An Evaluation of Stack Light Indicator Color Detection System Using Web Cameras for Automatic Production Lines

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***Abstract*—In production lines, manufacturing devices are operated in a pipelined manner to produce desired products. The pipeline stops when an error occurs at any manufacturing device. In order to prevent a decrease in production efficiency, it is necessary to detect the abnormality earlier. This work aims at early detection and record of the abnormal occurrence by judging the color of the stack light indicator informing the abnormality installed in each device. We utilize web cameras for this purpose, considering its versatility. In this paper, we show an evaluation result of a system for detecting stack light indicator color using web cameras.**

I. Introduction

Recent technology advances have made low-cost and high-fidelity image acquisition devices wide spread. Car dash cameras and unmanned aerial vehicles (UAVs) with mounted cameras are now commonly used. Hence, the demand for technologies processing videos acquired by such devices is becoming high. Also, imaging devices supporting relatively high-resolution are now regarded as commodities, such as not only camcorders but also smartphones, tablets. Under such a situation, 4K and 8K digital broadcasting and IP streaming are now becoming available [1,2]. Considering recent advancements and popularization of imaging devices and audio-visual appliances, video processing can alleviate difficulties in from our daily file to social issues. Actually, surveillance systems utilizing video technologies can help us in many aspects such as crime avoidance, criminal investigations, protection against disasters. Also, since such a situation makes high-performance but low-cost web cameras commercially available, we can obtain real-time video data to be processed without any difficulty.

In this paper, we utilize web cameras to monitor stack light indicators in production lines, where manufacturing devices are operated in a pipelined manner to produce desired products. In general production lines, each manufacturing device has its stack light indicator to show its status. When operators in the production lines notice the status change, they do necessary operations to the manufacturing devices. Such systems are known as Andon system [3] originated from Toyota production systems. Figure 1 shows an example of colors of a stack light. Some devices have network monitoring capability but some devices do not. Variable manufacturing devices are utilized to build a line. Therefore, such stack light indicator monitoring is always necessary. When one device goes paused due to, for example, empty of the input buffer and abnormal operation, the production line pipeline may stop soon. This degrades the production efficiency. To avoid such low efficiency, prompt device status detection and proper handling is required. In production lines, therefore, it is indispensable to detect irregular status caused by missing input or abnormal operations.

(a) Red (b) Yellow (c) Green

Fig. 1. Frame parts exampling each status of stack light indicator acquired by a camcorder.

Motivated by this, this paper presents a stack light indicator monitoring system using web cameras for production lines. The device status is detected by color detection of stack light. Using this system, the device status change can be detected automatically. When status change is detected, the system can make proper signals to notify this to the operators to cause proper feedback to the device. Also, such an automatic system can generate precise work record or log for each device, which may help us in terms of further production line pipeline optimization.

Our system uses commercially available web cameras. By processing images acquired by web cameras, indicator regions are semi-automatically detected and the status of the indicators are checked by estimating the color of the region. Its installation is not difficult compared to other approaches. Our approach is quite efficient since one web camera may cover many stack lights. Attaching a dedicated sensor to each device to send status signals to a server might be a possible approach. In another approach, all devices are made to be capable of generating status signals which are integrated into a centralized control system. In these approaches, there is a quite high barrier for installation and also suffers from flexibility issues. In the case of a large number of devices, these approaches are not feasible.

As for image processing to detect the stack light status, we utilize simple color detection with thresholding the pixel values in the lamp region. In [4], deep learning is used to judge the stack light status. However, considering the stable camera and the judgment based on only colors, our approach is simple but effective.

We carried out field experiments of the proposed system using a real production line. The experimental results show that the proposed approach can successfully detect stack light status.

The rest of this paper is organized as follows. In Section II, we explain the proposed system. In Section III, we show the experimental results. Finally, in Section IV, we conclude this paper.

II. Proposed Stack Light Indicator Monitoring System

The proposed system is focusing on the operation of automatic production lines. Therefore, ease of operation is the key to our system. The system consists of

- the installation phase where lamp regions are semi-automatically detected and
- the operation phase where lamp colors are detected.

In this paper, we also use the term, lamp, for the stack light.

A. Lamp Region Detection and Setting

In the installation phase, using frames acquired by the web camera, the user configures lamp regions. Since manual configuration requires much cost, especially in cases of a large number of stack lights, we developed a semi-automatic configuration system.

