Quantitative Evaluation of Hand Washing Skills Based on Convolutional Neural Network for Nursing Education

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The World Health Organization (WHO) reports that hand hygiene education is important for health workers. However, handwashing methods in hospitals require specialized handwashing knowledge. In this paper, we present a new quantitative handwashing skills assessment method based on the Convolutional Neural Network (CNN). An image capture box with blacklights was created and photos were taken before and after handwashing after the application of fluorescent paint. The photos after handwashing were labeled by specialists in each part. The total number of photos after handwashing labeled by specialists was 585. After that, 9-fold cross-validation was performed on the photos after handwashing to calculate the discrimination accuracy (F-value). As a result, the F-value was $81.26 \pm 6.18\%$ in the handwashing image evaluation system using CNN.
Key words: Hand Hygiene, Hand Washing Skills, Convolutional Neural Network (CNN), Classification

1. Introduction

Some nosocomial infections such as influenza can cause high fever and chills whereas others such as methicillin-resistant Staphylococcus aureus (MRSA) can cause death. In general, human immunity suppresses infections; however, children and the elderly are at high risk because their immune systems are not as mature or are weaker than those of healthy adults [1,2]. Thus, control of nosocomial infections is extremely important. Handwashing is recognized as effective in preventing nosocomial infections [3–5]. The World Health Organization (WHO) reports that hand hygiene education is important for health workers [6]. However, handwashing methods in hospitals require expert handwashing skills. In this paper, we propose a new method of quantitative handwashing skills assessment based on deep learning. This study contributes to the dissemination of the importance of handwashing training techniques by providing information on these techniques for future use.

2. Experimental Method

2.1 Image capture box

To evaluate handwashing skills, we developed a plastic box that we called the Image Capture Box to unify the experimental environment shown in Fig. 1. Both the height and width of the box were 30 cm and the depth was 45 cm. The Image Capture Box was composed of five carbon plastic boards, two blacklights (PL10BLB, Sankyo Denki), two LED lights (RE-BLIS04-60F, REUDO LIGHTING PRODUCTS), and a blackout curtain. The LED lights and blacklights were used to capture the edge of the hand area and the residual fluorescent paint of the hand. The blackout curtain was used to prevent ambient light from entering the box. A digital camera (Power Shot G7 X Mark II, Canon) was selected and attached to the box to take photos. The camera parameters were an f-stop of 2.8, a shutter speed of 1/60 second, and an ISO setting of 125. We selected these parameters to prevent overexposure when the visible light LEDs were turned on.

2.2 Acquisition of handwashing images

The University of Toyama offers lectures on handwashing methods to nursing students. In these lectures, handwashing training based on WHO guidelines is performed mainly using fluorescent paint and blacklights [7]. Handwashing images used in this paper were collected using an image capture box as part of one of these lectures. At lectures held at the University of Toyama, handwashing training is provided using the following procedure.

1. Subjects apply fluorescent paint to the entire hand. Afterward, they confirm under UV light whether the fluorescent paint has been applied correctly.
2. Subjects wash their hands with soap and tap water for one minute in accordance with WHO guidelines. Hands are then dried using a paper towel.
3. Finally, the subjects sketch their right palm to record the fluorescent area. The sketch is performed using visual inspection.

We took photos of the handwashing process before and after Step 2 of the above procedure. Subjects stood in front of the Image Capture Box and inserted their hands into the box, palm side up. After positioning the palm in the box, the photos were captured in both visible light and UV light. As a result, 585 photos were taken. Figure 2

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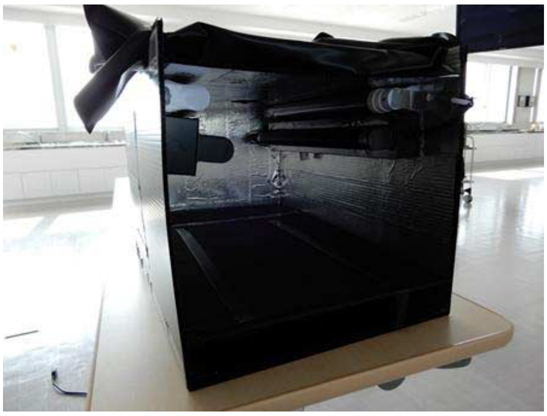

Fig. 1. Image capture box.

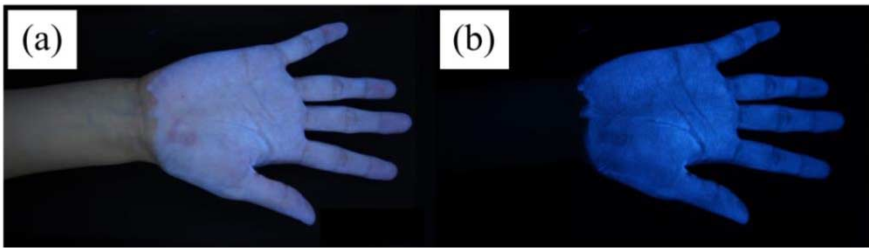

Fig. 2. Hand image taken under visible light (a) and UV light (b).

