity to each other and thus track if a sanitizer was used in between patient contacts. This so called *Patient Safeguard System* can only assist the health care worker with regard to compliance and only detects two of the five indications of hand hygiene defined by the WHO, namely entering and leaving the patient area. This system cannot assess if the disinfection was performed thoroughly enough or give any feedback about the quality of the disinfection.

A standard and direct way to check a surface for pathogenic germs is to inoculate agar plates with a cotton swab of the relevant surface. The Petri dishes can be evaluated after the incubation of the bacterial cultures. This method is expensive and comes with a delay of several days, which are both exclusion criteria when it comes to determining the cleanness of the hands of health care workers in daily clinical routine.

An alternative to a swab is to indirectly assure the cleanness of the hands. A valid assumption is that after a well performed disinfection, during which all parts of the hand have come in contact with the sanitizer, the hand can be considered clean, as correctly performed disinfections kill most pathogenic germs [KK04]. SzilâÂgyi et al. presented Stery-Hand, a setting in which the sanitizer is mixed with UV reflective powder. After disinfection, they capture pictures of the hands under UV light and evaluate the coverage of the disinfection [Sz10]. This process reveals missed spots and thus allows a statement about the quality of the hand disinfection. A disadvantage of this approach is that it is not approved for patient care and hence only advised for training purposes or continuing educations. Another disadvantage is that the user would need to wash off the UV-reflective powder completely after the measurement, because any residual reflective powder remaining on the hand from a previous disinfection tampers the results of the next evaluation. On the one hand, this takes additional time, which is not practicable with up to 20 opportunities for hand hygiene per hour. On the other hand, constant hand washing can irritate the skin of the hand and thus negate one reason why hand-rubs are used in the first place, e.g. to avoid irritant contact dermatitis [Or09b].

We propose a method to indirectly evaluate hand sanitization using thermography. As disinfections are usually performed with alcohol-based hand rubs, the alcohol evaporates and cools its surrounding area, which can be measured with a thermography camera. Thermography is already widely used in medicine [RA12]. It is a painless, non-invasive, and zero radiation method that gives immediate results. It is also suitable for consecutive hand disinfections in everyday hospital life as taking the necessary images only takes a few seconds, and no additional effort is needed.

3 Evaporative Cooling

A liquid evaporates into an adjacent gaseous phase if it is not saturated with the evaporating substance. This process needs energy (evaporation enthalpy). For this reason, the evaporating liquid cools down and consequently its surrounding area. This is also the case when a person disinfects his hands with alcohol-based hand rubs. The applied solution starts to evaporate, and thus the hands cool down. An own trial with a standard disinfectant (Sterillium classic pure) showed that the difference in temperature before and right after disinfection is about $-1.80\,^{\circ}\mathrm{C} \pm 0.7\,^{\circ}\mathrm{C}$. This is large enough to be measured with contemporary thermographic cameras.

4 Hardware

The setup consists of a rigid case as shown in Fig. 1, where in the top centre the thermography camera (InfraTec PIRuc180) is mounted and alongside an ordinary webcam (Logitech C910). Beneath is one line of LED lights and two lines of UV LEDs. The webcam and UV lights are not necessary for our proposed method, but only used for the evaluation and visualisation of the disinfection.

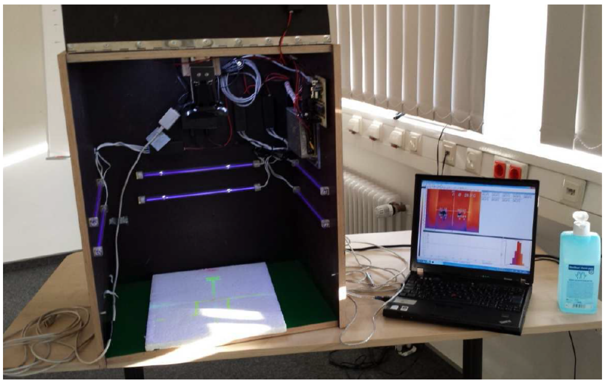

Fig. 1: The hardware setup consists of a black box with a thermography camera, LED lights, and a connected laptop for image processing

On the right side of the box a controller is placed, which can be connected via USB, to enable and disable the lights independently. The front of the box can be closed, so that only a small slot of about 15 cm on the lower side is left open. The slot is large enough to fit two hands at once. All sides of the box are black, except for the bottom which is green. Both cameras are connected to a usual laptop that takes care of the image processing and gives visual feedback to the user.

