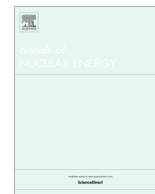




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Intelligent intrusion detection system featuring a virtual fence, active intruder detection, classification, tracking, and action recognition

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ABSTRACT

An intrusion detection system (IDS) is primarily used to protect nuclear power plants from external threats, such as sabotage and malicious attacks. However, earlier versions of IDSs are configured to detect an intrusion from visual inspection by an operator. This has the disadvantages of requiring standby human resources and relying on operator capabilities. In this paper, therefore, we propose an image-based intelligent intrusion detection system (IIDS) with a virtual fence, active intruder detection, classification, and tracking, and motion recognition to solve these limitations. An integrated acquisition device was manufactured combining optical and thermal cameras to compensate for the disadvantages of optical cameras, which have difficulty detecting an intrusion at night, under adverse weather conditions, and when the intruder is camouflaged. The virtual fence has a function to set the boundary between surveillance and external areas in a graphical user interface, and to define an early pre-alarm area if necessary. The background model is designed to detect moving objects, and detected objects are segmented into bounding boxes. We implemented a network model based on a convolutional neural network (CNN) to classify moving objects as either intruders or wild animals. If an intruder is detected in real time and is crossing the virtual fence, the alarm tile blinks with the associated color. Five types of intruder behavior patterns are recognized by optimizing a long-term recurrent convolutional network (LRCN) model. The proposed IIDS meets the physical protection requirements recommended in the nuclear regulatory guidelines, and can be used as an unmanned surveillance system. It is expected to perform more active and reliable intrusion detection in combination with existing sensors, such as microwaves, electric fields, and fence disturbance sensors in a nuclear power plant.

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1. Introduction

The physical protection system (PPS) of a nuclear power plant (NPP) provides a primary defense against physical intrusion (U.S. Congress, 1992), integrating people, procedures, and components (hardware and software) to protect assets or facilities from threats like malicious attacks, sabotage, and theft (Garcia, 2007). Nuclear regulatory agencies are urged to implement the following regulatory guidelines and requirements of physical protection systems for safe nuclear operations, and to emphasize the importance of systematic intrusion detection schemes and their implementation in order to prevent physical intrusions. The specific regulatory guidelines and requirements include 10CFR73.55, a top-level regulation that specifies physical protection requirements to protect nuclear facilities from radiological sabotage, covering security pro-

cedures, configuration, installation, and evaluation of intrusion detection systems (Nuclear Regulatory Commission, 2015).

IAEA NSS13 provides recommendations and guidelines for establishing, implementing, and maintaining a nuclear security program and its security regime. It specifies the elements necessary for nuclear security and security recommendations for nuclear power plants, particularly for the physical protection of nuclear facilities and nuclear materials from malicious acts by terrorists (International Atomic Energy Agency, 2011).

RG5.44-1997 covers intrusion detection sensors and methods recommended for nuclear facility protection. It also includes a list of sensors that can be integrated to form a systematic intrusion detection system in the protected area and specifies guidelines for methodologies (Nuclear Regulatory Commission, 1997).

NUREG1959-2011 covers in detail the design, installation, testing, and maintenance of an intrusion detection system (IDS) for the physical protection of nuclear power plants (Nuclear Regulatory Commission, 2017).

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IEEE692-2013 provides standards for the design, testing, and maintenance of electrical, instrumentation, and control equipment related to integrated security systems of nuclear power plants. This standard specifies the selection and application of equipment to monitor, detect, display, and record the security environment and events (IEEE Standards, 2013).

An IDS is a system that performs the intrusion detection function of a PPS. It detects physical intrusions through various highly sensitive sensors, as well as a protective barrier to isolate the facility from the outside. For example, existing IDSs use sensors, such as microwave sensors, electric field sensors, active infrared sensors, and fence disturbance sensors, to detect changes in electromagnetic wavelengths or the shaking of the barrier to detect intrusion by external objects (Garcia, 2005). However, existing IDSs have a disadvantage in that an operator visually inspects transmitted intrusion detection signals from an alarm using closed circuit television (CCTV). This is because the intrusion detection sensor is unable to identify the originator of the signal, and occasionally responds to natural phenomena (such as shadows created by sunlight) or the movement of wildlife around the facility. Even if this procedure is a reliable way to identify whether an attack has occurred, it has a limitation in that it requires the continuous presence of human resources (Fennelly, 2016; Fennelly and Perry, 2016). In order to overcome the disadvantages of the existing IDSs, we propose an intelligent intrusion detection system (IIDS) that can greatly enhance the efficiency and reliability of intrusion detection in nuclear power plants. The system uses dual cameras, image processing, computer vision, and deep learning technologies to set up virtual boundary regions optimized for geographic environments, automatic identification and tracking of intrusion signal entities, and intruder behavior recognition. In addition, the IIDS can itself function as an intrusion detection sensor, and can perform more active and reliable intrusion detection. In the rest of this paper, Section 2 describes the studies related to existing intrusion detection methods and techniques, and Section 3 provides the methods for manufacturing and physically controlling heterogeneous dual camera modules. through 47 describe virtual fence construction, intrusion object identification and visual tracking, intruder action recognition, and operator interfaces. In Section 8, experimental results with the proposed IIDS are presented. Finally, Section 9 provides a discussion and concluding remarks.