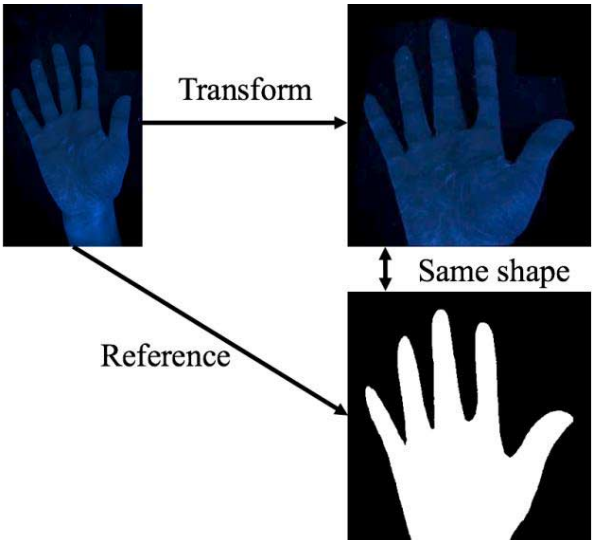

Fig. 3. Example of the transforming.

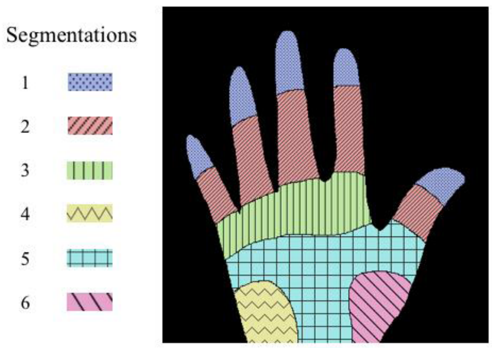

Fig. 4. Hand segmentation.

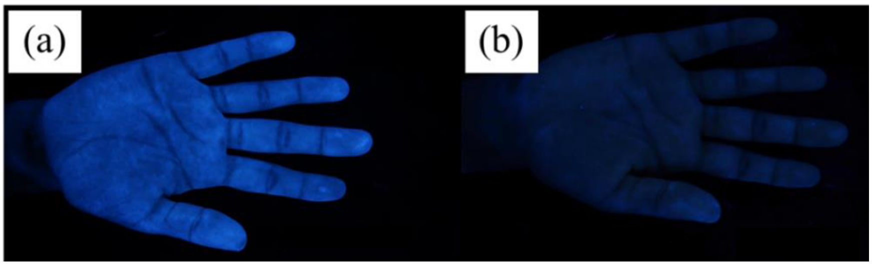

Fig. 5. Images taken under UV light (a) before handwashing and (b) after handwashing.

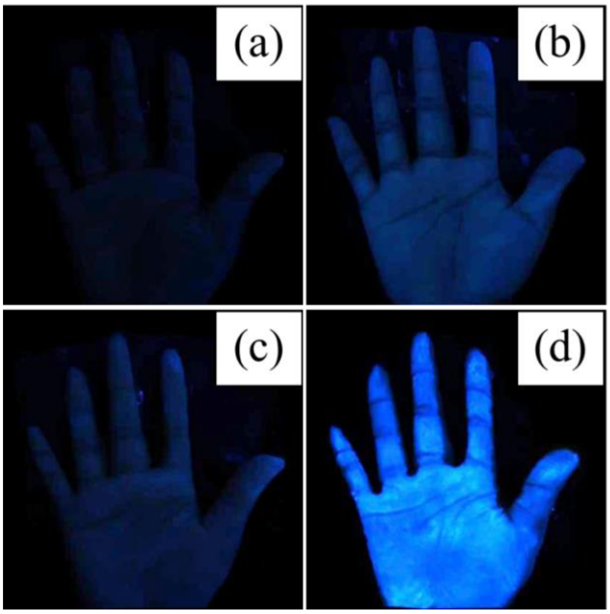

Fig. 6. Examples of classification results in segment 5. (a) The label and CNN prediction are good (b) the label is good and the CNN prediction is bad (c) the label is bad and the CNN prediction is good (d) the label and the CNN prediction are bad.

shows photos taken before handwashing in visible light and UV light. The photos used for deep learning were pre-processed in three steps before being inputted. First, the lower part of the wrists was excluded from the obtained photos and only the palms were extracted. After this, image registration using the Demons' algorithm was applied to all palm shapes photos taken after hand washing [8]. A typical example of image registration using the Demons' algorithm is shown in Fig. 3. Finally, an associate professor from the School of Nursing created a correct response label for all hand washing images.

