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RF 에너지 하베스팅과 마스크-RCNN 기반의 음식물 질 분류를 위한 딥러닝 접근

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A Deep Learning Approach for Food Quality Classification Based on RF Energy Harvesting and Mask-RCNN

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Abstract In this study, we aim to develop a battery-free monitoring system for food freshness based on radio frequency energy harvesting. The designed radio frequency (RF) energy harvester converts a 915 MHz RF signal into a constant DC power to supply for all tag components. To overcome some drawbacks of conventional food monitoring methods, an air pressure sensor is used to measure the gas emission during storage. In addition, we combined the battery-less sensor tag with an image classification system. Mask Region Convolutional Neural Network (Mask R-CNN) was used for food spoilage detection. Food detection results of 100 test images showed that the average detection precision rate was 97.78%, the recall rate was 96.41% and the mean intersection over union (MIoU) rate for instance segmentation was 90.75%. The trained detection model was used to find the values of inside pressure at which the food freshness turns from one level to another. The sensing circuit composes a high accuracy pressure sensor and other ultra-low power components, allowed it to consume low average power of only 1mW.

• Key Words – far-field RF energy harvesting, deep learning, food freshness monitoring, mask R-CNN

Ⅰ. INTRODUCTION

Radio frequency energy harvesting (RFEH) is a technology that allows to transfers power over radio bandwidths. It has become a promising solution for self-sustainable standalone wireless sensor systems due to its cost-saving ability, increasing lifetime and reducing maintenance [1]. On the other hand, food quality is one of the most concerned problems in our life as it is closely related to human health [2]. The food contamination process causes changes in food features, such as firmness, tenderness, and color that reduce the taste of food. Therefore, reliable system for food monitoring is essential in the food production, delivery, and retail industry to limit food waste and foodborne illness.

Moreover, deep learning over recent years has demonstrated excellent capabilities for learning image features and is widely used in image object detection. Nevertheless, Mask R-CNN, a state-of-the-art method in the field of object detection proposed by Kaiming et al. (2018) [3], has been able to integrate target detection and instance segmentation into a single framework. Mask R-CNN not only accurately recognized the categories and marked out object regions with bounding boxes but also extracted object regions from the background at the pixel level.

In this paper, we present a fully passive smart sensor tag using far-field RF energy harvesting operated at 915Mhz. To overcome the drawbacks of gas sensor in food monitoring, our study focuses on measuring the air pressure increased inside food package during storage.

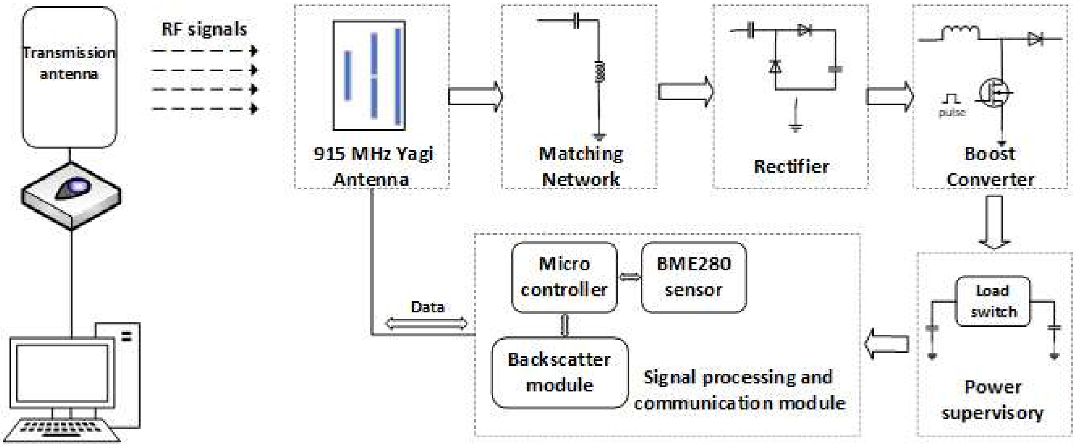

Fig.1 The block diagram of a proposed self-power food monitoring system.

The designed sensor tag and an object detection system utilizing Mask R-CNN are used to monitor food statement continuously in 5 days to find the values of air pressure at which the food turn from one level to another.

Ⅱ. SYSTEM DESIGN

2.1. Structure of the proposed smart sensor tag

The architecture of proposed food monitoring system contains a server, a reader and a smart sensor module as shown in Fig.1. There are two major factors required in a RF harvester. First, the receiving antenna must efficiently capture weak incident RF power. The system operating frequency is 915 MHz for harvesting and communication channels. Second, the power management circuits must efficiently generate constant voltages to supply for applications [4].

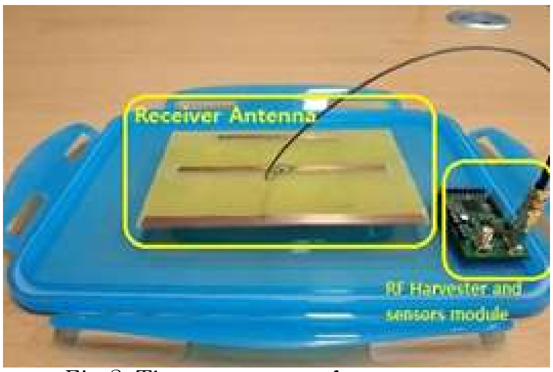

Fig.2 The prototype of a sensor tag.