2. Related works

The Robotics Institute of Carnegie Mellon University (Collins et al., 2000) developed autonomous video surveillance and monitoring systems. They proposed the ability to continuously monitor, detect, and track people and vehicles in complex environments. Moving objects are detected and classified as humans or vehicles using an artificial neural network. In particular, vehicles are classified by color and type. When a person is classified, the skeletal form is extracted, and then the behavior is analyzed and recognized using a Markov model.

The intelligent video surveillance (IVS) system proposed by Prakash and Thamaraielvi (2014) identifies security threats intelligently without user intervention. A Gaussian mixture model, which is an extended Kalman filter, is used for red–green–blue (RGB) background modeling and to detect moving objects using a background model. However, the IVS only includes a function for detecting an object, but does not include a function for classifying the detected object, and does not include a function for recognizing the behavior of the object.

Dimou et al. (2016) proposed a pedestrian detection framework based on a faster region-based convolutional neural network (RCNN) and a recurrent neural network (RNN) to robustly cope

with motion blur and scale deformation of objects generated by pan-tilt-zoom (PTZ) and low camera quality. In order to effectively detect pedestrians in motion-blurred images, blurred image data were used in training data sets. A transformation matrix was modeled to estimate object size and pose in successive input images.

Saran and Sreelekha (2015) proposed a surveillance system that uses CCTV to detect and classify vehicles. They applied real-time vehicle detection and classification algorithms. Object detection is performed with a background subtraction method, and the background is modeled by using a Gaussian mixture model. In order to classify the detected vehicles, a method combining histogram of oriented gradients (HOG) and artificial neural networks (ANN) was used. However, unlike CNN, which extracts features by itself, this method requires preliminary work to extract features of a vehicle using hand-crafted methods before classification using the ANN.

3. Camera modules

In general, the optical camera used in an IDS is an indispensable device for image acquisition, but it is difficult to detect an intruder at night, in adverse weather and when the intruder is camouflaged. In order to overcome these shortcomings, we manufactured an integrated image acquisition device that combines optical and thermal cameras.

3.1. Manufacturing and calibration of heterogeneous cameras

The baselines of the optical and thermal cameras were prepared by horizontally arranging the lens center point at intervals of 5 cm. We used a FLIR Tau2 thermal camera (field of view [FOV] 35 mm, resolution 640 × 512) and a SAMSUNG SCO-2120R optical camera (FOV 3.94–46.05 mm, resolution 811 × 508). In addition, an SPE-101 network video server with secure login and an IP-filtering function is used for network connection and pan-tilt control.

The manufactured multimodal camera is controlled by an SPT-3100 pan-tilt device with PANNING of 350°, a TILT rotation range (upper 30° ~ lower 80°), and pan and tilt rotation speeds of 6° per second and 4° per second, respectively. The pan-tilt device is connected to the RS-485 port of the network video server and is controlled using the Pelco-P protocol.

Each camera in the multimodal camera has radial distortion and tangential distortion from the manufacturing process. In order to eliminate such distortions, the calibration algorithm proposed by Zhang (2000), the correction function of OpenCV (Bradski et al., 2008), and a chessboard with a heat source, as shown in Fig. 1, were used to calibrate each camera.

The focal length, principle point, asymmetry coefficient, and distortion coefficient were extracted by applying a calibration algorithm to 26 chessboard images (13 images per camera) taken from different viewing angles. The extracted coefficients were input as parameters of the camera distortion correction function of OpenCV to correct the distortion.

3.2. Rectification of heterogeneous cameras

Image rectification aligns the calibrated image with the chessboard to the same size image through vertical and horizontal conversion. Fig. 2 shows the flowchart of the rectification algorithm.

First, the coordinates of each block's corner point are extracted by applying the Harris corner detection algorithm from the two calibrated chessboard images. After calculating the slope by substituting the two coordinates of the vertically positioned block's corner points of the optical image into Eqs. (1) and (2), below, the thermal image is rotated with respect to the perpendicular angle

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