Study on Internet of Things-driven Real-time Status Monitoring of Supply Chain Logistics

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Abstract. Real-time status monitoring of supply chain logistics is the basis of intelligent supply chain implementation. Supply chain logistics is essentially a process of objects move in space over time. It could also be abstracted as a process of materials transferred through nodes. First, therefore, this paper establishes a element node model of supply chain logistics to analyze the information collection required by supply chain logistics. It then uses internet of things to study the method of environment configuration of supply chain logistics real-time status monitoring, and classify the information collection required in supply chain logistics into two categories. A data processing model of supply chain logistics status monitoring is also developed based on Auto-ID calculation, with regard to the second information cannot be obtained directly through the data collection. Finally, software platform is built to verify theories and methods drawn.

Introduction

Intelligent supply chain has become one of the key technical constraints of transformation and development of manufacturing under the background of “Industry 4.0”. The main emphasis of intelligent supply chain implementation is to get real-time status information of underlying materials in supply chain, and the development of internet of things in recent years has provided a good theoretical basis and technical support for the monitoring of this information. The internet of things is used in this paper to study the theoretical method and key technologies of supply chain logistics real-time status monitoring to obtain the real-time information of logistics in the process of supply chain.

Literature Review

Many scholars have studied from all angles to bring out the real-time status monitoring of supply chain logistics. Sali Mustapha and Giard Vincent [1] proposed a new adaptive MRP framework to address the upstream supply chain monitoring issues in mass customization environment. McKinney Joseph and Hradford Arthur et al. [2] analyzed the commercial value of supply chain monitoring and visualization. RFID technology is now widely studied and applied. Thus, supply chain logistics monitoring mostly focuses on using RFID technology to
achieve its monitoring, there are few scholars study problems related to supply chain from the perspective of internet of things.

In the field of using RFID technology to supply chain monitoring: Bjork Anders et al. [3] used RFID to forestry timber track monitoring. Raab Verena et al. [4] used this technology to monitor meat supply chain. Trebar Mira and Lotric Metka et al. [5] solved the problem of monitoring the temperature in fish supply chain by RFID technology. It’s also adopted by Mainetti Luca and Mele Francesca et al. [6] to settle the problem of vegetable supply chain monitoring. Fan Hua and Wu Quanyuan et al. [7] studied the misreading problem of RFID technology to improve the accuracy of RFID data. Fan Hua and Wu Quanyuan et al. [8] analyzed the RFID data storage problems. The treatment of uncertain RFID tag data in supply chain monitoring was researched by Xie Dong and Xiao Jie et al. [9]. Chong Alain Yee Loong and Liu Martin J et al. [10] predicted and analyzed the adoption of RFID technology into medical supply chain from the a user perspective. Lin Iuon-Chang and Hsu Hung-Huei et al. [11] presented a cloud architecture plan, and highlighted the security issues of RFID technology. Shin Seungjae and Eksioglu Burak [12] took American retail supply chain as a case, analyzed the relationship between RFID technology and labor productivity of retailers. Fan Tijun and Tao Feng et al. [13] studied the influence of RFID technology in supply chain logistics to its decisions under inaccurate inventory.

In terms of the use of internet of things to supply chain logistics monitoring: Bardaki Cleopatra and Kourouthanassis Panos et al. [14] studied the method to deploy RFID in retailers supply chain to promote and manage fresh products sale in the supermarket by reference to things theory. Verdouw C N and BeulensA J M et al. [15] analyzed the conceptual framework of virtual flower supply chain from the point of network of things. Pang Zhibo and Chen Qiang et al. [16] researched the approach to integrating sensor data in supply chain logistics on the basis of food supply chain.

We can conclude that, in the aspect of supply chain logistics monitoring, most scholars focused on using RFID technology to solve the problem in this field, they also went into supply chain logistics in different industries. Bust most of them are researches alone on adopting RFID technology or adding a kind of sensing device to track and monitor supply chain logistics, there is a lack of methods to study multi-information collection from the perspective of general supply chain logistics monitoring. Few scholars have attempted to solve problems in supply chain logistics in adoption of internet of things through things theory and technology. Considering these characteristics, this paper extracts the common features of supply chain logistics, uses internet of things integrated with multiple data collection methods to achieve the real-time status monitoring of supply chain logistics.

