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# Asset Management of Digital Learning Factory Driven by 5G Based on Industrial Internet Identification and Resolution Technology

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**Abstract:** The rise and implementation of digital manufacturing have led to the widespread use of the industrial internet in workshop equipment management and manufacturing resource tracking. To manage the entire life cycle of products or equipment, it is essential to assign a unique identifier to each item, component, and piece of information. However, the increasing number of equipment and the decentralization of manufacturing workshops make it challenging to record the entire life cycle of products or equipment effectively. The industrial internet identification and resolution system is a crucial hub for the sharing and utilization of multi-source data. The fifth generation (5G) of mobile communication technology, with its inherent characteristics, catalyzes the efficient management of voluminous data. Consequently, a 5G-driven method based on industrial internet identification and resolution technologies will be the optimal solution for digital asset management in the future. This article presents the architecture and implementation of the industrial internet identification and resolution system of a digital learning factory driven by 5G. This article also elaborates on the design of digital asset management training courses in the Advanced Manufacturing Technology Center (AMTC). This study seeks to advance the continuous improvement of digital module platforms within learning factories and foster the development of compound engineering talents through relevant theories and technologies in fully connected digital learning factories. The objective is to establish a benchmark that will stimulate further exploration in the direction of digital-intelligent, environmentally sustainable, and integrated industrial transformation and enhancement.

**Keywords:** Digital Asset Management; 5G; Identification and Resolution; Learning Factory.

## 1. Introduction

The manufacturing industry is currently witnessing exponential growth in the number of industrial scenarios, as well as an expansion in systems, equipment, and products [1]. The Industrial Internet of Things (IIoT) is increasingly becoming a significant player in digital manufacturing workshops. Smart tracking of manufacturing resources can reduce the time between value-added steps and enhance collaboration efficiency. To achieve localization and tracking of these resources, the application of industrial internet identification and resolution can facilitate comprehensive interconnection among various industrial elements such as design, research and development, production, sales, and service. This is essential for promoting the open flow and aggregation of industrial data and optimizing industrial resources [2]. The IIoT imposes high demands on network service performance, particularly the factory's intranet which necessitates low-latency and high-reliability services. Furthermore, industrial internet identification and resolution systems should exhibit strong compatibility and expandability. To leverage the benefits of the fifth generation (5G) technology in efficiently managing large-scale assets, it is imperative to expedite the development of '5G + IIoT' and explore a 5G-driven method based on industrial internet identification and resolution technologies as an optimal solution for future digital asset management.

The Advanced Manufacturing Technology Center (AMTC) 5G learning factory at Tongji University offers an optimal environment for teaching the industrial internet identification and resolution system. This approach fosters students' capacity to develop and implement a 5G-driven method based on these technologies, thereby facilitating asset management within the learning factory and enabling the continuous improvement of digital module platforms for digital twins. Through the design and execution of the student training process, students acquire a comprehensive understanding of the theories and technologies associated with the entire life cycle management of digital assets. Furthermore, they can extend these applications to practical integrated industrial scenarios, such as identification information query, historical equipment identification registration, equipment networking visualization, high-speed and efficient online processing of equipment, lifecycle management of equipment data documentation, networking management of equipment program documentation, equipment loans, and so on.

In the realm of digital manufacturing workshops, Huang et al. [3] introduced a real-time localization platform designed for various elements within discrete manufacturing environments. This platform integrates area localization techniques based on Radio Frequency Identification (RFID) and Ultra-Wide Band (UWB) precision localization methods. Segura et al. [4] explored the potential of employing an Internet of Things (IoT) tag system in the fabrication and assembly of crankshafts to capture and transmit production data. Cao et al. [5] presented a collaborative framework for tracking materials and production processes from a supply chain perspective, leveraging IoT tags and Information Technology (IT) systems to gather real-time production data. However, there remains a lack of uniformity in asset identification research across workshops, factories, industry chains, and even cloud platform manufacturing. This disparity is due to varying encoding systems, modeling descriptions, and enterprise-specific rules, leading to challenges in encoding and resolution processes and hindering comprehensive life cycle management of industrial assets. Additionally, issues such as network latency and security vulnerabilities persist.

