Real-time Inspection System Based on Moire Pattern and YOLOv7 for Coated High-reflective Injection Molding Product

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Abstract: Recently, with the development of smart factories, innovation through automation is being carried out in various fields of industry. In particular, because quality control requires a lot of man-hours, many studies are being conducted to replace workers with machine vision. We proposed a real-time inspection system based on YOLOv7 using moire patterns to automate quality inspection in the industry. In particular, the inspection system was successfully applied in the actual industrial manufacturing environment by overcoming the limitations of the applying inspection system to high-reflective products. Not only did we confirm the possibility of applying YOLOv7 to industrial sites, but our proposed optical system can also be used for the inspection of other high-reflective products.

Key-Words: Inspection System, Deep Learning, Object Detection, Machine Vision, Smart Factory, Moire Pattern
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1 Introduction

Industry 4.0 is driving many innovations in manufacturing. A smart factory is a very important issue in Industry 4.0. Smart factory refers to a method that enables more efficient business operations by collecting and analyzing various types of big data generated in the manufacturing environment to improve productivity and quality. Implementing a smart factory has now become an essential element to strengthen a company's competitiveness and sustainability.

In particular, the quality control (QC) process for inspecting defects in the manufacturing process is one of the processes that requires a lot of manhours. Companies are trying to implement a real-time inspection system for automation in the quality control process. However, many problems need to be solved to inspect coated high-reflective injection molded products. The three most difficult problems in coated high-reflective injection molded products are:

- Various types of defects occur irregularly.
- It is difficult to distinguish between real defects and dust on the image
- It is difficult to see various defect types in one optical system.

In this paper, YOLOv7, an object detection algorithm, was used to detect irregular defects. In addition, we propose a system that solves the two problems described above by utilizing the Moire pattern and detects atypical defects in cylindrical high-reflective products in real-time. Our main contributions are summarized as follows:

- First, we propose a method of detecting very small defects using the Object Detection algorithm. A real-time inspection system that satisfies the tact-time and detection accuracy in the actual process environment was implemented using YOLOv7.
- Second, we propose an optical system design optimized for cylindrical high-reflective products. Real defects and dust are distinguished by using Moire pattern. In addition, both Bright Field and Dark Field are implemented to increase detection accuracy for various types of defects.

The structure of this paper is as follows. Section 2 introduces research or background knowledge related to the system proposed in this paper. Section 3 explains the structure and method of a real-time inspection system based on YOLOv7. Section 4 describes the experimental environment and the experimental results. Finally, Section 5 describes the results of the study and future research.

2 Related Work

2.1 Machine Vision

The introduction of automation in quality control (QC) in the manufacturing industry has revolutionized manufacturing as repetitive tasks can be replaced by machines. Mechanisms that had to be performed by humans in the past caused various human errors and inefficiency. These tasks have traditionally been performed by human operators, but these challenges make machine vision systems even more attractive. The main components of a typical vision system are described in references, [1], [2], [3], [4]. Fig. 1 shows a simple block diagram for a machine vision system, [5].

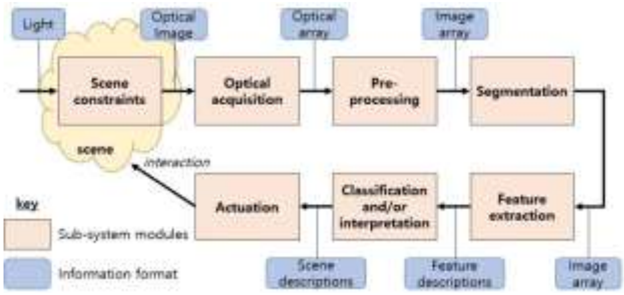

Fig. 1: A Simple Block Diagram for a Vision System Operation

2.2 Object Detection

For a computer to analyze images perfectly, it must not only focus on classifying different images but also try to accurately estimate the concept and location of objects contained in each image, [6]. These tasks are called object detection and have been studied in various fields such as image classification, [7], [8], human behavior analysis, [9], face recognition, [10], and autonomous driving, [11], [12]. However, it is difficult to perform perfect viewpoint object detection due to large variations in the lighting conditions, poses, occlusions, and lighting conditions. Therefore, in recent years, there has been a lot of interest in this field. Studies related to object detection can be largely divided into three categories: information area selection, feature extraction, and classification, and related studies are described in references, [13], [14], [15], [16]. The development roadmap of the framework of general object detection methods can be seen in Fig. 2