**Real-time Status Monitoring of Supply Chain Logistics**

Technologically, Real-time status monitoring of supply chain needs to solve problems such as data collection, transmission, processing, storage and display. Monitoring model development, monitoring environment configuration and means of data information processing are essentially the key issues need to be addressed. Thus, we extract three key technologies need to be addressed: establishment of element node model of supply chain logistics; the method of environment configuration of supply chain logistics real-time status monitoring on the basis of internet of things; data processing model of supply chain logistics status monitoring based on
Establishment of Element Node Model of Supply Chain Logistics

Supply chain logistics is essentially a process of objects move in space over time. Statuses of objects change in the whole process, and every change must be accompanied with events. Thus, the change point of every state could be abstracted as a node, the supply chain logistics then could be abstracted as a process of materials transferring among nodes.

Nodes certainly have their location information in physics, the location information may correspond to nodes with fixed geographic coordinates, such as suppliers, storage, access control, manufacturers, vendors and other points with moving geographic coordinates, like forklifts, transport vehicles, etc.. A plurality of nodes could correspond to a same location, it physically means that an object has multiple variations in a position. Nodes are connected by materials, and a complete supply chain is so formed. Nodes where objects’ states change are called element nodes here.

We define MS as the set of element nodes of supply chain logistics. That is,
\( MS = \{L, E, St, T, P, Su\} \)  
\( (1) \)

Then, the state of material \( i \) on node \( y \) is

\( MS^i_y = \{L_y^i, E_y^i, St_y^i, T_y^i, P_y^i, Su_y^i\} \)
\( (2) \)

Where \( L_y^i = \) Location, the physical location of material \( i \) on node \( y \); \( E_y^i = \) Event, an "operation/action" on node; \( St_y^i = \) Status, the state change of material \( i \) after \( E_y^i \), describe a state of material in transferring (such as entering, exiting and maintaining a state; \( T_y^i = \) Time, the time \( E_y^i \) happens; \( P_y^i = \) Path, the route a material passes when it transfers between two nodes; and \( Su_y^i = \) Surroundings, the environment of element node when material \( i \) is there (such as the temperature and humidity, gas leakage values, sound, images in monitoring area).

Figure 2 shows the change of materials when they transfer between node \( y \) and node \( y + 1 \).

Figure 2. Illustration of the Model of Materials Transfer between Element Nodes.

Supply chain logistics process can be described as the process of materials being monitored transfer among nodes. Thus, the state information of material \( i \) under monitoring can be expressed as:

\( MS^i = \{MS_1^i, MS_2^i, \ldots, MS_{y-1}^i, MS_y^i\} \)
\( (3) \)

Where \( m \) donates the number of element nodes material \( i \) flowed through.

**Real-time Status Monitoring Environment of Supply Chain Logistics Based on Internet of Things**

According to the description of element nodes model in this paper, material information \( Ma \), position information \( L \), event information \( E \), status information \( St \), time information \( T \), the path information \( P \), personnel information \( W \), device information \( De \), environmental information \( Su \) et al. are included in the monitoring information of supply chain logistics process.

We define \( Da \) as the set of information. That is,

\( Da = \{Ma, L, E, St, T, P, W, De, Su\} \)
\( (4) \)
Nodes with real physical meanings need to be monitored are extracted by analyzing the location information L of element nodes, which are called monitoring nodes here. As an example, Figure 3 shows the process of warehousing in supply chain logistics, monitoring nodes can be extracted as transport vehicles, storage buffers, forklifts, warehouse shelves et al. Therefore, a monitoring node with real physical meaning can involve several nodes.

![Figure 3 The Extraction of Supply Chain Logistic Monitoring Nodes.](image)

Monitoring nodes physically comprise fixed monitoring nodes (areas are geographically fixed, like warehouse door) and moving monitoring nodes (such as transport vehicles, forklifts, etc.). The information they collect is the predefined information collection Da, and the data collection on monitoring nodes need to meet requirements of Da.

Internet of things is a technology to connect objects, as well as collect and integrate data through RFID and various sensors. This paper adapts internet of things to collect terminal data (on fixed and moving monitoring nodes). Then the data collected is uploaded to the cloud server through the network, subsequently processed and stored by the cloud server. The deployment of data collection terminal depends on the information collection Da, which can be divided into two types: information can be collected directly by sensors and that can be only obtained after data processing. The former one includes material information Ma, position information L, time information T, personnel information W, device information De and environmental information Su. The other one involves event information E, status information St and path information P. Data collection terminal collects the former information, and the latter type of information is gained after data processing by the cloud server, that is the data processing model of logistics status monitoring based Auto-ID.

Thus, the method of environment configuration of supply chain logistics real-time status monitoring illustrated as Figure 4.
Data collection terminal integrates information after the data collection of fixed and moving nodes, then sends it to the cloud server in the format of XML. Data processing is brought about by the cloud server to get the second kind of information and it then saves it to the database. The monitoring board is used to achieve the visual presentation of supply chain logistics. The client ensures the basic functions of the system.