To address the aforementioned issue, this article introduces the application of 5G and the recursive resolution of industrial internet identification in Chapter 2. With the use of the low latency, safety, and stable communication features of 5G, this article proposes a reliable local identification and resolution architecture driven by 5G technology in Chapter 2. These methods are subsequently validated through data collection, factory element connection communication, and the information management system architecture presented in Chapter 3. To enhance students' relevant skills, training courses have been designed and implemented at the AMTC 5G learning factory as detailed in Chapter 4.

# 2. Methodology

## 2.1. Identification Encoding and Carrier

As illustrated in Figure 1, the international top nodes offer top-resolution services directly to secondary and other enterprise nodes [6]. The industrial internet identification and resolution platform enables creators to register and modify identifiers.

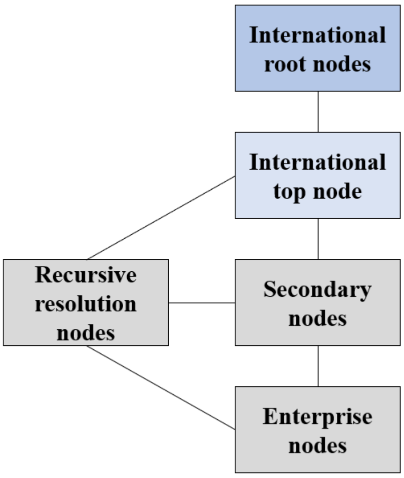

**Figure 1.** International Industrial Internet Identification and Resolution Architecture [7]

Figure 2 illustrates the structure of the standard asset identification codes. This specification serves as a guide for the learning factory to assign a unique identifier to each resource derived from past transactions or events, owned or controlled by the enterprise, and anticipated to yield economic benefits. The asset identification code is composed of a prefix and a suffix. The prefix encompasses national top node identifiers, machine tool industry secondary node identifiers, and enterprise node identifiers. The suffix comprises four segments: basic classification code, product model/specification code, product serial number, and enterprise custom code. The Industrial Internet Identification Alliance manages the prefix. The industry alliance oversees the product category code in the suffix, while the manufacturer defines the product model/specification code, product serial number, and other codes. Everyone has access to the platform to retrieve identification information using complete identification codes.

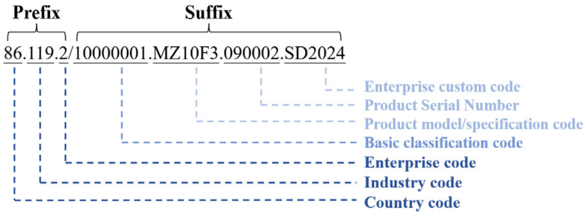

**Figure 2.** Standard Asset Identifier Encoding Specification

An identification carrier refers to the label that bears the identification code, encompassing both passive and active identification carrier technologies. Passive identification carrier technology encompasses but is not limited to one-dimensional barcodes, two-dimensional barcodes, and RFID tags. Active identification carriers include the UICC (Universal Integrated Circuit Card), mobile communication module, and security element [8]. It is recommended to use passive identification carriers for products. Before formal implementation, specific carrier types should be tested and selected.

## 2.2. Application Status and Prospects of 5G

### 2.2.1. Current status of 5G Technology Application

1. Power Consumption and Actual Performance of 5G Devices

Currently, the power consumption and actual performance of 5G devices significantly influence their application in industrial internet identification and resolution systems. Compared to 4G devices, 5G devices typically consume more power in general due to the use of higher frequency bands and larger bandwidths. This increased power consumption not only reduces the battery lifespan of the device but also escalates the complexity and cost of heat dissipation design. Furthermore, the coverage and penetration of 5G networks require further optimization, particularly in indoor settings and complex industrial environments where the attenuation and interference of 5G signals are more pronounced [8]. These factors constrain the application of 5G devices in industrial internet identification and resolution systems to a certain degree.