2.3 YOLOv7

The YOLOv7 model was proposed by Wang et al. In 2022, we realized faster rates and higher in the COCO dataset. YOLOv7 includes several trainable bags of freebies so that real-time detectors can significantly improve detection accuracy without increasing inference costs. We also study how the module reparameterization strategy can effectively replace the original module and how the dynamic label allocation strategy can allocate different output layers. The speed and accuracy exceed other detectors in the range of 5 160 FPS. It also supports both mobile GPUs and GPU devices from edge to cloud. In the future, this model can be deployed in practical working applications and utilized in real-time industrial inspection systems, [17].

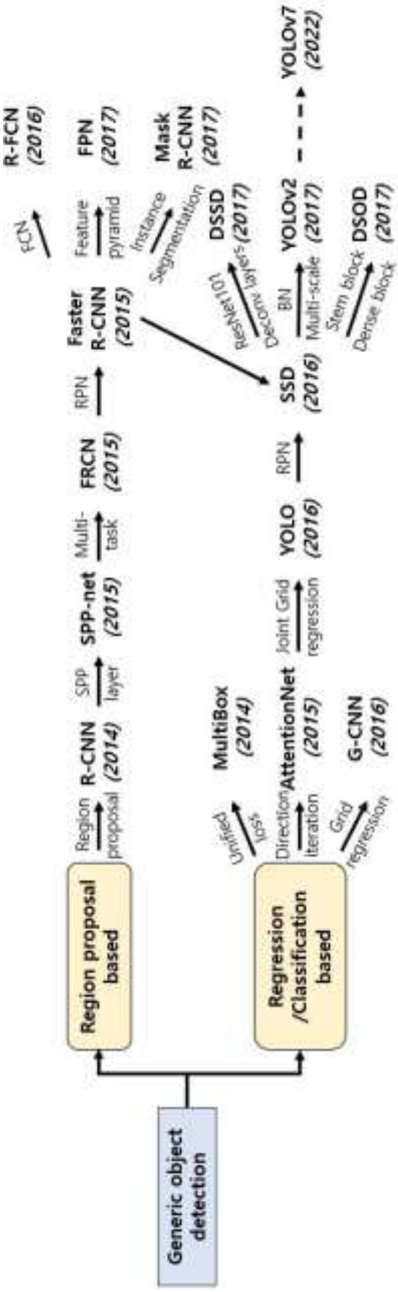

Fig. 2: Two Types of Frameworks: Region Proposal Based and Regression/Classification Based

YOLOv7 is evaluated to have the best performance among the recently announced object detection algorithms. In Fig. 3, you can see the performance evaluation table of Object Detections, [18].

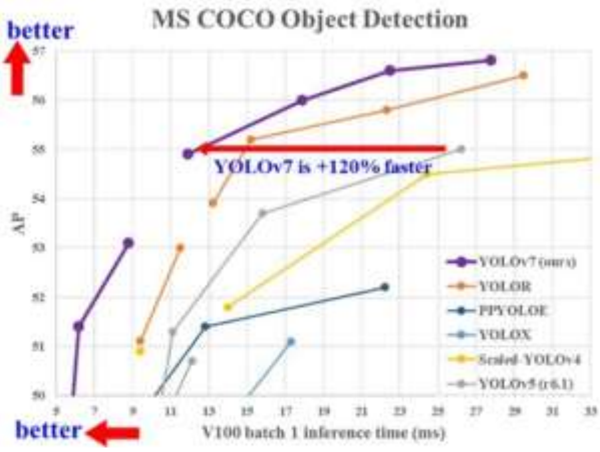

Fig. 3: Comparison with Other Real-time Object Detectors

2.4 Moire Pattern

Oster (1964) and Oster (1968) proposed the Moire pattern as a tool for the optical examination of surface structures in materials science (e.g., mechanical distortion and experimental strain analysis during thermal expansion), [19]. Moire pattern refers to a pattern in which a certain pattern repeats regularly, as shown in Fig. 4. The Moire pattern can make the small curves of a three-dimensional shape stand out more.

