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nID-based Internet of Things and Its Application in Airport Aviation Risk Management*

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Abstract — Internet of Things (IoT) is attracting intensive attention. Currently, most existing IoT systems heavily rely on the identification (ID) number of each object/thing, referred as ID-based IoTs. However, in many cases, the ID-based IoT becomes inapplicable due to non-cooperative things that are not attached with any ID number or difficult to obtain an existing ID number. This paper proposes a new non-ID (nID) things concept for non-cooperative things, and nID-based IoT to make IoT suit more real situations. Then, a nID-based IoT solution is designed for the airport aviation risk management, and some key issues including sensing, coding and resolving are discussed. Additionally, an exemplary case study of bird-strike hazard management is presented to further explain how to apply the nID-based IoT for the scenario with non-cooperative things. It is envisioned that nID-based IoT will support increasing number of applications where the things have no any available IDs.

Key words — Internet of Things (IoT), nID things, nID-based IoT, Radar sensing, Aviation security, Risk management

I. Introduction

Internet of Things (IoT) currently attracts increasingly intensive research activities in academia, industries and governments[1−2]. IoT was introduced by Auto-ID Center at MIT in 1999. The original vision of IoT stands for a world where all physical things are tagged with RFID transponder with a globally ID, *i.e.* the Electronic product code (EPC)[3]. With the development of various technologies, IoT is rapidly evolving and its scope is considerably expanding[4−5]. Particularly, a typical architecture, Unit IoT and Ubiquitous IoT (U2IoT) model, integrates the conceptions of mankind neural system and social organization framework into future IoT[6].

Currently, most existing IoT systems heavily rely on the thing ID number, which are referred as ID-based IoT. The exemplary services include bar coding and RFID systems. However, in practical systems, there are a large number of non-cooperative things that are not attached with any ID number or that are difficult to obtain an existing ID number due to the unavailability of appropriate readers. In this case, the ID-based IoT solutions become inapplicable. In addition, with the development of IoT, a variety of new environments will be involved in IoT. For instance, vision detection，infrared and some Electromagnetic identification (EMID). A system built on these devices is based on the things' attributes (*e.g.* type, color, shape, weight and spatial-temporal information) instead of an assigned ID. Thus, the things without identifiable IDs pose a significant challenge in the developed IoT system and need a purely new definition.

In this paper, we introduce a new concept of nID things to represent the things without any available assigned ID number. Accordingly, we propose a new kind of IoT systems based on nID things, which is referred as nID-based IoT. Within this context, a novel application of nID-based IoT in airport aviation risk management is further presented to make an inherent integration of airport aviation hazards management including bird-aircraft strike[7], wind hazards[8] (wind shear, wake vortex, *etc.*) and Foreign object debris (FOD) risk[9]. The main objective is to use multiple sensor/radar technologies to collect aviation hazards information, identify the hazards risks, assess the risk levels to make the risk responding, and enhance the airport automated monitoring and risk control.

The remainder of this article is organized as follows. nID things and nID-based IoT are firstly introduced in Section II. A nID-based IoT solution to aviation risk management is described and further discussions are provided including things sensing, coding and resolving in Section III. Furthermore, a case study, bird-strike hazard management, at Nanyang airport in China is illustrated and analyzed in Section IV. Conclusions are drawn in Section V.

II. nID Things and nID-based IoT

In the context of "Internet of Things", the "thing" is defined as a real/physical or digital/virtual entity that exists and moves freely in both space and time dimensions; and is capable of being identified[10]. Following this definition, we categorize the IoT things into two types: the ID things and nID things as follows:

The ID things: IoT things that are attached with the assigned available IDs, such as the GSI bar code labeled or EPC global RFID tagged things.

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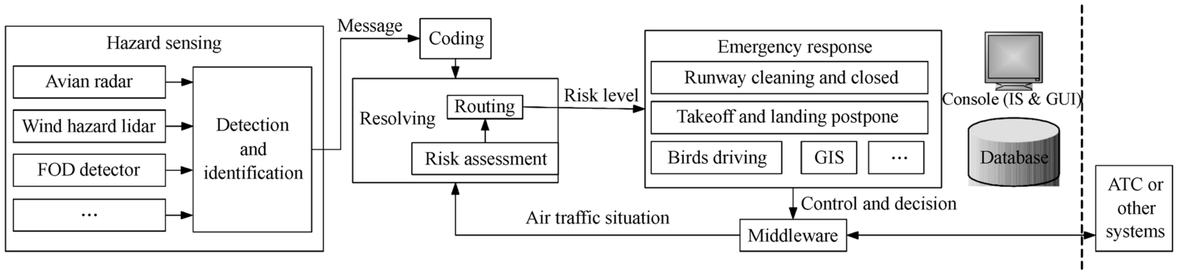

Fig. 1. nID-based IoT solution for airport aviation risk management with radar sensors

The nID things: Non-cooperative IoT things that have no available ID numbers but need identified, for instance, the thing whose existing ID number is unreadable.