**Data Processing Model of Supply Chain Logistics Status Monitoring Based on Auto-ID**

The first type of information can be obtained by terminal data collection through the adoption of internet of things. However, the second category of information regarding to event information E, status information St, path information P can only be gained after data processing. The server collects data from a number of monitoring nodes during the process of supply chain logistics real-time status monitoring, we define $SD_c$ as the raw data set collected in the process of logistics. That is,

$$SD_c = \{RF, Bar, Gps, Sen, De\}$$

Where, RF is the set of electronic tag data collected by RFID readers; Bar is the data set collected by code scanners; Gps is the data collection collected by pointing devices, such as GPS and Compass; Sen is the collection of data obtained by other sensors (such as temperature and humidity sensor, CCD image sensor, etc.); De is the only number of device collect data.
Data obtained from RF tag can trigger the data processing procedures to achieve data coupling because of the function of active recognition of RFID. RF, thus, is regarded as Auto-ID (ie. the unique code of a material) for data processing.

When material $i$ flows in supply chain logistics, its status set is

$$St^i = \{St_1^i, St_2^i, ..., St_n^i\}$$

(6)

$n$ is the number of statuses of material $i$, then the set of events when it transfers in supply chain logistics is

$$E^i = \{E_1^i, E_2^i, ..., E_n^i\}$$

(7)

And every trigger has a device to collect RF tag. The device related to $n$ times of events is

$$De^i = \{De_1^i, De_2^i, ..., De_n^i\}$$

(8)

If the device collects electronic tag $RF^i$ is $De_k$ now, the way to identify status $St^i$ of material $i$ in this collection process is

$$St^i = St_j^i \quad (De_k = De_j^i)$$

(9)

Similarly, the method to identify event $E^i$ triggered by material $i$ in this process of collection is

$$E^i = E_j^i \quad (De_k = De_j^i)$$

(10)

If a monitoring node corresponds to several statuses, events triggered and the current status are identified by the time series of tags.

Path information $P$ of material $i$ can be represented as: the path diagram with time attribute developed by the location information of material $i$ based on a certain order, so it can be described by graph theory

$$P_i = \{V_{-}L_i, E_{-}L_i\}$$

(11)

Where, $V_{-}L_i$ denotes the location information collection of material $i$; $E_{-}L_i$ is the collection of material $i$ transfer to another location from a place, ie. a collection of directed edges; and

$$V_{-}L_i = \{L_1^i, L_2^i, ..., L_m^i\}$$

(12)

Where, $m$ means that material $i$ has information of $m$ locations, and $L_m^i$ is obtained by GPS device.

$$E_{-}L_i = \{(L_1^i, L_2^i), (L_2^i, L_3^i), ..., (L_{m-1}^i, L_m^i)\}$$

(13)

Where, $(L_1^i, L_2^i)$ is material $i$ moves to location 2 from location 1.

With this, a data processing modal of logistics process based on Auto-ID is established, and it provides a theoretical basis for following research.
Platform Development

A software and hardware platform of supply chain logistics real-time status monitoring is developed according to theories and methods discussed earlier. Figure 5 shows connections among devices within the hardware platform, based on the monitoring environment configuration described in this paper.

![Figure 5. Connections among Devices within the Hardware Platform.](image)

Card computer is critical to monitoring environment configuration, it has three functions: data collection, data aggregation and information transmission, and the last one is achieved in format of XML. Data aggregated (including data of RFDI label, data from bar code scanning, GPS data, temperature and humidity data and image data, etc.) is sent to the cloud server by card computer through the network (3G / 4G / Wifi / cable) for further processing, then it is saved to the database by the cloud server. The client interacts with the database, save and modify data through the network, and the cloud server provides accesses to real-time information for it. The monitoring board receives real-time triggering signals from the cloud server through the network, then reads the information in the database to visually represent the real-time status of supply chain logistics process.

The Software and hardware platform of supply chain logistics real-time status monitoring involves database technology, card computer development, cloud server program development, PC computer development and monitoring board development. Figure 6 shows part of the program interfaces.
Summary

The paper studied the problem of supply chain logistics real-time status monitoring, as well as established element node model of supply chain logistics and analyzed the information model required in supply chain logistics. Then based on this, developed an environment configuration model of supply chain logistics real-time status monitoring using internet of things, and studied the data processing method based on Auto-ID according to the second type of information cannot be directly collected. Finally, a software and hardware platform of supply chain logistics real-time status monitoring was set up to verify theories and methods presented above. It provides a theoretical basis and technical support for logistics and supply chain real-time status monitoring.

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