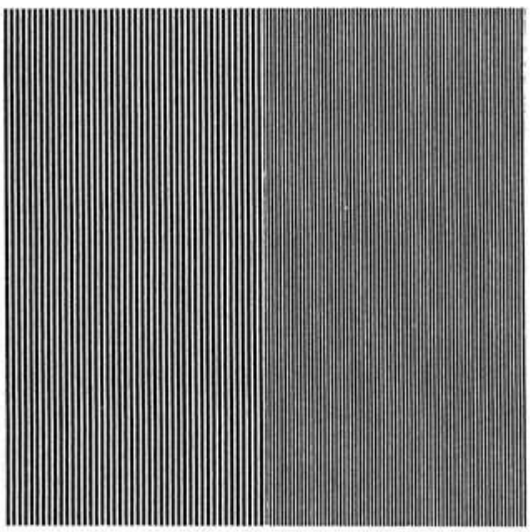

Fig. 4: Example of Moire Pattern

3 Real-time Inspection System based on Moire Pattern and YOLOv7

3.1 Target Product

In this paper, a study was conducted to detect defects on the surface of a cosmetic case, which is a coated high-reflection injection molding product, using deep learning. Fig 5. shows the description of the target product and defect types

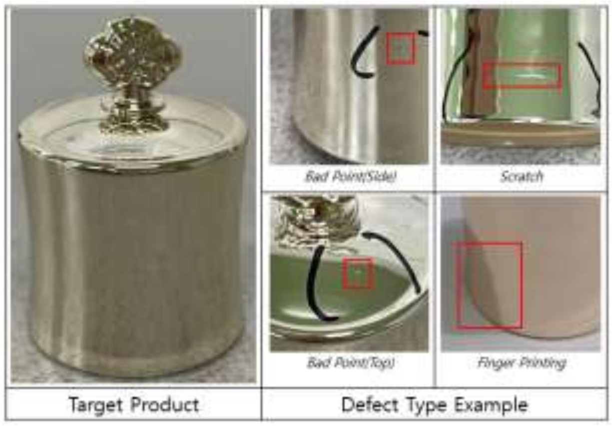

Fig. 5: Target Product / Defect Image Example

The size of the product is a height of 32.52mm, a diameter of 22.25mm, and has a cylindrical shape. The defect occurs on the top and side, and the types that occur are as follows: Scratch, Bad point, Weld, Oil, Finger Printing, and Pollution.

3.2 Optical Setting

The target product is a product coated on the surface of an injection molded product, and it is difficult to accurately acquire a defect image due to diffuse reflection due to the high-reflective surface. We constructed an optimal optical system that can detect defects in all aspects of the product by taking images of the product using 10 cameras, Dark Field and Bright Field, and Moire Pattern. Working distance (WD) is 180mm, and Field of view (FOV) is 50mmx50mm. The concept is described in Fig 6.

Among the types of defects that occur in the product, Bad Point is difficult to distinguish from dust on the image. We used the Moire pattern to solve the problem. In the left image, dust and bad points are treated as NG. On the other hand, in the image on the right, Bad Point is distorted on the stripe and is clearly distinguished from Dust. Fig. 7 shows the difference between when Moire pattern is applied and when it is not.

