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Research Article

High-speed remote visual monitoring of roll-to-roll (R2R) printed packages

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ABSTRACT

Roll-to-roll (R2R) processing is a widely adopted method in the industry, especially in the label and packaging sector. The processes involving R2R equipment are typically conducted at very high speeds, which makes it preferable. However, high-speed processing poses challenges in monitoring the products throughout the process.

In this study, a high-speed monitoring system using computer vision, capable of working remotely via an IoT module, is developed specifically for R2R manufacturing in the packaging industry. Here, the developed monitoring system is used to detect and recognize the alphanumeric series printed on the packages in the R2R production line. The series are the promotional winning codes, the system needs to capture them, recognize the characters, and compare them with a library of available codes for controlling the process. The system should verify that all codes are registered, there are no repeated codes, and the broken codes should be marked to remove and print again. For this purpose, a method of synchronizing the camera and rapid movement of the web (printed packages) is proposed. The camera captures the code on each product just in time when it passes through. The embedded OCR (optical character recognition) program inside the camera controller detects the characters and sends them for remote comparison and further processes. In this way, the system can work effectively with the linear velocity of the web up to 100m/min.

The successful implementation of the high-speed remote monitoring system paves the way for various applications, as well as opens a chance for further improvements and development of in-house technologies.

Key words: Roll-to-roll, IoT, Computer Vision, remote monitoring, packaging

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INTRODUCTION

In roll-to-roll (R2R) processing, a flexible substrate, known as a "web", is continuously fed through the stations of the R2R production line, where it is continuously processed. As the web moves through each station, specific tasks are applied to the material to create the desired product. Once the processing is completed, the finished product is also rolled up into a new roll. This roll format allows for easy utilization, storage, and potential use in subsequent manufacturing processes. The continuous nature of R2R processing allows for high-volume production with low cycle times, making it a cost-effective and efficient manufacturing method [1–3].

Due to its advantages, R2R processing is widely used in various industries, especially paper processing, printing, and packaging. However, the processes involving R2R equipment are typically conducted at very high speeds, posing challenges in monitoring the products throughout the process [4].

This study proposes the development of a high-speed monitoring system for R2R systems that employs computer vision and remote connectivity. Since all products in an R2R system go through the same processes iteratively, a synchronization method has been established to generate triggers for visual capturing. In this study, the proposed system is used to monitor the printing of alphanumeric series on packages. For this purpose, a sensor is used to detect the appearance of packages. Based on the sensor's findings, the system generates a trigger signal for the camera to capture the approaching package. With the help of the IoT module, the process can be remotely monitored.

METHODOLOGY

System configuration

Fig. 1 illustrates the monitoring system developed for printed packages in the R2R process. As shown, the system includes a roll of flexible substrate. The unwinder rotates to feed the substrate (web) through all processing stations. The rewinder then collects the final products and rolls them back into another new roll. This concept could enable the production of kilometers of products per day [5]. The system in this study

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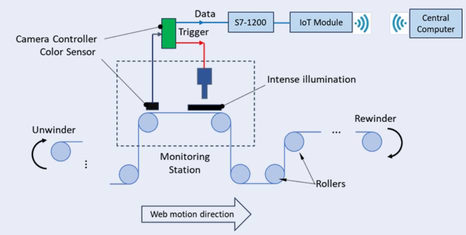

Figure 1: Illustration of the vision system

works with the packages as shown in Fig. 2. Thousands of products could be processed continuously in a workshift.

Figure 2: Packages working in R2R process.

Figure 3: Printed alphanumeric codes on packages in R2Rprocess.

To verify the working of the process, a monitoring system has been developed. The monitoring uses an industrial camera to visualize the products for inspection. More specifically, the alphanumeric series are printed on the packages as shown in Fig. 3. Since the series are used as winning codes for promotional uses, the codes are inkjet printed on a pre-made security pad (Fig. 3). The high-speed monitoring system needs to ensure that all printed codes are registered, free of duplicates, and any broken codes are addressed promptly.

For this purpose, an industrial camera is used to capture the images of printed codes. To overcome the highspeed motion of the web to capture the images at the proper locations, a color sensor is used to detect the packages and trigger the capturing so that the system can be synchronized. When a package moves along the rollers and passes through the monitoring station, a color sensor detects and sends a signal to the controller. The controller then generates a trigger for the camera to capture images of the package, as shown in Fig. 4. Here, the delay time between the package detection signal and the triggering signal is adjustable to calibrate the capturing location. Since the system aims to work at high-speed capturing, the exposure time of the camera is short. Intense lighting is used to stabilize the illumination and enhance the quality of the captured images.