There exists a kind of IoT systems aiming to identify the nID things, which is referred as nID-based IoT. Such system is characterized by the things identification based on things' space-time and attributes instead of IDs, and the communication based on future internet of worldwide interconnected networks, where things particularly refer to the nID things.

III. nID-based IoT Solution to Airport Aviation Risk Management

Currently the ID-based IoT technologies are being increasingly incorporated into existing aviation applicatio[11], including the 2D barcode passenger processing with automated check-in and boarding, the RFID-enabled luggage handling with automated tracking and sorting[12], the GPS/Wi-Fi/Bluetooth RFID aircraft products anti-counterfeiting and maintenance. It is clear that ID-based IoT has already improved their operational efficiency significantly. However, the distinctive requirements of existing ID-based IoT, requiring travelers, airport/airline personnel, air cargo/luggage, aircraft and vehicles equipped with IDs to better identify, limit their adaptability to some specific aviation scenarios.

For example, in aviation scenario, there exist many things without any ID numbers such as the birds. Bird detection is a significant phase to avoid bird strike in aiport aviation risk management. However, the extremely dynamic and uncontrollable birds generally cannot be attached with any available IDs. In this case, the ID-based IoT solutions become inapplicable, and then nID-based IoT can be designed. In practical, these hazardous things without any IDs would be sensed by nID sensing technologies (*e.g.* vision or radar), and the captured data may include things' location, time and attributes such as appearance, motion, radar echo characteristics, and will be mapped into a resolvable nID code with a special coding rule. The new assigned nID for hazardous thing will be sent to resolving module for risk assessment, further providing a basis for aviation hazards warning, prediction and emergency response.

Fig.1 shows the nID-based IoT solution for airport aviation risk management. There are three crucial components in the framework. One component is the hazards sensing, which will be discussed in detail in subsection 1. Several sensing technologies are used for safety surveillance at the airport. Target detection and identification algorithm is adopted for information extraction from original data collected by multiple heterogeneous sensors. And data sensor fusion is implemented by joint detection and integration.

The second component is the coding and resolving services, which will be discussed in detail in subsection 2. Target space-time and attributes information are encoded. The resolving service reads the codes and translates them into readable information. In the aviation risk management, the resolving module plays a role of risk evaluation and judgment. The hazard information is obtained by risk assessment model together with real-time air traffic situation provided by Air traffic control (ATC). Middleware has a key function for data compatibility among different systems and its data is integrated for risk assessment. It consists of a set of services that allow multiple processes to run over one or more machines.

The third component is the emergency response. After routing according to the risk assessment with fusion data, different measures are taken based on different risk levels. For low risks, warning messages are sent to the corresponding personnel. For middle risk levels, professional teams are sent immediately to deal with the things, *e.g.* driving birds or cleaning runway. For high risk levels, runways are closed temporarily and aircraft takeoff and landing are postponed.

1. Hazards sensing

The reliable and correct sensing of aviation hazards is extremely important in the aviation risk management. In this section, we focus on three sensing techniques for hazard sensing including avian radar, wind hazard lidar and FOD detector.

• Avian radar

More than 60% of Bird-aircraft strike hazards (BASH) occurs within the airfields. Airport-based avian radar system can be used to provide operating personnel with higher bird situational awareness. Based on the provided information, actions like giving warning messages or driving birds can be taken to reduce bird hazards at airports.

For the sake of affordability, two marine radars are often used in typical airport-based avian radar system. The system utilizes a two radar configuration. One operates in S-band and sends out a fan-shaped beam 360° around its location, scanning the airport in horizontal direction. The other works in X-band and is tilted on its side, operating in a windmill-type manner and scanning in the vertical direction. As the two radars use different frequencies, they can operate simultaneously without interference so that data in both directions can be collected. These systems can reliably detect and track birds in a certain range depending on the chosen radar power. Plan position indicator (PPI) images collected are stored and processed to obtain the bird situation.