3. Convolutional Neural Networks (CNN)

Recently, deep learning has been applied in various fields [9,10]. One method of deep learning is the convolutional neural network (CNN), a network often used for image analysis that has good performance results [11,12]. CNNs allow not only a correct answer but also a multiple labeling method with many correct answers [13,14]. Our proposed CNN was also constructed based on multiple labeling methods. As the proposed CNN used supervised learning, it was necessary to attach labels to the data of the hand images taken under UV light. The image data used in this study were classified into two classes (good and bad) for each area by an associate professor from the School of Nursing. Figure 4 shows how the hands were divided into each segmentation. The 585 images collected were randomly classified into 535 training data and 50 test data. Of the 585 images, the number of labels judged to be as good in each part was 86, 74, 78, 66, 117, and 79. The CNN structure with the classification was composed of four convolutions, two max-pool, and three full-connected layers. In addition, the Softmax classification function was applied. The CNN hyperparameters were determined by Bayesian optimization [15] within the range shown in Table 1. Finally, the proposed CNN performance was evaluated by 9-fold cross-validation.

4. Results

Figure 5 shows images taken under UV light before and after handwashing. The pre-wash image shows how the fluorescent paint applied to the hands glows under the blacklight (Fig. 5a). The image after handwashing reveals an absence of fluorescence as the fluorescent paint has been effectively removed after handwashing (Fig. 5b). Table 2 shows the CNN architecture configured based on the hyperparameters determined by Bayesian optimization. The CNN architecture using the determined hyperparameter was verified with 9-fold cross-validation. As a result, the F-value was found to be $81.26 \pm 6.18\%$. Table 3 shows the F-value of each segmentation. Notably, the best F-value was $85.47 \pm 7.12\%$ in segmentation 4 and the worst F-value was $77.44 \pm 6.79\%$ in segmentation 1. Figure 6 shows examples of classification results at segmentation 5. Figure 6a shows that both the label and the CNN prediction are good in all segmentations; Figure 6b shows that the label is good and the CNN prediction is bad; Figure 6c shows that the label in segmentation 1 is bad and the CNN prediction is good; and Figure 6d shows that both the label and the CNN prediction are bad in all segmentations.

5. Discussions

In this paper, we proposed a novel method for quantitative evaluation of handwashing skills based on a convolutional neural network (CNN). Moreover, we created an image capture box equipped with blacklights and took photos of the fluorescent paint applied to the hands before and after handwashing. The resulting F-value was $81.26 \pm 6.18\%$ in the handwashing image evaluation system when CNN was used. Alternatively, considering the F-values of each seg-

Table 1. Search range for Bayesian optimization.

Attribute	Search range
Filter size	3, 5, 7, 9
Number of filters	16, 32, 64, 128, 256
Number of full-connected neuron	16, 32, 64, 128, 256
Drop rate	0.1, 0.3, 0.5, 0.7, 0.9
Learning rate	10^{-5}, 5×10^{-5}, 10^{-4}, 5×10^{-4}

Table 2. Proposed CNN architecture

Layers	Layer name	Kernel size	No. of filters	Strides	Output shape	Regularization
0	Input	—	—	—	$64 \times 64 \times 3$	—
1	Convolution	3×3	64	1	$64 \times 64 \times 64$	Dropout(0.9)
2	Convolution	3×3	64	1	$64 \times 64 \times 64$	Dropout(0.9)
3	Max-pooling	4×4	64	4	$16 \times 16 \times 64$	—
4	Convolution	9×9	16	1	$16 \times 16 \times 16$	Dropout(0.9)
5	Convolution	9×9	16	1	$16 \times 16 \times 16$	Dropout(0.9)
6	Max-pooling	4×4	16	4	$4 \times 4 \times 16$	—
7	Dense	—	—	—	64	Dropout(0.9)
8	Dense	—	—	—	64	Dropout(0.9)
9	Dense	—	—	—	2	—

Table 3. F-value for each segment (Mean ± SD).

Segment	F-value [%]
1	77.44 ± 6.79
2	82.05 ± 7.66
3	82.63 ± 6.96
4	85.47 ± 7.12
5	78.13 ± 8.55
6	82.56 ± 6.05

ment, the best value was $85.47 \pm 7.12\%$ and the worst was $77.44 \pm 6.79\%$. There were several possible reasons as to why the F-value varied between each segment. Probably, as the number of training data used in this experiment was only 535, CNN was unable to acquire enough features. For example, by looking at the region of segment 1, which had the worst discrimination accuracy, the same labeling was performed when there were an unwashed thumb and little finger. As there were only 86 correct labels for segment 1, it is very unlikely that CNN could acquire enough features. Therefore, we will continue collecting data for further study. Also, given the existence of zones where there were a large number of unwashed areas or zones where there were hardly any unwashed areas, the correct answer labels in this experiment are biased. As the bias may be reflected in the classification result, greater weight will be applied in the future when learning with a reduced number of classes. Additionally, segment 5 had the second-lowest classification accuracy after segment 1 and, because of its shape, its features are complicated. Therefore, it is necessary to reconsider the division of the palm region and to establish one that improves the discrimination accuracy on CNN.

6. Conclusions

In this paper, we proposed a method that allows an evaluation equivalent to that of a nursing teacher to assess handwashing skills in each hand segment using a CNN, a deep learning method. The proposed CNN achieved an F-value of $81.26 \pm 6.18\%$. In the future, we will collect more data and retrain the network to improve the F-value. Additionally, as thorough hand hygiene is important to prevent nosocomial infections, it is necessary to capture images of the back and side of the hand, collect data, and train the CNN to improve its performance.

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