Once the camera captures an image, the camera controller, also an industrial computer, decodes the characters and sends them to the PLC. Here, the present of the PLC equipped with the IoT module is to remotely communicate with a central computer in another place. The PLC sends batches of recognized codes to the computer via the IoT module for real-time verification and receives the feedback as described in Fig. 1.

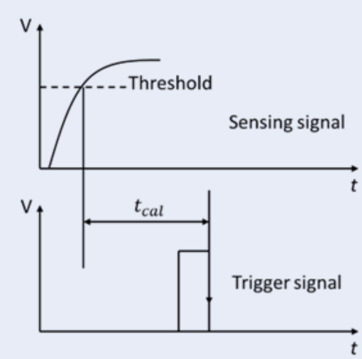

Figure 4: Printed alphanumeric codes on packages in R2R process.

Camera and production parameters

To ensure the capability of image capturing, camera specs and motion velocity of the web should be selected so that images of every package could be captured for processing. Consider a system with the speed of the packages is v_w. In the case of the distance of the 2 consecutive packages is fixed as d as shown in Fig. 5, the time interval between 2 consecutive packages, (δt), could be estimated as:

$$\delta t = \frac{d}{v_w}$$

In such a case, the exposure time t_e of the camera should be selected to satisfy:

$$t_e < \delta t$$

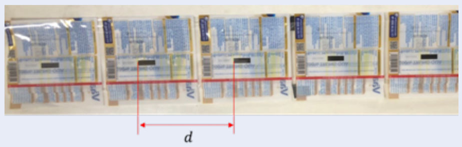

Figure 5: Ilustration of the vision system.

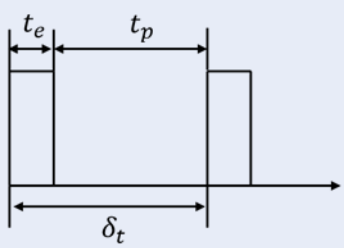

Figure 6: Timebetween two consecutive package.

Figure 7: The implemented system. (a) High-speed Camera,(b) Camera controller, and (c) PLC equiped with IoT module.

Therefore, the maximum frame rate of the camera (F) and the speed of the web should be selected so that:

$$F\ X\ v_w > d$$

However, the target is to control the process in real-time, which means the processing time (t_p), including character recognition time, communication time, and codes comparison time, should be considered as shown in Fig. 6.

In this case, the exposure time (t_e) should be as small as possible to make room for processing, and the processors should be strong enough to minimize the processing time. The maximum speed that the system can handle is:

$$v_{max} = \frac{d}{min(t_e) + min(t_p)}$$

This can be a constraint for selecting the specs of the camera, as well as processing algorithms and hardware for the systems regarding the production requirements and parameters.

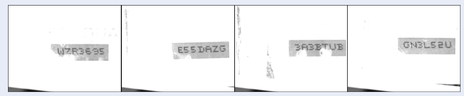

Figure 8: Imagecaptured at the speed of 100m/min.

RESULTS AND DISCUSSION

Fig. 7. shows the implementation of the monitoring system. The basic components of the system included a highspeed camera (Keyence CA-H048MX, Keyence Corp., Japan), a camera controller (CV-X470F), and a PLC (S7-1412, Siemens, Germany) equipped with an IoT module (SIMATIC IOT2050, Siemens, Germany).

The system allows the camera to be configured with an exceptionally short exposure time (1/100000). It was optimized to operate with a motion velocity of 100 m/min, and the distance between the codes was approximately 100 mm. The results depicted in Fig. 8 demonstrate the good performance of the synchronization system under these high-speed conditions. All the images were acquired clearly, and the codes were captured accurately.

Moreover, the IoT device in Fig. 9 is capable of high-speed processing and communication. All the acquired images were processed to recognize the characters and sent to the computer (Fig. 9(a)). The IoT module sends the data in batches of 9 codes for further processing. The total processing time and communication time was several ms, which is suitable for real-time application. It can acquire images, process them to recognize characters, and send the processed data to a computer in just a few milliseconds, which makes it suitable for real-time applications.