- **Wind hazard Lidar**

Wind shear and wake vortex have been recognized as two typical and serious wind hazards for aircrafts, especially during takeoff, initial climbing, final approaching and landing. Once the aircraft is airborne, two counters rotating cylindrical are created, which are hazardous to the following close aircrafts. Hence, protection against wake vortex turbulence hazards requires a reasonable distance gap between aircrafts. The waiting time interval of the following aircraft should be long enough to avoid wind hazard, while long time interval decreases the flight numbers and reduces the airport efficiency. Wind hazard detection can be used to determine the appropriate time interval to achieve maximum efficiency on condition that wind hazard can be avoided.

Microwave radar, Doppler Lidar and infrared are applicable technologies that enable wind hazard detection in all weather conditions[8]. Lidar systems with their extremely narrow beam widths are ideally suited to detect the peak velocities and the shear within the recirculation cell. They can accurately detect and track wake vortices in real-time along the arrival and departure corridors, providing critical wind and wake vortex data. Then the data can be used to estimate the wind hazard and then optimized calculation can be done to decide the proper waiting time interval.

- **FOD detector**

FOD at airports refers to any thing that locates in an inappropriate place and may damage equipment or injure an airport or airline personnel[9]. Typical FOD includes the aircraft and engine fasteners, aircraft parts, flight line items and runway materials. The resulting FOD damage is estimated to cost the aerospace industry \$1.1–\$2 billion per year in direct, and as much as ten times of that amount indirectly. "Airport inspections" are normally performed manually every 4 hours. Obviously the effectiveness is very limited due to the time gap and potential human errors. However, by FOD detection, the inspections can be realized automatically and the reliability is improved with much lower error rate. Once FOD is detected, warnings can be given immediately to help avoid hazards.

Different kinds of sensors have been considered for runway FOD detection, including visual sensors (CCD, infrared and stereo cameras) and electromagnetic sensors (ground movement radar, SAR, millimeter wave radars and Lidar). The Federal aviation administration (FAA) has conducted research on four FOD detection systems from Qinetiq (a millimeter wave radar system), Stratech (a high resolution intelligent vision system), Xsight (a combination radar and camera system), and Trex Enterprise (a mobile millimeter wave radar and infrared camera system) to examine the performance during 2007 and 2008. The detailed analysis is given by FAA advisory circular in 2009[13].

2. Coding and resolving

Since the hazards sensing may generate a vast quantity of sensed data, it will occupy large communication resources to transmit all of them. In the airport aviation scenario, surveillance systems usually collect and transmit so much image data that wideband network is required. However, such networks may be inconvenient to build at airports due to strict air safety policies. Therefore, coding process is needed to decrease data and make it suitable for transmission. Our attributes-based nID coding approach is designed to avoid transmission of large amounts of data, and the method chosen is wireless transmission, such as wifi. After encoding, the amount of data transmitted is reduced by a wide margin to suit wireless transmission. The nID code structure for airport aviation risk management is proposed and shown in Fig.2, which consists of three main parts. The first part represents the hazard location. The second part is the detection time. The third part is the extracted hazard attributes, such as shape, size, color, and velocity, *etc.* More required attributes can be incorporated, depending on different scenarios and applications. For instance, the attributes include the bird type, size, quantity and flight direction for the bird hazards, the wind speed, strength and flight direction for wind hazards, and the FOD size, color and materials for FOD hazards.

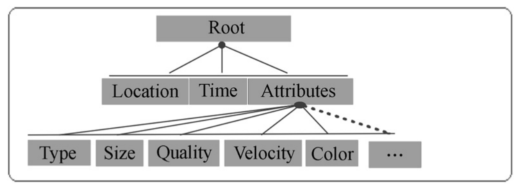

Fig. 2. nID code structure for airport aviation risk management

In the resolving phase, codes are translated into readable information again. In airport aviation risk management, resolving procedure plays a role of risk evaluation and judgment. It involves risk assessment and routing. Then the emergency response is routed according to the risk assessment.

Risk assessment analyzes the risk range, measures the degree of exposure as likelihoods and impacts, ranks risk levels and evaluates risk tolerance. Risk assessment based on resolved data and air traffic information given by ATC is critical for safety management. For airport aviation risk management, the bird strike risk assessment index T can be calculated by the following formula:

$$T = \frac{1}{n}\sum_i w_i G_i$$

where w_i is the index weight of each factor, representing the factor importance degree for the overall evaluation. Each factor index can be divided into n grades, and the grade score G is set to be 1 to n. G_i is the corresponding grade score of the ith factor, which can be obtained from the expert feedback.

It is a complex problem to evaluate the index weight w_i. Analytic hierarchy process (AHP) can be employed to obtain weight values of different factors, improving the accuracy in risk estimation[14]. In AHP, a complex problem can be effectively investigated if it is hierarchically decomposed into a number of small components. It is hard to evaluate the important degree of each factor directly, while we can make use of their pairwise relative importance comparisons to derive.