2. Comparison Between 5G and Existing Industrial Communication Technologies

At present, prevalent communication technologies in the industrial sector encompass industrial Ethernet, Fieldbus, Wi-Fi, ZigBee, and NB-IoT. The performance comparison of 5G and existing industrial communication technologies is illustrated in Figure 3. While 5G offers a superior transmission rate, reduced latency, and increased connection density compared to these technologies, it grapples with challenges related to network deployment costs and ecological maturity [9]. For instance, while industrial Ethernet boasts a comprehensive standard system and industrial chain, the integration of 5G into certain industrial scenarios remains nascent. The advancement of pertinent standards and equipment for 5G continues to evolve. Consequently, both 5G and established industrial communication technologies present distinct benefits in various application contexts. Their selection and integration should be tailored to meet specific requirements.

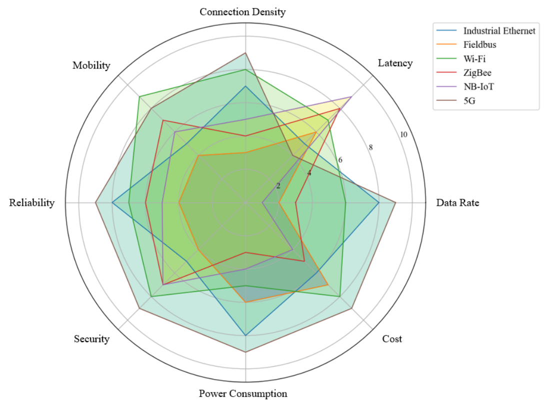

**Figure 3.** Performance Comparison of 5G and Existing Industrial Communication Technologies [10, 11]

### 2.2.2. Network Architecture Selection for 5G-powered Identification and Resolution Solutions

1. Public 5G Networks

Public 5G networks, designed and implemented by telecommunications operators, offer extensive coverage at a reduced construction cost. These attributes make them ideal for large-scale applications of identification and resolution. For instance, in cross-regional supply chain traceability scenarios, public 5G networks can facilitate the comprehensive tracking and management of raw materials, semi-finished products, finished products, and other items. However, these networks present limitations in terms of security and customizability, making it difficult to meet the specific requirements of the industrial sector.

2. Private 5G Independent Networks

Private 5G networks, designed and constructed by enterprises themselves, offer the benefits of independent deployment and flexible network control. These networks also ensure data security and maintain service quality. In specific scenarios such as equipment management and production line traceability within a factory, private 5G networks can provide customized network slicing and edge computing capabilities. This allows for local resolution and real-time response to identification data. However, the high cost of constructing a private 5G network is a significant barrier. Enterprises must possess certain network planning, operation, and maintenance capabilities to successfully implement these networks.

Therefore, the resolution solution for identification can adaptively select between public or private 5G networks based on the application environment and performance requirements. Alternatively, it may employ a hybrid networking mode to facilitate on-demand calls and dynamic configuration of network capabilities.

3. Application Prospects of 5G

As 5G network construction continues to advance and performance optimization persists, the application prospects for 5G-powered industrial internet identification and resolution technologies are set to broaden significantly. The 5G Release 17 (R17) standards have enhanced the speed, accuracy, and reliability of 5G to meet the stringent demands of the industrial internet [12]. Concurrently, the incorporation of new features such as 5G millimeter wave and 5G Ultra-Reliable Low-Latency Communication (URLLC) is expected to offer innovative application possibilities for these technologies. In the realm of smart factories, 5G-powered industrial internet identification and resolution technologies can be employed for real-time monitoring and predictive maintenance of production equipment, thereby improving equipment utilization and product yield. In the domain of smart logistics, these technologies can achieve precise positioning and comprehensive visual management of digital assets, thereby enhancing logistics timeliness and delivery accuracy. Furthermore, in the realm of product life cycle management, these technologies have the potential to overcome data barriers across various stages including design, production, sales, use, recycling, etc., thereby enabling end-to-end sharing and value mining of product information. The continuous expansion of these application scenarios is likely to foster the formation of a trillion-dollar industry centered around 5G-powered industrial internet identification and resolution technologies, thereby injecting fresh momentum into the digital transformation of the economy and society.