5 Image Acquisition

A health care worker is instructed to use the device right before disinfecting his hands and right afterwards. The connected laptop gives feedback about the current position of the hands within the box and also instructs the user to position his hands correctly and to spread his fingers, so that the skin in between the fingers becomes visible for the cameras, too.

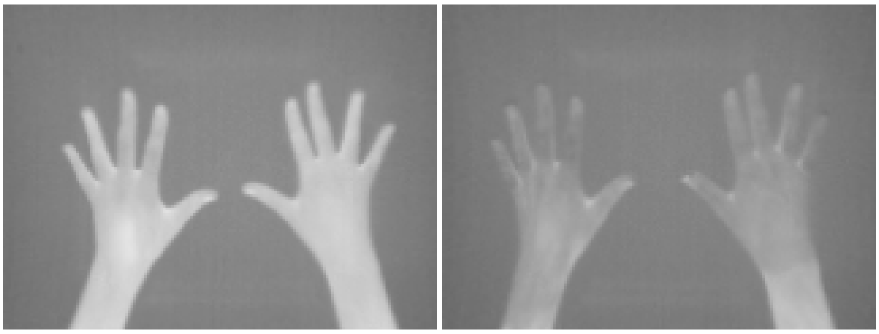

Fig. 2: Exemplary greyscale representation of thermal images taken before (left) and after (right) disinfection with dorsal side facing up

If the images were successfully captured, the user is told to turn his hands, so that the palmar side faces up. Afterwards, the user is given time to disinfect his hands in a usual way. Immediately after disinfection, the user needs to put his hands again in the box, like before, first dorsal side up, then palmar side up.

Figure 2 shows greyscale images representing the temperature of both hands before and after disinfection on the left and the right side, respectively. As the thermographic camera captures the surface temperature, the value of each pixel stands for a temperature, with brighter pixels meaning a warmer surface and darker pixels a colder one.

6 Image Processing

As the position of the hands in the before and after images can slightly differ, it is not possible to just calculate the temperature difference pixelwise for the two thermal images. Therefore, it is necessary to detect the hand in the infrared images, which is achieved by binarization. The threshold used for the binarization is calculated with the well known

Otsu's method [Ot75]. After detecting the hand, it is divided into 20 segments, which are loosely based on the bones of the human hand. Figure 3 illustrates the previously in Fig. 2 shown images with the resulting segmentation. The resulting border of each segment of the hand is superimposed in white on the thermogram. Afterwards, the mean temperature of each segment is calculated. That way, it is possible to compare the temperature of each segment from the before image with the corresponding temperature in the after image.