Dark Field and Bright Field (with Moire pattern) were cross-applied to solve the problem that some defects were not expressed on the image when Moire

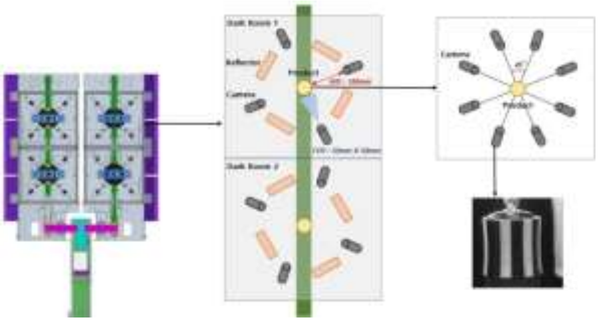

Fig. 6: Equipment / Optical Setting

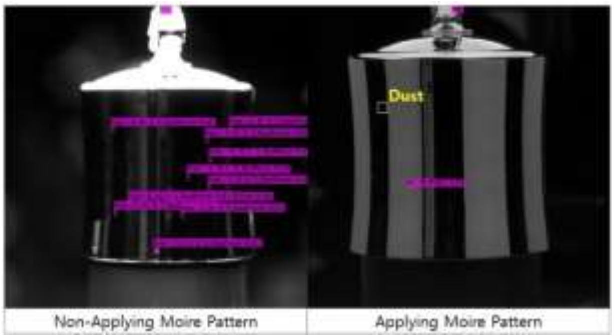

Fig. 7: Distinction between Applying the Moire Pattern and Not

Pattern was applied. In Fig. 8, it can be identified that the Finger Printing defect is covered in Dark Field.

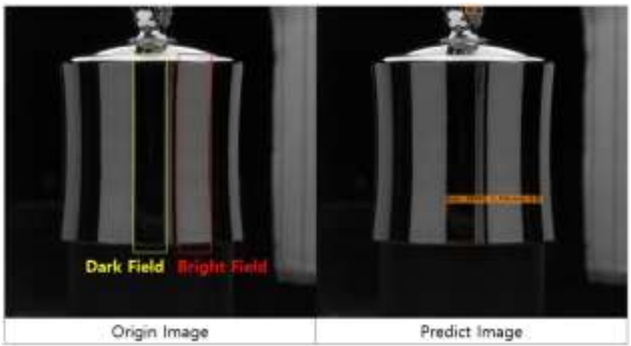

Fig. 8: Inspecting Pollution Defect on Dark Field

3.3 System Architecture

Existing anomaly detection techniques have various classes of defect types and were difficult to apply to manufacturing inspection systems that need to detect irregular defects. We propose a system that uses an object detection algorithm to detect defects by dividing defect types into each class and learning, and if no objects are detected, it is judged normal. This content is schematized in Fig. 9. We trained on 23,852 bad images

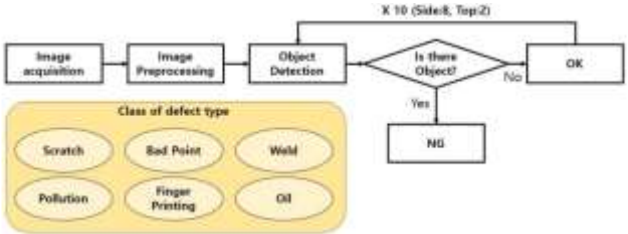

Fig. 9: Concept Diagram of Real-time Inspection System Based on YOLOv7

In order to take and analyze 10 images within 1.2sec, which is the Tact-time in the actual production line, YOLOv7, which is evaluated as the best in terms of current speed and prediction accuracy, was adopted. Fig. 10 shows the network structure diagram of YOLOv7 where captured images are processed, [20].

