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A Framework of RFID-based Complex Event Processing System for Assembly Manufacturing

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Abstract. Owing to the dynamic and competitive business environment, manufacturing companies take real-time monitoring and rapid decision making based on RFID applications, which brings huge volume of information and events generated in the defined manufacturing workflows. Complex Event Processing (CEP) is introduced to solve the problems mentioned above. CEP is applied to handle diverse and large amount of low-level multiple data and primitive events for the purpose of identifying meaningful event patterns. It is very important to integrate the CEP technology to the manufacturing workflows. In this paper, we provide a novel framework of RFID-based complex event processing system for assembly manufacturing applications like cars and high-speed trains. It bridges the hardware in workshops and enterprise applications. The Complex Event Management System (CEMS), which is the kernel of the framework, can filter the irrelevant events and work with uncertain data. Furthermore, a concrete example is used to describe the framework and validate the feasibility in assembly monitoring of the car manufacturing.

Introduction

Owing to the dynamic and competitive business environment, manufacturing companies need to transform themselves into real-time enterprises, which have high effective in manufacturing products. The realization of enterprise-wide real-time monitoring and rapid decision making requires not only the network of information systems, but also a network of physical objects, the so-called Internet of Things [1]. Ubiquitous sensor network and RFID are emerging as widely adaptable and also promising technology in industry. With the application of sensor network and RFID in manufacturing, a new challenge is also introduced. That is how to deal with the huge volume of information and events generated in enterprise-wide systems and physical environment, especially when real-time response is a requirement.

In this paper, we focus on the RFID manufacturing applications which often contain large number of data collection points with RFID devices in fields. The RFID technology provides a feasible solution for capturing the real-time production data from manufacturing shop-floors and brings the data visibility for the manufacturing environments. The events produced by RFID devices from manufacturing fields are called primitive events. However, the primitive events captured from RFID devices on manufacturing fields are not meaningful enough to be directly used for business and execution level due to the lack of an effective event and data management system to link up the isolated information.

The enormous primitive events generated from RFID devices usually only carry an identity code (EPC) for the tagged object, captured time and perhaps the location information when the deployed tag is not sophisticated. Therefore, the primitive events are often too low level and too simple for day the usage of application layer. Meanwhile, the misreading detections which cause the uncertainty and cumulatively reading in manufacturing shop-floors are also issues needed to be considered. Furthermore, currently many enterprises apply workflows technology to manage their business processes or production flows. However, it is still a problem how to efficiently and effectively deal with the information from RFID applications in defined workflows.

As a result, Complex Event Processing (CEP) is introduced to meet the challenges mentioned above. Complex event processing [5] is the research field that handles diverse and large amount of low-level multiple data and primitive events for the purpose of identifying meaningful event patterns within the event cloud [2]. CEP engines can be applied to detect real-time event patterns from RFID and sensor event streams [3, 4] and trigger business rules [2].

In recent research, CEP technology is widely used in many types of applications from different fields, including manufacturing, enterprise business application, logistics management system, security, etc. In the paper of [6], the author discussed the design of RFID middleware system based on CEP with manufacturing scenarios. A RFID middleware framework for processing logistics information with contextual event assistant was proposed in [7]. The authors in [8] applied CEP technology to enterprise information systems, and demonstrated how the event processing engine works and interacts with other existing information systems, including ERP, SCM and CRM. Especially, the authors extract complex event pattern from workflow model in their proposed system, which makes CEP more cooperative. In the paper of [11], the author proposed a novel architecture of business process integration and management for ubiquitous manufacturing and service systems. The paper [14] provided a methodology to model CEP using Timed Net Condition Event System to analyze and describe discrete-event dynamic systems in a manufacturing line.

On the basis of previous studies, we provide a novel framework of RFID-based complex event processing system for assembly manufacturing applications like cars and high-speed trains. And then a concrete example is used to describe the framework and validate the feasibility in the monitoring of manufacturing for the car assembly line.

The rest of the paper is organized as follows. Section 2 presents a framework of RFID-based complex event processing system for product manufacturing. It consists of the three parts as architecture, Complex Event Management System (CEMS) and event model. And CEMS is emphasized as the kernel of the framework. In Section 3, we take the car assembly line as an example to further understand the framework discussed above, which shows the effectiveness of the framework in assembly monitoring of the car manufacturing. Finally, the conclusion is highlighted in Section 4.

A Framework of RFID-based Complex Event Processing System for Manufacturing

In this section, we propose a framework of RFID-based complex event processing system for product manufacturing. In the following, we describe the three parts of the system concretely.

Architecture. The complex event processing system integrates the crucial complex event processing with the hardware in workshops and enterprise applications. It can gather and process the primitive events from sensors and RFID devices based on the pre-defined rules or patterns. Besides, it analyses the matched complex event patterns and notifies other enterprise applications. Fig. 1 shows the architecture of complex event processing system in monitoring of manufacturing for heavy weighable product.

