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Recommendation

ITU-T F.747.11 (12/2022)

SERIES F: Non-telephone telecommunication services

Multimedia services

Requirements for intelligent surface-defect detection service in industrial production lines

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Recommendation ITU-T F.747.11

Requirements for intelligent surface-defect detection service in industrial production lines

Summary

Intelligent surface-defect detection service in industrial production lines refers to the accurate product defect location determination, high-speed classification of defect types, real-time output and transmission of visual and auditory information to ensure the quality of industrial products. Compared with inspection carried out manually by workers, the intelligent surface-defect detection service can improve efficiency and consistency and reduce manual operations in dangerous areas. This Recommendation specifies requirements for intelligent surface-defect detection service in industrial production lines, including performance requirements, application requirements and functional requirements. To provide an effective surface-defect detection service, it is required to fulfil three important parts. Firstly, it is important to ensure the accuracy location determination and classification. Secondly, the inference efficiency of the service is also required to satisfy the real-time settings. Last but not least, the service is required to adapt to the typical application scenarios in industrial production line inspection tasks.

Recommendation ITU-T F.747.11 provides related requirements for intelligent surface-defect detection service in industrial production lines.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T F.747.11	2022-12-14	16	11.1002/1000/15192

Keywords

Industrial production line, intelligent, multimedia video, surface-defect detection.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Recommendation ITU-T F.747.11

Requirements for intelligent surface-defect detection service in industrial production lines

1 Scope

This Recommendation specifies requirements for intelligent surface-defect detection (ISD) service in industrial production lines, including performance requirements, application requirements and functional requirements. The reference architecture, multiservice management and development tools in general machine vision-based platform are out of the scope of this Recommendation.

The scope of this Recommendation includes:

– performance requirements of ISD service;

– application requirements of ISD service;

– functional requirements of ISD service.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T F.748.21] Recommendation ITU-T F.748.21 (2022), *Requirements and framework for feature-based distributed intelligent systems.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following term defined elsewhere:

3.1.1 machine vision [b-ITU-T F.748.16]: Signal processing to acquire, process and interpret an image or video to support visual analysis for applications, such as automatic inspection, process control and guidance.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 surface-defect detection: Surface-defect detection refers to the identification of defects on the surface of industrial products, including the location determination, classification and measurement of different types of defects.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CPU Central Processing Unit

FPGA Field Programmable Gate Array

GPU	Graphics Processing Unit
ISD	Intelligent Surface-defect Detection
mAP	mean Average Precision
PCB	Printed Circuit Boards
SoC	System on Chips

5 Conventions

In this Recommendation:

– The keywords "**is required to**" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this document is to be claimed.

– The keywords "**is recommended**" indicate a requirement which is recommended but which is not absolutely required. Thus this requirement needs not be present to claim conformance.

– These terms are not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

6 Overview of the intelligent surface-defect detection service

Surface defects are mainly caused by occasional machine failure, operation error or production environment problems in the production process. For surface defects, images captured by cameras can be directly used for detection. Under the influence of various factors, the types of surface defect are diverse. Taking the surface of aluminium product as an example, there are various types of defect such as paint bubble, erasing, orange peel and so on. To identify the defect type and defect area, overkill rate and miss rate are two important metrics for an intelligent surface-defect detection service. Overkill rate is measured by the number of defects incorrectly identified while the miss rate is measured by the number of defects not identified. the tolerance of the miss rate is stricter than the tolerance of the overkill rate.

Different operation measures are required to be taken for different defect types. Some defects have little impact on quality and can be accepted by the purchaser if the product is offered at a lower price, while some defects can be repaired. Products with a defect with a serious quality impact cannot be sold. Therefore, in practical application, it is recommended to classify products and distinguish between normal samples without defects and defective samples. Further, it is recommended to locate defects and mark the specific location of defects, which is collectively referred to as defect detection in this Recommendation.