Candidate regions are extracted from frames acquired by the web camera. Since lamp region usually has high-intensity value, such high intensity pixels are extracted by the following thresholding for each pixel P.

$$\max(P_{\mathrm{R}}, P_{\mathrm{G}}, P_{\mathrm{B}}) > 0.8, \quad (1)$$

where P_i, $i \in \{\mathrm{R}, \mathrm{G}, \mathrm{B}\}$ is the each color component value assuming $0 \leq P_i \leq 1$. After picking up pixels, morphology operations are applied to extracted pixels to remove noise. Checking the connectivity of pixels, regions are created, and the minimum rectangular region covers each region will be the candidate of the lamp region. In this phase, rectangular regions whose shape is similar to the square are selected. Others are omitted. This is because horizontal rectangle region have a high possibility of the production line room lighting.

After automatic lamp region candidate detection, users select lamp region. Also, when lamp region information includes error, users may apply an adjustment for each region. By such user confirmation, finally, the lamp regions are configured for the operation mode.

Procedure 1 estimates lamp status

Input: $(\bar{R}, \bar{G}, \bar{B})$, the moving averaged average pixel value for a lamp region, and $0 \leq \bar{R}, \bar{G}, \bar{B} \leq 1$
Output: lamp status $s \in \{\mathrm{Unknown}, \mathrm{Red}, \mathrm{Yellow}, \mathrm{Green}\}$

if $\max(\bar{R}, \bar{G}, \bar{B}) < 0.4$ **then**
  $s \leftarrow \mathrm{Unknown}$
else if $\min(\bar{R} - \bar{G}, \bar{R} - \bar{B}) > 0.1$ **then**
  $s \leftarrow \mathrm{Red}$
else if $\min(\bar{R}, \bar{G}) > \bar{B}$ **then**
  $s \leftarrow \mathrm{Yellow}$
else if $\min(\bar{G}, \bar{B}) > \bar{R}$ **then**
  $s \leftarrow \mathrm{Green}$
else
  $s \leftarrow \mathrm{Unknown}$
end if

Procedure 2 estimates lamp status

Input: $(\bar{R}, \bar{G}, \bar{B})$, the moving averaged average pixel value for a lamp region, and $0 \leq \bar{R}, \bar{G}, \bar{B} \leq 1$
Output: lamp status $s \in \{\mathrm{Unknown}, \mathrm{Red}, \mathrm{Yellow}, \mathrm{Green}\}$

if $\max(\bar{R}, \bar{G}, \bar{B}) < 0.4$ **then**
  $s \leftarrow \mathrm{Unknown}$
else if $\min(\bar{R} - \bar{G} - 0.35, \bar{R} - \bar{B}) > 0$ **then**
  $s \leftarrow \mathrm{Red}$
else if $\min(\bar{R}, \bar{G}) > \bar{B}$ **and** $\bar{G} - \bar{R} < 0.1$ **then**
  $s \leftarrow \mathrm{Yellow}$
else if $\min(\bar{G}, \bar{B}) > \bar{R}$ **or** $\bar{G} - \bar{B} > 0$ **then**
  $s \leftarrow \mathrm{Green}$
else
  $s \leftarrow \mathrm{Unknown}$
end if

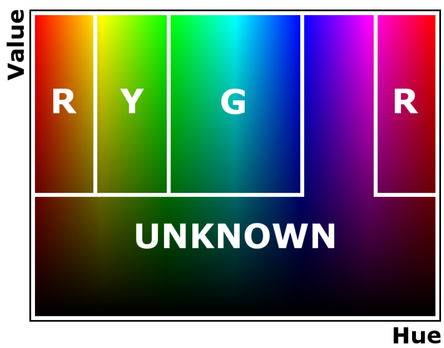


Fig. 2. Lamp status estimation in HSV color space.

B. Lamp Color Detection

Assuming that the lamp is on or off and that the color is green, yellow, or red when the lamp is on, our system detects these four lamp status using a web camera. We name these statuses as follows.

- Red: the lamp is on and red,
- Yellow: the lamp is on and yellow,
- Green: the lamp is on and yellow, and
- Unknown: the lamp is off, or the color is unknown.

Fig. 3. A example frame of a production line acquired by Camera 1.

Fig. 4. A example frame of a production line acquired by Camera 2.