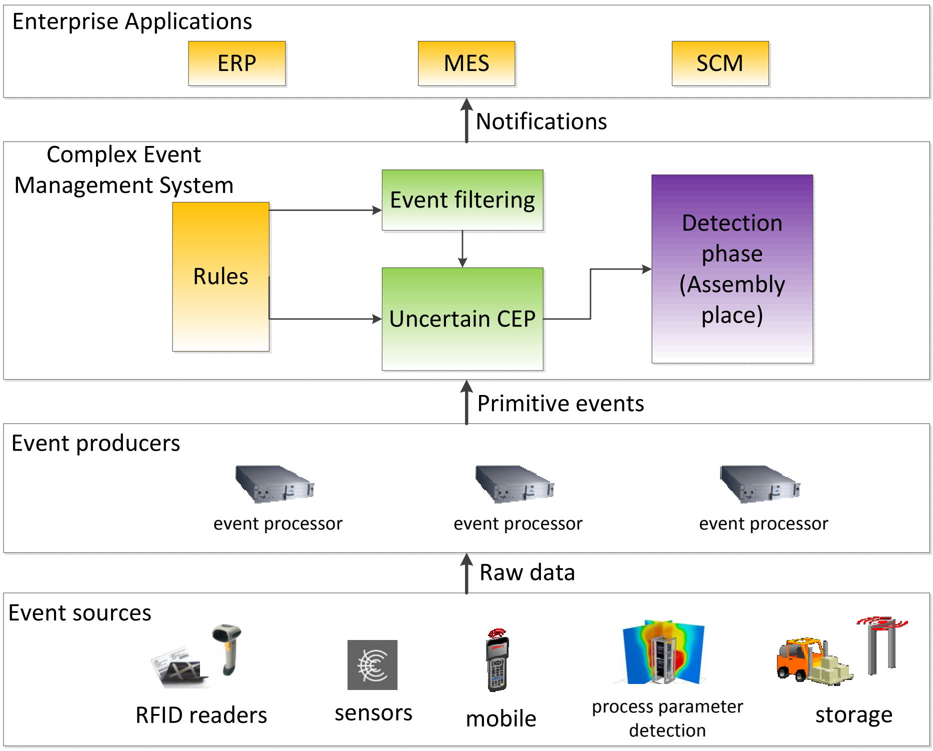

Fig. 1 Complex event processing model in product manufacturing system

As shown in Fig. 1, we use RFID readers, sensors and other devices to get raw data from the physical world in manufacturing workshops. And then primitive events are transformed from raw data by event processors and submitted to the Complex Event Management System (CEMS). In CEMS, all the primitive events are integrated into high-level complex events, which are used to take the detection phase in assembly place in order to monitor the manufacturing of heavy weighable product. The notifications from CEMS are sent to the other enterprise applications such as Enterprise Resource Planning (ERP), Manufacturing Execution System (MES), Supply Chain Management (SCM), etc. for the support of decision making.

Complex Event Management System (CEMS). As discussed above, CEMS is the core of complex event processing model in product manufacturing system. It mainly consists of four parts, that is, rule engine, event filtering, uncertain complex event processing and detection phase. They are discussed respectively in the following sections.

Rule Engine. In order to process the incoming primitive event streams, domain experts identify their required rules or event patterns in the rule engine. These pre-defined rules or patterns are described in a query language, that is, Complex Event Processing Language (CEPL). Like SQL, CEPL is a Query Language which provides a more declarative, expressive and sequence-based language to express the attributes and values of the events. The rule engine can have a dynamic adaptation about rules to the changing situations.

Event Filtering. In this section, we clean the duplicate, redundant and abnormal events from the incoming events [9]. At the same time, rules from the rule engine are used to perform effective semantic data filtering to discard the irrelevant product parts and move the relevant product parts to the assembly place in order to make the correct assembly of the product. This approach can manage the large number of incoming events so that it directly improves scalability and provides less response time.

Uncertain Complex Event Processing. Due to the uncertainty caused by unreliability of raw data, events are uncertain rather than deterministic in nature. Therefore, we propose an uncertain model to enable complex event extraction considering uncertainty. And then, we can translate the event streams into probabilistic event streams. In this section, CEMS models the uncertainty, computes the probability of the events and detects complex events in probabilistic event streams based on NFA or other structures. In this section, there are two processes according to the detected complex event. If the detected complex event matches the rule or pattern constructed in the rule engine, it allows the detected event into the assembly place for further processing. Otherwise, it generates a notification as an alarm to domain experts for fault recovery.