Let us consider the factors $C_1, C_2, \cdots, C_n$ and denote their index weights by $w_1, w_2, \cdots, w_n (w_1 + w_2 + \cdots + w_n = 1)$. The pairwise relative importance comparisons are structured into $n \times n$ matrix $\boldsymbol{A}$ called comparison matrix to calculate w. In the matrix $\boldsymbol{A}$, a (C_i, C_j) denotes the importance degree of the factor C_i with respect to C_j.

$$\boldsymbol{A} = \begin{bmatrix} a_{11}(C_1,C_1) & a_{12}(C_1,C_2) & \cdots & a_{1n}(C_1,C_n) \\ a_{21}(C_2,C_1) & a_{22}(C_2,C_2) & \cdots & a_{2n}(C_2,C_n) \\ \vdots & \vdots & & \vdots \\ a_{n1}(C_n,C_1) & a_{n2}(C_n,C_2) & \cdots & a_{nn}(C_n,C_n) \end{bmatrix}$$

The nine-scale approach is used to measure the importance degree:

$a(C_i, C_j)$
$= 1$ if C_i and C_j are equally important
$= 3$ if C_i is weakly more important than C_j
$= 5$ if C_i is strongly more important than C_j
$= 7$ if C_i is very strongly more important than C_j
$= 9$ if C_i is absolutely more important than C_j
$=$ 2, 4, 6, 8 used to compromise between the two judgments.

Additionally, $a(C_j, C_i) = 1/a(C_i, C_j)$ for all $j = 1, 2, \cdots, n$.

According the nine-scale approach, element value of matrix $\boldsymbol{A}$ can be set depending on the expert feedback. Then w_i can be obtained by square root law or approximate calculation method.

IV. An Illustrative Experiment for Bird Risk Management in Nanyang Airport

Here we take a real case of bird-strike hazard management as an example of nID-based IoT applications. This experiment is carried out at Nanyang Airport on 15 October, 2008. One horizontal scanning radar operating in X-band is used to detect bird hazards.

Fig.3 is the image displayed on the screen of PPI radar in an avian radar system. It is the raw PPI radar image. With radar sensing information shown in Fig.3, the target can be detected and reflected in Fig.4 using the flying bird targets detection and tracking algorithm. Fig.4 is a macro-graph obtained by applying geographic information software to the corresponding airport area. It shows the fusion image on display of console at 17:45:32. In this figure, a landing airplane from Beijing is marked in the image, as well as three birds.

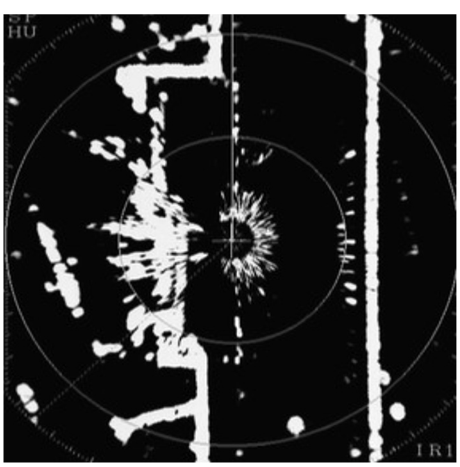

Fig. 3. Raw PPI radar image

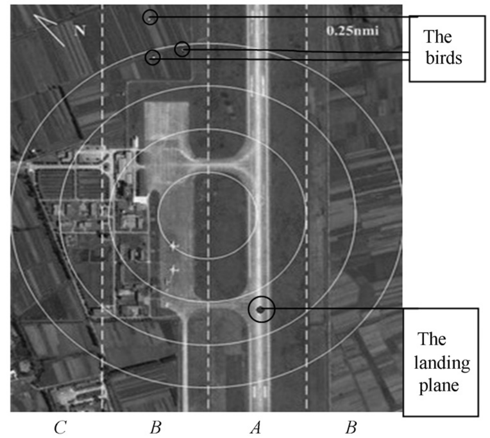

Fig. 4. Display at Nanyang Airport

The result of bird detection seen from Fig.4 matches the result in the PPI radar image which can be observed and judged by human eyes.

The Airport is divided into three regions of A, B and C as shown in Fig.4. Region A is the runway and close areas, and Region B is the areas next to region A. Other areas at the airport belong to region C. With the flying bird targets detection and tracking algorithm, the things description arguments including location, time, type, size and quality, the important factors for bird strike risk evaluation, are listed in Table 1.