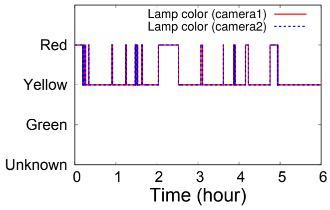


Fig. 5. Lamp state estimation result for Lamp A (near).

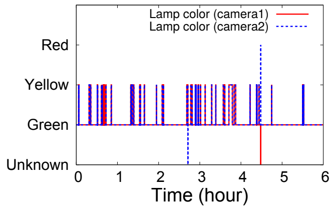


Fig. 6. Lamp state estimation result for Lamp B (far).

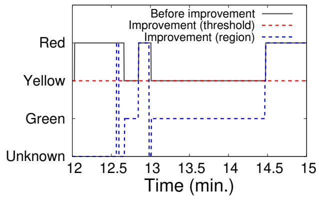


Fig. 7. Lamp state estimation comparison using two types of optimization.

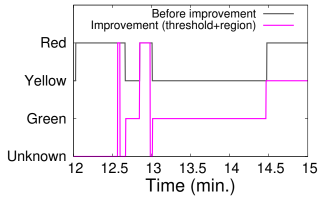


Fig. 8. Lamp state estimation comparison using both two types of optimization.

First, the proposed system calculates the average pixel value in each lamp region. To suppress the noise effect, we apply a moving average whose window size is one second to each obtained average pixel value. Using noise suppressed average pixel value for each lamp region, the lamp status is estimated by thresholding as shown in Procedure 1.

Figure 2 demonstrates this lamp status estimation. As can be seen in Fig. 2, the expressions in Procedure 1 are based on the HSV color space. As for Unknown, if the V component of $(\bar{R}, \bar{G}, \bar{B})$ in HSV color space, that is $\max(\bar{R}, \bar{G}, \bar{B})$, is smaller than a specific value, in this case 0.4, the system estimates the lamp status is Unknown, where the lamp is usually off. As for Red, if $\bar{R}$ is larger than both $\bar{G}$ and $\bar{B}$ by 0.1, the system estimates the lamp status is Red. Similarly, Yellow and Green statuses are estimated, as shown in Procedure 1. Otherwise, the system outputs Unknown status.

The values in Procedure 1, such as 0.1 and 0.4, are decided based on preliminary experiments using the frames acquired by a camcorder. These values will be optimized for web cameras later in this paper, which results in Procedure 2.

III. Experimental Results

A. Web Cameras

To cover as many stack lights as possible, we put web cameras at a high place to acquire so-called commanding view. We used the following four web cameras.

- Camera 1: Logicool HD Pro Webcam C920 [5,6], FHD (1,920×1,080), 5 fps
- Camera 2: Logicool QuickCam Pro 9000 [7], UXGA (1,600×1,200), 5 fps
- Camera 3: Logicool BRIO C1000eR [8], FHD (1,920×1,080), 5 fps
- Camera 4: Buffalo BSW200MBK [9], 3,264×2,448, 2 fps

We carried out field experiments twice in each of which two different web cameras were used. The duration of each field experiment was about one week. Figures 3 and 4 show example frames of Cameras 1 and 2, respectively. The web cameras are connected to a Linux Note PC using with the Linux USB video class (UVC) driver. In this experiment, the frames are obtained by frame-by-frame in raw data. Therefore, the frame rate is relatively low due to data transfer speed limitation. In these experiments, we use all lamp regions that we can see and each of which is not overlapped with each other.

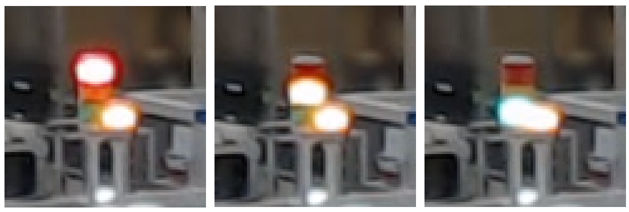
B. Results

Figures 5 and 6 show the lamp status estimation results of Cameras 1 and 2 of different six-hour duration cases. Figure 5 is a result of a lamp near to the web camera. The shape of the lamp is clearly obtained since the lamp is relatively near to the camera, as shown in Fig. 9. Note that two lamps are overlapped in Fig. 9, but the left one is used for evaluation. Since the estimated lamp status is always Red or Yellow, which is unnatural, the estimation includes some errors. Figure 6 is a result of lamp estimation for a lamp far from the web camera. Some noise is included, but we confirmed the result is almost correct. The noise is due to the moving average, which makes the change of average pixel values smooth. Smooth value transition causes wrong estimations. Such noise can be removed by filtering the estimated status in time series. A significant performance difference between cameras cannot be seen, but we confirm that high-resolution cameras can cover a larger number of cameras than low-resolution cameras.