In the real production environment, the imaging quality of some images is poor and there is a lot of noise and interference. It is difficult to obtain good detection efficiency in these scenes by implementing traditional image processing algorithm or the manual feature extraction method. AI has entered a period of rapid development, and deep learning has made significant breakthroughs in the field of computer vision. In image classification, target detection, image segmentation and other computer vision tasks, AI has a good effect. The application of computer vision based on deep learning in surface-defect detection has become a major development trend.

The ISD service in industrial production lines refers to accurate products defect location determination, high-speed prediction of defect types, real-time outputs and transmission of visual and auditory information to ensure the quality of industrial products. Compared with the inspection carried out manually by workers, the ISD service can improve efficiency and consistency and reduce manual operations in dangerous areas.

7 Requirements of the intelligent surface-defect detection service

7.1 Performance requirements

a) Applications include but are not limited to detecting surface defects on electronic devices, steel, and so on. The shapes and scales of defects vary in different scenarios, so the service is recommended to carry out classification, object detection, semantic segmentation and low-level vision tasks, including identification of defects type, location by overlaid rectangular box or defect outline, and measurement of defect area.

b) Noisy annotations are inevitable even for human experts, thus image-level acceptance metrics, such as overkill rate and miss rate, are usually adopted in industrial applications. Besides, the performance requirements vary in different industries. Tasks specified as having a strict control on the miss rate are normally allowed to meet a relatively relaxed overkill rate requirement, and system efficiency is recommended to be considered with the spatial size of the input image and the universal workflow.

7.1.1 Steel or steel products

It is recommended to have a 5-10% overkill rate, but the miss is strictly controlled under 0.1%. The processing time is recommended to be between 0.5 s and 1 s. However, in some exterior steel accessories, such as seat slide rail detection, although scratches and bumps still need to be detected, the requirements will be relaxed compared with the aforementioned standard.

7.1.2 Electronic devices

The application for electronic devices is highly associated with the industries described in clauses 7.1.2.1 to 7.1.2.4.

7.1.2.1 Battery industry

Since surface elevation is essential for identifying pit-like defects and the widely used black/white photography further increases the difficulty of identification, the overkill and miss rates are recommended to be below 5% and 1% respectively. Input images are recommended to retain high resolutions to better locate any tiny defects.

7.1.2.2 Magnetic core and magnetic ring

For magnetic core applications, the runtime is recommended to be less than 100 ms per image and the overkill and miss rates are recommended to both be lower than 1%. For magnetic ring, the target overkill and miss rates are recommended to be less than 0.5% and 1%, respectively. The recommended input image size is 2 000 × 2 000 pixels, much larger than that of magnetic core, e.g., 500 × 800 pixels, thus the systematic runtime is recommended to be less than 500 ms and independent stations can work in parallel.

7.1.2.3 Display industry

The overkill and miss rates are recommended to be controlled under 5% and 0.1%, respectively. The efficiency requirements are conditioned on the image size. For example, the defect detection system is recommended to recognize tiny cracks, breakages and dirt on an 8 000 × 16 000 pixel image within 500 ms, hence additional plug-in algorithms and modules are not accessible due to the strict runtime constraint and limited computation resources.

7.1.2.4 Semiconductor industry

The semiconductor industry usually cannot tolerate any missed defective products, while the overkill rate can be even relaxed to 20% because the major production purpose lies in the quantity growth and a compulsory manual check will follow the machine inspection. Also, images are rather small. The runtime is recommended to be 15 ms on 400 × 400 pixel images.

7.2 Application requirements

a) The ISD service is required to provide flexible and extensible service interfaces.

b) The ISD service is recommended to adapt to the actual input in diverse scenarios according to the specific use case.

c) The defect detection results are recommended to be delivered with low latency to the manufacturing executive system.

d) The output of the service is recommended to include both visual description (defect location and types) and the synchronous audio messages (normal and alarm) if needed.

7.3 Functional requirements

a) The data pre-processing algorithms deployed in edge devices should be efficient to remove unrelated information for detection.

b) The surface-defect algorithms are required to support classification, prediction, regression and clustering.

c) The AI models are required to be deployed in various embedded platform, such as the graphic processing unit (GPU), central processing unit (CPU), system on chips (SoC) and field programmable gate array (FPGA).