A single-stage Dickson rectifier based on Schottky diodes have been used for the harvesting module. The commercial diodes HSMS 285C with a turn-on voltage as low as 150 mA is selected. Because the harvested power was small, an ultra-low power microcontroller (MSP430FR5969, Texas Instruments, USA) is chosen to process data and control the operational models. A pressure sensor (BME280, Robert Bosch GmbH, Germany) is utilized to measure air pressure, temperature and humidity inside food package. A backscatter tag chip (SL900A, AMS AG, Austria) is chosen for wireless data communication. The prototype of the tag is shown in Fig.2

2.2. Model structure of Mask R-CNN

Computer vision is a scientific field that deals with how computers can improve their understanding of digital images such as photos or videos. Mask R-CNN is developed to solve problems in instance segmentation or image segmentation which is one of computer vision task. The overall network structure of Mask R-CNN is shown in Fig.3.

The idea of Mask R-CNN is based on Faster R-CNN [5] which is a model of combining object detection and classification. Mask R-CNN adds a third branch that output a binary mask indicating the pixels where the object is in the bounding box. ResNet and FPN is used to extract the feature map instead of CNN. The more refined ROI Alignment layer is applied to replace the ROI pooling layer in Faster R-CNN architecture. Finally, the FC and FCN layers is chosen for target classification and instance segmentation, respectively. For the reader who is interested in Mask R-CNN, we highly recommended reading the reference [3].

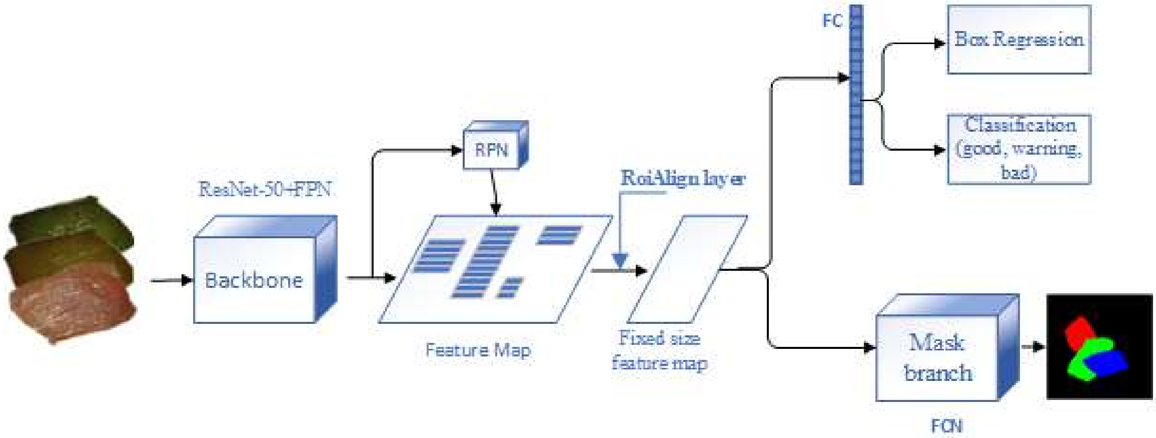

Fig.3 Mask R-CNN architecture for instance segmentation.

Ⅲ. EXPERIMENT RESULTS

3.1 Air pressure measurement with sensor tag

For each experiment with pork, fish and chicken, 200g of food is stored in a 2L container integrated with the designed sensor tag. The battery-free sensor tag is powered by a 915 MHz dedicated RF transmitter. Temperature and air pressure inside food container are read by sensor tag every two minutes in 5 days. The results are shown in Fig 4.

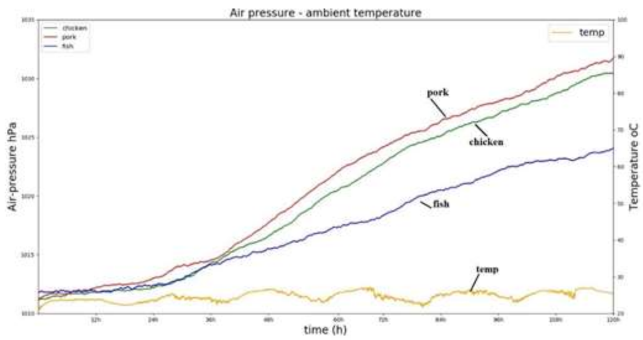

Fig.4 Air pressure variation in the food package in 5 days.

3.2 Food freshness detection with Mask R-CNN

In this study, pork is used to assess food freshness. A three-color scale for pork that reflect its freshness was used to label 1000 images of the training dataset. A pre-trained based on the COCO dataset (Lin et al., 2014) [6] was introduced using transfer learning to solve the problem of a small training set. During experiment, ResNet-50 had the best performance combined with FPN architecture and was chosen as the backbone network of the pork quality detection model. The confusion matrix of the detection results for 100 image samples is investigated to evaluate the trained model. Finally, the overall precision and recall rates were 97.78% and 96.41%, respectively.

Even though the average processing frames per second (FPS) is slower than the standard for video application due to the large amount of computation from the backbone. The image detection is performed every two minutes in five days. So that the trained model is possible to use for the real-time requirement.

At present, the method used in this paper can accurately realize the target detection of pork freshness. The trained Mask R-CNN model able to use for real-time measurement in our application. The computer vision system and air pressure sensor tag are operated synchronously to gather data. Then the relationship between the image classification and air pressure variation is studied to find the threshold value of pressure inside the food package.

Ⅳ. CONCLUSION

In this paper, we have adopted the combined food monitoring system based on far-field RF energy harvesting technique and mask regional convolutional neural network. Owing to the high accuracy of the image detection system, the threshold air pressure inside food package is found to classify the quality of food during storage. The experimental results of pressure measurement during food monitoring showed that the proposed sensor node able to efficiently employ as a state-of-art food freshness monitoring technique.

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