CONCLUSION AND FUTURE PERSPECTIVE

This study presents the development of a remote visual monitoring system tailored for high-speed R2R

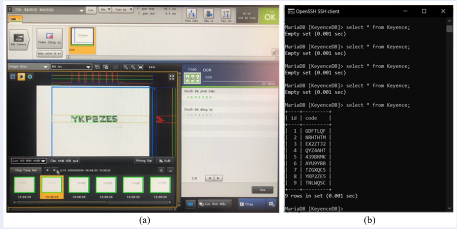

Figure 9: Processing results. (a) Character detection andrecognition, and (b) send-receive the codes via IoT module

processes. The system effectively captures images of alphanumeric codes on packages during their rapid motion (100m/min). These codes are promptly detected, recognized, and transmitted to the central computer within a few milliseconds, ensuring real-time processing.

One limitation of the current system is that the controller and algorithm for optical character recognition rely on a costly pre-built industrial camera, which restricts its applicability for various uses. To address this concern, future efforts could focus on developing an in-house system that encompasses both the controller and algorithm. By doing so, the system would gain enhanced flexibility and affordability, paving the way for broader deployment and application across different industries.

AUTHORS' CONTRIBUTION

Concepts: T. H. Phung and Q. C. Nguyen, Methodology: Q. -P. Tran, P. -T. Pham, Experiments: D. -A. Nguyen, P. -T. Pham, Q. -P. Tran, Analysis: T. H. Phung, D. -A. Nguyen, Q. C Nguyen, Writing and Review: Q. -P Tran, T. H. Phung, Q. C. Nguyen, D. -A Nguyen and P.-Tung Pham.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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Bài nghiên cứu

Hệ thống giám sát từ xa quá trình in theo cuộn (R2R) tốc độ cao

Trần Quang Phước[1,2], Nguyễn Duy Ánh[2,3], Phạm Phương Tùng[2,3], Nguyễn Quốc Chí[2,3], Phùng Thanh Huy[2,3,*]

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TÓM TẮT

Phương pháp gia công theo cuộn (Roll-to-roll hay R2R) là một phương pháp phổ biến trong công nghiệp, đặc biệt là trong lĩnh vực nhãn và bao bì. Ưu điểm của các phương pháp R2R là các quá trình được thực hiện liên tục và với tốc độ cao, điều này giúp tăng năng suất của hệ thống sản xuất. Tuy nhiên, quá trình xử lý ở tốc độ cao đặt ra những thách thức trong việc kiểm soát quá trình cũng như giám sát sản phẩm trong khi gia công.

Trong nghiên cứu này, một hệ thống giám sát được phát triển cho sản xuất R2R trong ngành công nghiệp bao bì. Hệ thống giám sát sử dụng công nghệ thị giác máy tính, có khả năng hoạt động từ xa thông qua một mô-đun IoT và có thể giám sát hệ thống đang vận hành ở tốc độ cao. Trong nghiên cứu, hệ thống giám sát được sử dụng để phát hiện và nhận dạng chuỗi chữ số in trên các bao bì trong dây chuyền R2R. Các chuỗi chữ số là các mã giành thưởng quảng cáo được in phun lên bao bì, hệ thống cần phải xác định, nhận dạng các ký tự được in và so sánh chúng với thư viện mã giành thưởng có sẵn để kiểm soát quy trình. Hệ thống phải đảm bảo rằng tất cả các mã đã được đăng ký từ trước, không có mã nào bị in lặp lại và các mã bị in hỏng sẽ được đánh dấu để loại bỏ và in lại. Để thực hiện công việc này này, một phương pháp đồng bộ hóa giữa camera và chuyển động của bao bì được in mã được đề xuất. Theo đó, máy ảnh có thể chụp mã trên mỗi sản phẩm ngay khi nó chạy qua. Một chương trình OCR (optical character recognition – nhận dạng ký tự) được tích hợp bên trong bộ điều khiển camera phát hiện các ký tự và gửi chúng để kiểm duyệt từ xa và tiến hành các quy trình tiếp theo. Bằng cách này, hệ thống có thể hoạt động hiệu quả với tốc độ di chuyển của cuộn lên đến 100 mét mỗi phút. Việc triển khai thành công hệ thống giám sát từ xa tốc độ cao mở ra cơ hội ứng dụng cho nhiều quá trình sản xuất khác nhau, cũng như tạo cơ hội cho việc cải tiến và phát triển công nghệ sau này.

Từ khoá: Roll-to-roll, IoT, Thị giác máy tính, giám sát từ xa, sản xuất đóng gói

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