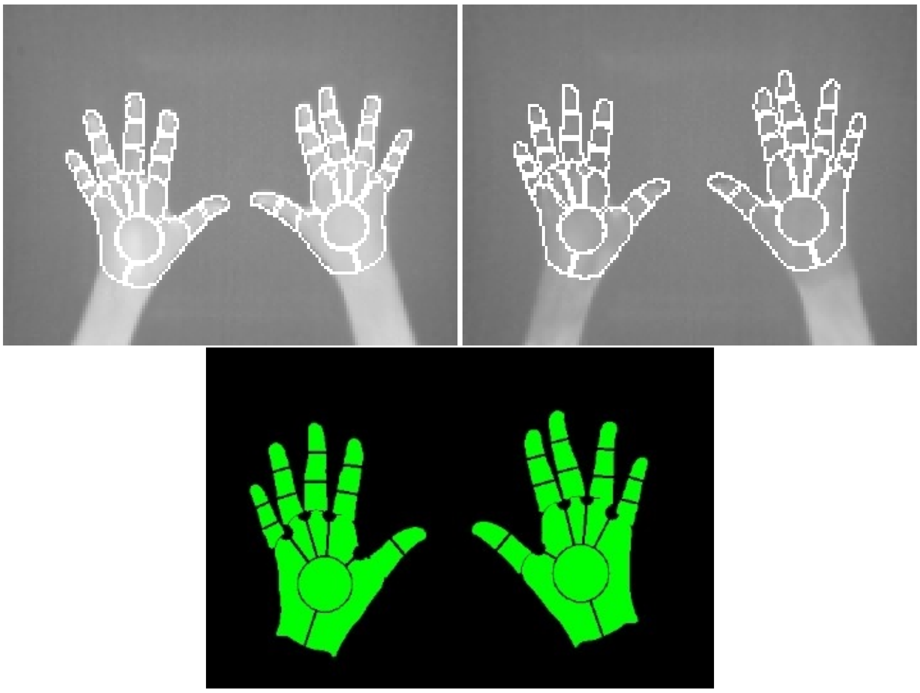

Fig. 3: Greyscale thermograms superimposed with the contours of the segments in white (top left and right), colour coded temperature difference between before and after disinfection (bottom)

If a significant drop in temperature between the before and after disinfection measurement is present, the region is assumed to have been well disinfected. This temperature difference is colour coded from green, over yellow and orange, to red. In Fig. 3 the right image shows the resulting colour coded image. In that case, the hand has been well disinfected, which is visualised by a completely green hand.

7 Results

The measured differences in temperature are depicted colour coded in a result image. A hand region is shown green if the difference of temperature between the before and after image is large enough. The closer to zero the difference is, the redder the region is coloured. In order to evaluate this new method, the disinfectant has been mixed with UV reflective powder, and additionally to the thermal image an RGB image under UV light has been taken after disinfection. That way not sanitized hand regions can be visually spotted and the results of the thermography can be verified. Figure 4 shows disinfected hands under UV light on the left.

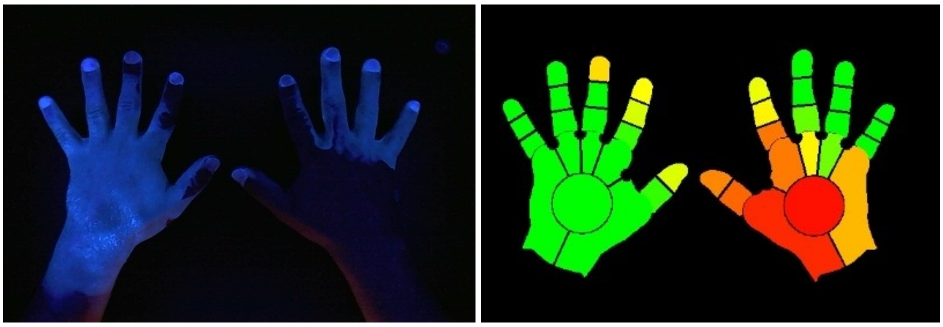

Fig. 4: Exemplary images of both hands after poor disinfection from dorsal: RGB under UV light (left) and colour coded temperature differences (right)

It is obvious from the RGB image under UV light that the right three finger tips of the left hand and the left and lower part of the right hand have not been disinfected properly. The results of our method are shown on the right. The temperature difference is colour coded as explained earlier. The dark areas of the image taken under UV light appear as orange and red hand regions in our result image. This exemplarily shows that it is possible to detect not properly disinfected hand regions using thermal imaging. We evaluated five more disinfections and the results were comparable to those shown in Fig. 4. We are thus convinced that thermography can be considered a valid approach to determine the quality of a hand disinfection objectively.

8 Conclusion

In this paper, we presented a corner stone of a medical cyber-physical system which shall improve compliance and measure the quality of each hand disinfection. In a proof of concept setup, we showed that thermal imaging is suitable to reflect the quality of a disinfection, and compared to Stery-Hand, it has the advantage that no additions to the disinfectant are needed. Moreover, previous disinfections do not alter the results, which makes this method suitable for daily clinical routine.

But our trial also showed that there are limitations. If the temperature difference between the hands and the background is too small, the binarization cannot longer reliably distinguish between hands and background, and then the segmentation of the hands fails. This problem needs to be addressed in further studies and improvements of the used algorithms. Besides, with further development and miniaturization, our system could also be embedded into one of the previously presented hand hygiene monitoring systems or real-time location systems, which up to now are only able to monitor compliance to a limited extend.

References

[BP02] Boyce, J. M.; Pittet, D.: Guideline for hand hygiene in health-care settings: recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. American Journal of Infection Control, 30(8):1–46, 2002.

[Ek15] Ekahau: , Real-Time Location Systems. `http://www.ekahau.com/real-time-location-system/technology`, 2015. Accessed 30-Nov-2015.