8 Reference architecture

The ISD service introduces a cooperation mechanism among the terminal devices, edge devices and servers shown in Figure 1. The images captured by the front-end need to be transferred to the edge devices and GPU server to finish high-speed inference and the final visual detection results and the corresponding auditory information will be updated in the real-time application system.

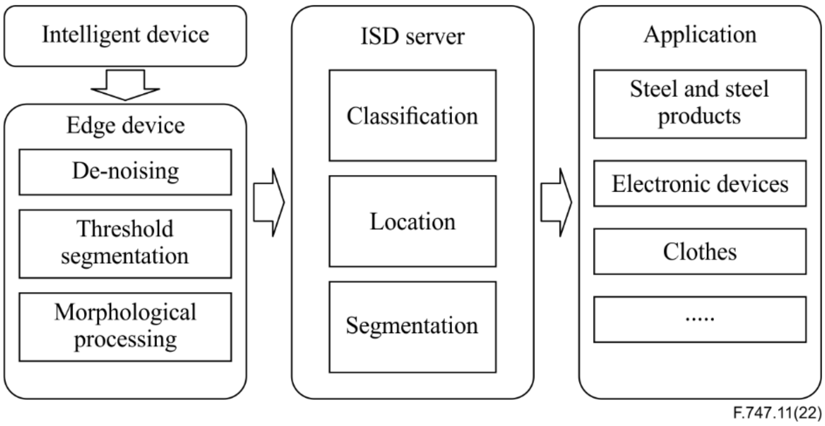

Figure 1 – Illustration of the ISD service

8.1 Intelligent device

Intelligent devices are mainly image acquisition devices combined with AI chips to complete image/video acquisition. The image acquisition devices generally include cameras, lenses and light sources. The camera is an indispensable part of a defect detection service. Its function is to convert the optical image generated by the lens into the corresponding analogue or digital signal through the imaging sensors, and transmit the information to the upper computers for processing through the interface between the cameras and the computers. For surface-defect detection, linear array cameras and planar array cameras are commonly used. Cameras are combined with AI chips, using the algorithms within the cameras to set the shoot parameters. The algorithms can automatically identify each kind of environment, and adjust the camera settings, in order to make shooting achieve excellent results. When there is a poor shooting environment, to the algorithms should activate shoot and advanced features such as automatic high dynamic range (HDR), thus further enhancing the image quality.

8.2 Edge device

The output of intelligent devices should be pre-processed. The pre-processing of multimedia mainly includes image de-noising, threshold segmentation, morphological processing and so on. In the process of image collection, transmission and processing, the image quality will be degraded and various noises will be generated due to the influence of the cleanliness of the surface of the detected object, the cleanliness of the industrial lens, the internal noise of the sensitive components and lighting changes. Image noise has a great influence on subsequent image processing, which affects each link of image processing and the output result. Therefore, before surface detection, de-noising algorithms are used to remove the noises of the detected image. Image threshold segmentation algorithms are used to compress the amount of data and simplify the steps of image analysis and processing, and this is an essential image pre-treatment process before image analysis, feature extraction and pattern recognition. Image morphology processing algorithms are used to analyse the structure and shape characteristics of the image, so as to facilitate the processing of the subsequent defect detection process.

In support of the requirements in clause 7.1, the edge device provides:

– support of image de-noising, image threshold segmentation and image morphological processing;

– support of feature [ITU-T F.748.21] extraction, such as human designed features and convolution neural network features.

8.3 ISD server

ISD servers have the capability to solve three problems of surface-defect detection: "what is the defect", "where is the defect", and "how large is the defect". "What is the defect" is corresponds to the classification task, "where is the defect" corresponds to the locating task and "how large is the defect" corresponds to the segmentation task.

In support of the requirements of clauses 7.1 and 7.2, the ISD server provides:

– support of defect classification, defect location and defect segmentation;

– support of model training and model inference.

The model performance is required to be evaluated before deployment; the model performance can be mean average precision (mAP).