Table 1. Things description for the three birds

Thing	Location		Time	Type	Size (pixel number)	Quantity
	ϱ (m)	θ (°)				
Bird 1	546.0	104.5	17:45:32	bird	89	1
Bird 2	451.0	97.1	17:45:32	bird	2	1
Bird 3	444.4	106.4	17:45:32	bird	10	1

Here, ϱ and θ are the arguments of the three birds' position in polar coordinates, whose pole point locates in the center of the figure and the positive direction is counterclockwise. The information above is encoded according to the nID code structure for airport aviation risk management. In this case, as the three birds shall be seen as three different things, they should be encoded and analyzed independently. Otherwise, if birds are close enough they can be seen as one thing to be encoded with the coding rule.

Based on the information encoded in the nID code structure, risk assessment can be done in the resolving module after the code is translated. To calculate bird strike risk assessment index T we need to obtain the index grade score G and index weight of each factor w. In this experiment, the four factors are number (quantity), size, height, and region.

1. Index grade score (G)

After investigation and statistical analysis, BASH assessment model is built. The rating standard of each factor based on the model is shown in Table 2.

As the bird size can be evaluated by pixel number in the picture, we use p (the pixel number) to divide the size level.

Bird whose p is in a certain range is set a corresponding rating score. From the arguments in things description, the four factors value can be obtained and according to the table, we can get the index grade score of N, S, H, R to be 1, 2, 3, 2 for Bird 1, and 1, 1, 3, 2 for Bird 2 and 3 respectively.

2. Index weight of factors (w)

After web forms are filled by ornithology experts, factors pairwise relative importance comparisons can be obtained, shown in Table 3.

Table 2. Rating standard in term of BASH assessment at Nanyang Airport

Factors	Grade division	Score
Number (N)	11∼100	3
	2∼10	2
	1	1
Size (S)	Big ($p > 100$)	3 1
	Medium ($50 \leq p \leq 100$)	2
	Small ($p < 50$)	1
Height (H)	0∼150m	3
	151∼600m	2
	601∼1500m	1
Region (R)	A	3
	B	2
	C	1

Table 3. The expert feedback for bird-strike risk assessment factors

Factors	Number (N)	Size (S)	Height (H)	Region (R)
Number (N)	1	4	2	6
Size (S)	1/4	1	1/3	3
Height (H)	1/2	3	1	5
Region (R)	1/6	1/3	1/5	1

According to the expert feedback, comparison matrix $\boldsymbol{A}$ is constructed, and we can get w for each factor by square root law or approximate calculation method, which is 0.564, 0.098, 0.304, and 0.034 correspondingly.

Using the formula for T introduced in Section III, the risk assessment index T is calculated to be 0.580, 0.547 and 0.547 for Bird 1, 2, 3 respectively. If birds' characteristics satisfy the conditions of bird flock, the risk assessment should be done by method for bird flock to obtain T. There are five levels represented by five colors to indicate the risk level: blue ($0 \leq T < 0.2$), green ($0.2 \leq T < 0.4$), yellow ($0.4 \leq T < 0.6$), orange ($0.6 \leq T < 0.8$) and red ($0.8 \leq T < 1$). After calculating T, risk level can be obtained and then corresponding actions can be determined.

The aviation risk management fits well with the application of nID-based IoT due to the dynamic things without any ID at airports. The risk management system integrates different sensing systems for airport hazards management to leverage the efficiency and cost. The proposed nID-based IoT provides many potential benefits, *e.g.* scalability, information availability, automated monitoring and processing of sensitive information, and risk control. In addition, the proposed system is flexible to expand and accommodate multiple things.

V. Conclusions

This paper mainly focuses on the three innovative parts: (1) a new nID things concept and nID-based IoT solution proposed, to solve the problem of non-cooperative things. (2) nID coding and resolving method designed. Since in the airport aviation scenario the amount of sensing information is enormous, things' space-time and attributes information shall be extracted by detection and identification algorithm and the nID coding method shall be applied to make it suitable for subsequent wireless transmission. Resolving module is also designed to translate the nID code and do risk assessment and routing. (3) Heterogeneous sensor fusion applied. As the information is collected from multiple sensors, data fusion is implemented by joint detection and integration. Here a real nID-based IoT application example for the airport aviation risk management is given and studied in detail, which applies the above concepts and methods to realize its risk management. It is believed that more nID techniques including microwave, vision-based and infrared sensing will be incorporated into the airport aviation risk management, and the nID-based IoT will support increasing number of applications where the things have no available ID. In addition, given the complementary capabilities of nID-based and ID-based IoT, practical systems are more likely to use their integration to deal with the cooperative and non-cooperative things in reality.

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