[Ha85] Haley, R. W.; Culver, D. H.; White, J. W.; Morgan, W. M.; Emori, T. G.; Munn, V. P.; Hooton, T. M.: The efficacy of infection surveillance and control programs in preventing nosocomial infections in US hospitals. American Journal of Epidemiology, 121(2):182–205, 1985.

[KK04] Kampf, G.; Kramer, A.: Epidemiologic background of hand hygiene and evaluation of the most important agents for scrubs and rubs. Clinical Microbiology Reviews, 17(4):863–893, 2004.

[Ma04] MacDonald, A.; Dinah, F.; MacKenzie, D.; Wilson, A.: Performance feedback of hand hygiene, using alcohol gel as the skin decontaminant, reduces the number of inpatients newly affected by MRSA and antibiotic costs. Journal of Hospital Infection, 56(1):56–63, 2004.

[Ma14] Magill, S. S.; Edwards, J. R.; Bamberg, W.; Beldavs, Z. G.; Dumyati, G.; Kainer, M. A.; Lynfield, R.; Maloney, M.; McAllister-Hollod, L.; Nadle, J. et al.: Multistate point-prevalence survey of health care–associated infections. New England Journal of Medicine, 370(13):1198–1208, 2014.

[Or09a] Organization, World Health et al.: , Implementation toolkit for the WHO hand hygiene improvement strategy. `http://www.who.int/gpsc/tools/faqs/implementation/en/index.html`, 2009. Accessed 30-Nov-2015.

[Or09b] Organization, World Health et al.: , WHO guidelines on hand hygiene in health care: first global patient safety challenge. Clean care is safer care. `http://whqlibdoc.who.int/publications/2009/9789241597906_eng.pdf`, 2009. Accessed 30-Nov-2015.

[Ot75] Otsu, N.: A threshold selection method from gray-level histograms. Automatica, 11(285-296):23–27, 1975.

[Pi00] Pittet, D.; Hugonnet, S.; Harbarth, S.; Mourouga, P.; Sauvan, V.; Touveneau, S.; Perneger, T. V. et al.: Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. The Lancet, 356(9238):1307–1312, 2000.

[Pi01] Pittet, D.: Compliance with hand disinfection and its impact on hospital-acquired infections. Journal of Hospital Infection, 48:40–46, 2001.

[PMP99] Pittet, D.; Mourouga, P.; Perneger, T. V.: Compliance with handwashing in a teaching hospital. Annals of Internal Medicine, 130(2):126–130, 1999.

[Pr01] Pratt, R. J.; Pellowe, C.; Loveday, H. P.; Robinson, N.; Smith, G. W.; Barrett, S.; Davey, P.; Harper, P.; Loveday, C.; McDougall, C. et al.: The epic project: developing national evidence-based guidelines for preventing healthcare associated infections. Phase I: Guidelines for preventing hospital-acquired infections. Department of Health (England). The Journal of Hospital Infection, 47:3–82, 2001.

[RA12] Ring, E. F. J.; Ammer, K.: Infrared thermal imaging in medicine. Physiological Measurement, 33(3):33–46, 2012.

[So15] Sonitor: , RTLS technologies – Experience Real Time Intelligence. http://www.sonitor.com/products-sonitor-sense.html, 2015. Accessed 30-Nov-2015.

[Sz10] Szilágyi, L.; Lehotsky, Á.; Nagy, M.; Haidegger, T.; Benyó, B.; Benyó, Z.: Stery-hand: a new device to support hand disinfection. In: Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE. IEEE, pp. 4756–4759, 2010.

[Ul14] UltraClenz: , Key features of Hand Hygiene systems. http://www.ultraclenz.com/apic-2014/, 2014. Accessed 30-Nov-2015.

[Ve15] Versus: , Location Advantages for Healthcare. http://www.versustech.com/rtls-technology/, 2015. Accessed 30-Nov-2015.

[Yo14] Yokoe, D. S.; Anderson, D. J.; Berenholtz, S. M.; Calfee, D. P.; Dubberke, E. R.; Ellingson, K. D.; Gerding, D. N.; Haas, J. P.; Kaye, K. S.; Klompas, M. et al.: A compendium of strategies to prevent healthcare-associated infections in acute care hospitals: 2014 updates. American Journal of Infection Control, 42(8):820–828, 2014.