8.3.1 Defect classification

In the real industrial production environment, defect classification in a complex environment becomes a difficult task due to the huge variety in object shape, size, texture, colour, background, layout and imaging illumination. The classification network based on a convolutional neural network with a powerful feature extraction ability is used in surface-defect classification.

In support of the requirements of clauses 7.1 and 7.2, defect classification includes:

– identifying common industrial defect types including wrinkles, pits and scratches;

– supporting multiple algorithms including machine learning algorithms;

– supporting the coordination of edge devices and ISD servers for time limitation.

8.3.2 Defect location

The purpose of defect localization is to obtain accurate location and category information of the target. It not only obtains the types of defects in the image, but also gives the specific location of the defects.

In support of the requirements of clause 7.1, defect location includes:

– support for the identification of the location of defects by overlaid rectangular boxes.

8.3.3 Defect segmentation

The surface-defect detection segmentation network transforms the task of surface-defect detection into semantic segmentation and even instance segmentation of the defect and the normal area. It can not only segment the defect area, but also obtain the location, category and corresponding geometric attributes of the defects including length, width, area, contour and centre location.

In support of the requirements of clause 7.1, defect segmentation includes:

– support for the identification of defect outlines and measurement of defect area.

8.4 Application scenario

Compared with traditional image processing methods, which are divided into multiple steps and links to process defect detection tasks, a deep learning based ISD service unify these into end-to-end feature extraction and classification. There are different types of defect detection in different industries and fields. The intelligent defect detection service in different application scenarios should correspond to real surface-defect data.

In support of the requirements of clauses 7.1 and 7.2, the application provides:

– support of flexible and extensible service interfaces;

– support of both visual description including defect location and types and synchronous audio messages including normal and alarm.

Appendix I

Use cases of ISD service

(This appendix does not form an integral part of this Recommendation.)

I.1 Provide detection service for steel and steel products

The defects, i.e., cracks and pits on steel products, shown in Figure I.1, are identical to the background region, and the reflective surface might even fail the defect detection system equipped with a normal lighting system. In consequence, the lighting scheme is recommended to be designed carefully according to the sample surface property, because the system efficacy is the major concern of the related industries. The requirements of steel instruments such as accelerators, rollers and so on, will focus on the scratches and bumps of the work piece, because they may risk safety.

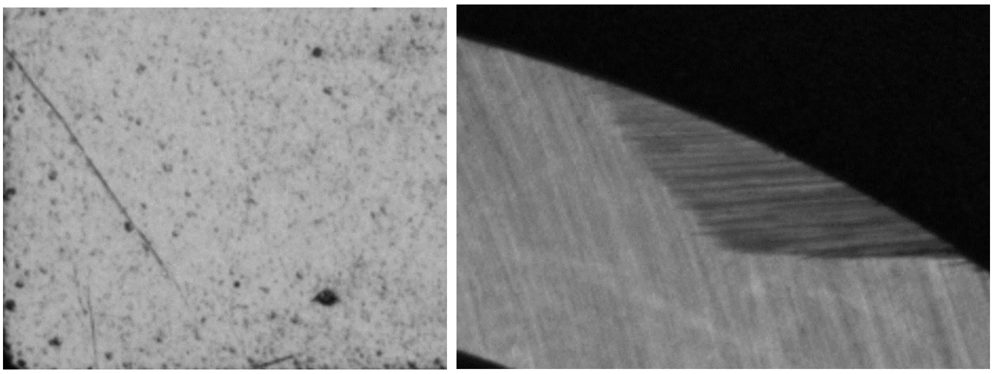

Figure I.1 – Illustrations of defects (crack and pit) on steel products

I.2 Provide detection service for electronic devices

A detection service for electronic devices locates and identifies surface defects including cracks, wrinkles, pits, scratches and other possible anomalies.

Surface defects in the battery industry mainly include wrinkles, pits and scratches, as shown in Figure I.2, thus detection- and segmentation-based techniques can handle these issues.