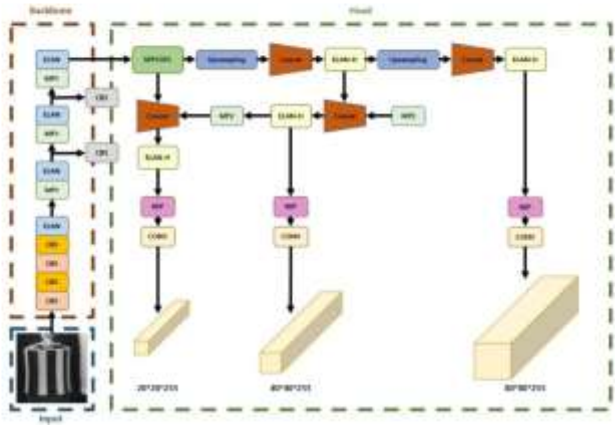

Fig. 10: Network Architecture Diagram of the YOLOv7

3.4 Application

The experiment was conducted in an actual production line of a cosmetic container manufacturer in Gangwon-do, Korea. Equipment was manufactured to satisfy the existing production capacity of
1.2sec/ea. The input part sorts the product and regularly puts it into the inspection system. The optical setting described in section 3.2 is implemented in the optical setting part. The OK/NG output part pushes NG through the cylinder. The monitoring part shows images and statistics being inspected in real-time. You can see an actual case in Fig. 11. A brief system architecture can be found in Fig. 12.

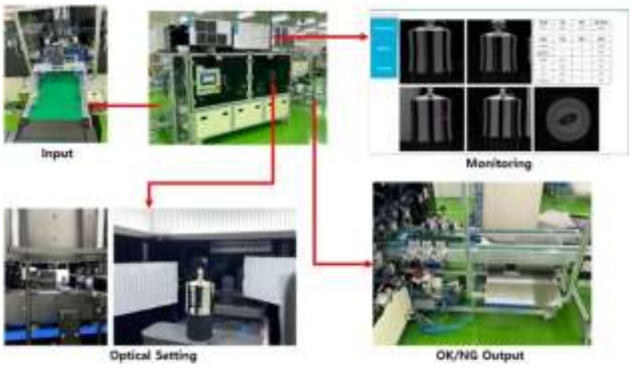

Fig. 11: Application in an Actual Production Line and Image for Each Part

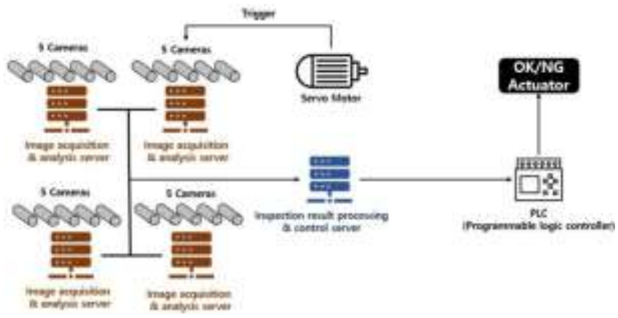

Fig. 12: Simple Hardware Architecture of Real-time Inspection System Based on YOLOv7

4 Experiment Results

4.1 Experience Environment

Table. 1 describes the specifications of the hardware used in this system.

In this paper, we aim to secure inspection speed and detection capability applicable to the actual manufacturing environment. Therefore, the evaluation index of the experiment evaluated the values of miss-detection and over-detection when the actual product was inspected by the inspection system.

4.2Result

In this paper, we proposed an inspection system using the Moire pattern and YOLOv7. Therefore, we evaluated how effective Moire pattern and YOLOv7 were, and each test targeted 1000 products (OK: 700, NG: 300). Table. 2 shows the comparison results when Moire pattern is applied and when it is not applied, and when YOLOv4 and YOLOv7 are applied.

When Moire Pattern was applied, miss-detection improved performance by about 5 times and over-detection by more than 2 times. Compared to YOLOv4, it was confirmed that YOLOv7 improved by about 30%.

Table 1. Specification of the hardware

Industrial Computer	**Analysis**	**Processor**	i5-1160KF
		RAM	16GB
		GPU	RTX 3070
	Control	**Processor**	i5-11400
		RAM	8GB
		GPU	-
Camera		**Sensor Format**	1/1.8”
		Shutter	Global
		Sensor Type	CMOS
		Mono/Color	Mono
		Resolution	1.3MP
Lens		**Focal length**	25mm
		Lens mount	C-Mount

Table 2. Experiment result

Apply Moire Pattern	O		O	O
Applied YOLOv4			O	
Applied YOLOv7		O		O
Total Amount	1,000	1,000	1,000	1,000
Defect Inspection	408	356	343	322
Miss Detection	102	87	21	17
Over Detection	210	143	107	73
Miss Detection Rate	10.2%	8.7%	2.1%	1.7%
Over Detection Rate	21%	14.3%	10.7%	7.3%

5 Conclusion

We proposed a real-time inspection system using YOLOv7 and Moire pattern for coated high-reflective injection molding products. As shown in Table 2, the Moire pattern was able to obtain very effective results for high-reflective products, and the applicability of the inspection system using YOLOv7 to industrial applications was also confirmed.