Detection Phase. The detection phase is accomplished in the assembly place to monitor the manufacturing of heavy weighable product. It is possible that unfortunate situations occur even after entering relevant parts to the assembly place. For example, in order to assemble the product effectively, the detected different product parts should arrive at the assembly place within the defined time. A delay or break up of this clockwork precision may lead to incorrect assembly of the product. An incorrect assembly occurs when two parts that do not belong to the same product are assembled together.

Event Model. General speaking, an event is an atomic (happens completely or not at all) occurrence [2]. Event types specify the event structures, whereas event instances indicate the occurring of events defined by the specific event type. Event can be broadly classified into the primitive event and the complex event.

Definition 1. primitive event. Primitive event is represented as a triple, Event=<RID, A, T, Pro>, where RID refers to the mark of RFID readers, it is the unique identifier of the event; A refers to the set of attributes in the event and T refers to the time when event occurs. Pro is the value of the probability of occurrence.

Definition 2. complex event. Complex event is a combination of primitive events or complex events by some rules. A complex event is represented as a triple, Complex Event=<E, R, Ts, Pro>, where E refers to the elements that compose the complex event and R refers to the rule of the combination. Ts refers to the time span of the complex event and Pro is the probability.

In the following we define the rules used in the complex event processing system.

Definition 3. rule format. The rule format is represented as:

SELECT attributes of event
FROM Filter (Φ) or Pattern (Φ_1, Φ_2, $\cdots$, Φ_n)
    IF condition
    DO $action_1$; $action_2$; $\cdots$; $action_n$
WITHIN time period

Where SELECT specifies the attributes required to select from the incoming event stream; Filter (Φ) refers to only selection of events which satisfy the predicate Φ , while Pattern(Φ_1, Φ_2, $\cdots$, Φ_n) is same as Filter (Φ) but takes more than one selection; conditon is a boolean combination of user-defined boolean functions; and $action_1$; $action_2$; $\cdots$; $action_n$ is an ordered list of actions.

Case Study

In this section, in order to further understand the complex event processing system in monitoring of manufacturing, we take the car assembly line as an example. In the car assembly line, we consider every part as an event. If the part can be divided into other parts that are existed in the manufacturing process, the part represents a complex event; otherwise, it represents a primitive event. Only when two parts of the car are assembled together correctly, a meaningful event reflecting assembling partly finished and ready for the next assembly event could be generated.

In the example mentioned above, we define the parts of the car with meaningful and actionable event formats. The event formats are represented as follows [10]:

Event e_1 $\rightarrow$ {PartType = "Tyre-TT", PartName = "TRANSTONE", PartModel = "12RR22.5-TT616", PartDesign = "RADIAL"};

Event e_2 $\rightarrow${PartType = "Brake Equalizer", PartName = "DETROIT", PartModel = "60 SER 12.7", Spacers ID = "#790", Bolts = "YES"};

Event e_3 $\rightarrow${PartType = "Engine", CC = "1196", PartModel = "1.6L 4A-GEC14", FuelType = "Petrol", Mileage = "116kmph"}.

Considering the rule represents that the part called as engine with relevant specifications suitable to manufacture the car Ford-Figo. We define the rule as follows:

```
SELECT  PartType, CC, PartModel, FuelType, Mileage
FROM   Filter (PartType = "Engine")
         Pattern (PartModel = "1.6L 4A-GEC14", CC = "1196", FuelType = "Petrol")
         IF  true
         DO  allow → Assembly place
         ELSE  notify → domain experts
WITHIN  15 minutes
```

According to the rule, the detected event e_1 and e_2 are discarded due to the inconformity with the value of PartType, while event e_3 is moved to the assembly place to be integrated with the car in CEMS. In order to assemble the car effectively, we use the virtual device to monitor the car manufacturing in detection phase. When the virtual device is not able to detect the corresponding part within a defined time span, it generates a synchronization error event or a delay event. When a physical device detects two parts, its corresponding virtual device compares these two parts with the product to which they belong. If both of these parts belong to the same product, then it triggers an event of correct assembly detection. Otherwise, it generates an incorrect assembly error event and notifies the supervisor.

Conclusions

Because of the dynamic and competitive business environment, manufacturing companies use RFID technology to realize real-time monitoring and rapid decision making and workflows technology to manage their business processes or production flow. CEP is introduced to handle diverse and large amount of low-level multiple data and primitive events for the purpose of identifying meaningful event patterns. So it is necessary to integrate the CEP technology to the manufacturing workflows.

In this paper, a framework of RFID-based complex event processing system for product manufacturing is proposed. It bridges the hardware in workshops and enterprise applications. Event filtering in CEMS filters the irrelevant events from the large number of incoming events to reduce the cost of the processing engine. The CEMS can also work with uncertain data. Furthermore, a concrete example is used to further describe the framework and validate the feasibility in assembly monitoring of the car manufacturing. In the future work, we can introduce the semantic concept to the uncertain CEP engine for more effective event processing.

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