C. Lamp Status Estimation Optimization

From the results of field experiments, we found some issues as follows.

- There are estimation errors due to the effect of the color when stack light is off. If the lamp is near to the



(a) red (b) yellow (c) green

Fig. 9. A frame part of lamp near the camera. The left one is used for evaluation.

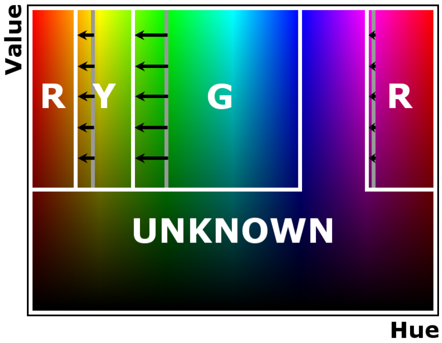


Fig. 10. Lamp status estimation in HSV color space optimized for the web cameras.

camera, the acquired frame clearly shows the shape of the lamp and its color, even the light is off. This causes an estimation error. The actual state of light is Unknown (off), but the system outputs Red or Yellow.
- Yellow state is sometimes estimated as Red.

To overcome these issues, we revised the proposed system in the following two aspects.

(1) Procedure optimization.
The procedure is developed using camcorder data obtained preliminary experiment. The difference between camcorders and web cameras causes errors. Therefore, we optimized the procedure using the frames acquired by web cameras.

(2) Lamp value optimization.
Also, the input values used in Procedure 1 is the moving-averaged average value of lamp region, which can be regarded as a representative or a feature value of lamp region. In the case of near lamps, simple averaging cannot be efficient due to overexposure, which can be seen in Fig. 9.

1) Procedure Optimization: Checking the values which cause estimation error, we optimized the procedure as shown in Procedure 2 Figure 10 demonstrates this lamp status estimation optimization. The first stage, where Unknown state is estimated using V component, shows good estimation performance with the value of 0.4, we do not change this stage. Other expressions based on H component in HSV color space are optimized for the web cameras.

2) Lamp Value Calculation Optimization: The average pixel values of a near lamp tend to be red or yellow regardless of its light status on and off due to the lamp shape and its color. Therefore, we developed a lamp pixel value calculation for near lamp regions to obtain precise color information of lamp lighting. When a lamp is on, the center of lamp relatively white surrounded by color, as shown in Fig. 9. First, we extract the white region in the rectangle lamp region. By applying morphology gradient operation to the extracted information, we extract the surrounding region of the white region. Then, the proposed approach calculates the average pixel value of this surrounding region as the lamp value, instead of the average pixel value in the rectangle lamp region.

3) Lamp Status Estimation Optimization Result: Figure 7 shows the results applying the above mentioned proposed revisions separately. Using Procedure 2, the Yellow state can be estimated correctly. However, due to stack light's color when it is off, the state is sometimes estimated as Yellow. By applying the revised lamp value calculation, the system can estimate Unknown, Green, and Red correctly. Figure 8 shows the result of applying both revisions, where the state can be estimated correctly.

The revised lamp value calculation is valid for the near lamps but not for the far ones. As for the far lamps, the white region cannot be found in the center of lighting parts, which can be seen in Fig. 1. Therefore, the calculation is dynamically changed depending on the distance from the camera to the lamp. Note that the far lamps are easy to cover in terms of its number.

IV. Conclusion

In this paper, we presented a proposed stack light indicator monitoring system using web cameras for production lines. From the evaluation results, we confirmed that the proposed system could successfully detect stack light status using our color detection approach based on web cameras. Further extensions to the proposed system may be possible such as detecting not only colors but also the status of the manufacturing devices such as the number of remaining inputs. The system integration to show the many stack light status at a glance on the local web site of monitoring center also remains as future work.

Acknowledgment

This study is supported in parts by the Ministry of Internal Affairs and Communications for SCOPE Program (185001003).

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