However, it is true that inspection performance is still insufficient for application in industrial applications. In addition, it is difficult to properly secure defective samples in an actual industrial environment. In order to solve these problems, future research will propose a method to solve the class imbalance problem.

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Corresponding author: Professor Jongpil Jeong

References:

[1] Awcock GJ, Thomas R,"Applied image processing", *London: Mac Millan New Press Ltd.*, 1995.
[2] Pugh A, Robot sensors, *UK: IFS Publication Ltd*, 1986.
[3] Davies ER,"Machine vision theory. Algorithms, practicalities", *UK: IFS Publication Ltd*, 1986.
[4] Bastuchech CM, "Techniques for real time generation of range images. In: Proceedings on computer vision and pattern recognition", *San Diego*, p. 262-8, 1989.
[5] H. Golnabi, A. Asadpour, "Design and application of industrial machine vision systems", *Robotics and Computer-Integrated Manufacturing*, 23, pp. 630-637, 2007.
[6] P. F. Felzenszwalb et al., "Object detection with discriminatively trained part-based models", *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 32, no. 9, pp. 1627–1645, Sep. 2010.
[7] Y. Jia et al., "Caffe: Convolutional architecture for fast feature embedding", *in Proc. ACM MM*, pp. 675–678, 2014.
[8] A. Krizhevsky et al., "ImageNet classification with deep convolutional neural networks", *in Proc. NIPS*, pp. 1097–1105, 2012.Z. Cao et al., "Realtime multi-person 2D pose estimation using part affinity fields", *in Proc. CVPR*, pp. 1302-1310, 2017.
[9] Z. Yang and R. Nevatia, "A multi-scale cascade fully convolutional network face detector", *in Proc. ICPR*, pp. 633–638, 2016.
[10] C. Chen et al., "DeepDriving: Learning affordance for direct perception in autonomous driving", *in Proc. ICCV*, pp. 2722–2730, 2015.
[11] X. Chen et al., "Multi-view 3D object detection network for autonomous driving", *in Proc. CVPR*, pp. 6526–6534, 2017.
[12] R. Girshick et al., "Rich feature hierarchies for accurate object detection and semantic segmentation", *in Proc. CVPR*, pp. 580–587, 2014.
[13] R. Girshick, "Fast R-CNN," *in Proc. ICCV*, 2015, pp. 1440–1448.
[14] S. Ren et al., "Faster R-CNN: Towards real-time object detection with region proposal networks", *in Proc. NIPS*, pp. 91–99, 2015.
[15] J. Redmon et al., "You only look once: Unified, real-time object detection", *in Proc. CVPR*, pp. 779–788, 2016.
[16] Jianfeng Zheng, Hang Wu, Han Zhang, Zhaoqi Wang and Weiyue Xu, "Insulator-Defect Detection AlgorithmBased on Improved YOLOv7", *Sensors 2022*, 22, 8801.
[17] Wang, C.Y., Bochkovskiy A. and Liao, H.Y.M., "YOLOv7: Trainable bag-of-freebies sets new state-of-the-art for real-time object detectors" *arXiv*, arXiv:2207.02696, 2022.
[18] Nishijima Y, Oster G, "Moire patterns: Their application to refractive index and refractive index gradient measurements", *Journal of the Optical Society of America 54*, pp. 1-5, 1964
[19] Kailin Jiang, Tianyu Xie, Rui Yan, Xi Wen, Danyang Li, Hongbo Jiang Ning Jiang, Ling Feng, Xuliang Duan and JianjunWang, "An Attention Mechanism-Improved YOLOv7 Object Detection Algorithm for Hemp Duck Count Estimation", *Agriculture*, 12, 1659, 2022.