Figure I.2 – Illustration of defects (wrinkle, pit and scratch) in the battery industry

The magnetic-core-related industries have much smaller input images, e.g., 500 × 800 pixels, with clear boundaries between the fore- and background regions. The individual defect specification has been well established and multidefect identification is not common. The acceptance standard changes only if multidefect scenarios need to be considered. In contrast to the magnetic-core-related industries, the majority of the magnetic ring community requires simultaneous multidefect identification including cracks, waterlogging and impurities that usually cause a slight abnormal surface appearance.

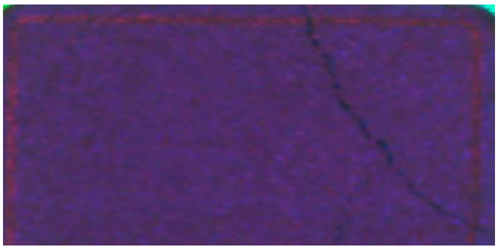

Figure I.3 – Illustration of defects (crack) in the magnetic core or ring industry

The display industry focuses on defect detection at the display edges, thus the foreground region can be located based on the colour contrast. However, some high-quality display producers might have demanding inspection standards in extreme cases. Defects including crack and breakage are shown in Figure I.4.

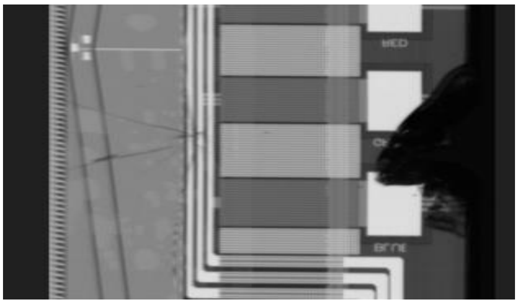

Figure I.4 – Illustration of defects (crack and breakage) in the display industry

As a main product of the semiconductor industry, the PCB-sub board has been widely used in electronic products. The randomness and variety of the defective products are the key issues for the defect detection system. In contrast to the other settings, the query sample is always provided with a perfect template sample for better identifying the potential defects on the query sample. Besides, to achieve better performance, the design drawings can be also leveraged to locate the regions of interest on various PCB-sub boards. The defects including lost, impurity and pits are shown in Figure I.5.

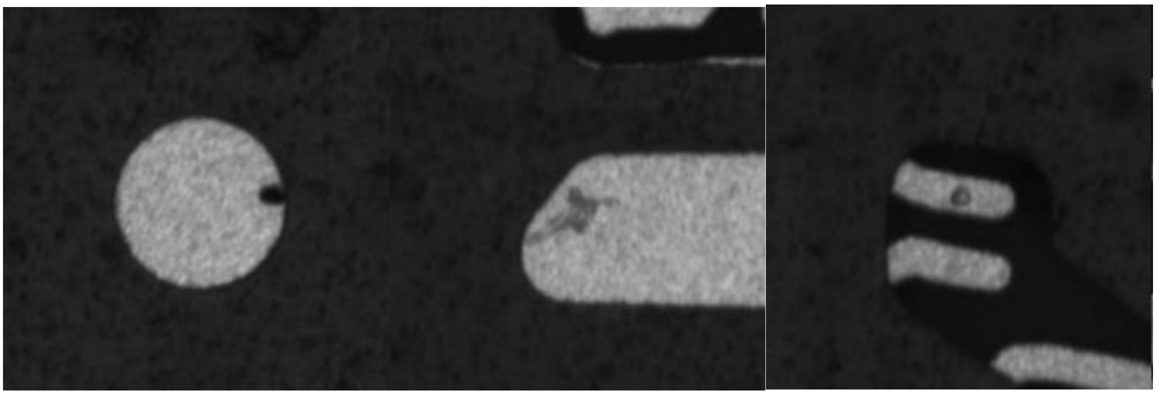

Figure I.5 – Illustrations of defects (lost, impurity and pit) in the semiconductor industry

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[b-ITU-T F.748.16] Recommendation ITU-T F.748.16 (2022), *Requirements for machine vision-based applications and services in smart manufacturing*.

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