## 2.3. Local Identification and Resolution Architecture with 5G

Compared to conventional Local Area Networks (LANs) and Virtual Private Networks (VPNs), 5G LAN-type services present superior features. These enhancements harness the capabilities of 5G technology, delivering improved performance, extended reach, mobility support, and heightened security measures [13]. In this context, by implementing a local domain name resolution server, data is directed to the 5G intranet. The permission for equipment domain name resolution could be confined to specific areas, such as an entire factory or campus, which are within the coverage of the local 5G signals.

As depicted in Figure 4, the identification of manufacturing assets is resolved recursively to facilitate information retrieval. This process involves iteratively querying the responses provided by the authoritative resolution server until the enterprise application data is ultimately retrieved. Subsequently, this data is returned to the client, and the request results are locally cached. The communication among the application, the recursive resolution service system, and the enterprise server is facilitated by a 5G LAN. In contrast, the national node resolution server, the recursive resolution service system, and the secondary node resolution server are interconnected via the internet. The core network serves as the communication bridge between the cloud and the IIoT.

The identification recursive resolution processes are as follows:

(1) The application initiates an identification query request to the industrial internet identification resolution system's recursive resolution service system via the client.

(2) After receiving the request, the recursive resolution service system analyzes the query request from the client with its message being handled or Domain Name System (DNS) protocol and sends a resolution query request to the national top node.

(3) The national top-resolution service node system returns the address information of the identification secondary resolution service node.

(4) The recursive resolution service system continues to initiate query requests to the identification secondary resolution service node based on the results returned by the national top-resolution service node system.

(5) The identification secondary resolution service node returns the result data to the query requester, and the recursive resolution service system gets the address information of the enterprise resolution system for the identification.

(6) The recursive resolution system initiates an identification lookup request to the former address.

(7) The enterprise resolution system receives the request and returns the enterprise storage data.

(8) The client links to the corresponding information based on the identification enterprise application data returned by the recursive resolution service system.

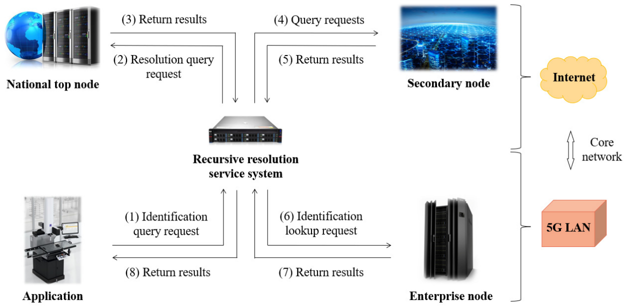

**Figure 4.** 5G and the Recursive Resolution of Industrial Internet Identification

# 3. Method Implementation

Within the digital asset management framework of the AMTC 5G learning factory, 5G-driven identification and resolution technologies play a crucial role. These technologies enable rapid and precise collection and integration of equipment or product data, including location, specifications, dimensions, and other pertinent information. It facilitates unified data management and supervision, reduces associated costs, and streamlines subsequent management and query processes. Additionally, these technologies can identify, classify, number, and mark equipment or products, thereby enabling managers to quickly access and utilize data. This enhances the efficiency and accuracy of infrastructure management within the AMTC 5G learning factory. The primary applications of industrial internet identification and resolution technologies in this context include the following points.

## 3.1. Data Collection

The iSESOL company developed a framework for the machine tool connection scheme, as well as customized hardware and software interfaces. Using AMTC equipment as the subject, they ensured compatibility with the existing identification systems' encoding scheme by assigning a uniform prefix granted by the state. This ensures the consistent transmission of identification information along the industrial chain, with each enterprise node possessing a fixed prefix. The prefix utilized in this study is 86.119.2.

Within the 5G learning factory, production equipment such as machine tools are equipped to collect and transmit data via 5G networks. Leveraging the expansive bandwidth of 5G, these tools can gather operational data in real time with precision, thereby offering robust support for production management and optimization. In accordance with the equipment or products within the AMTC and environmental characteristics, passive marking carriers—either RFID or Quick Response (QR) codes—are employed. These carriers are outfitted with specialized scanners designed for identification purposes.

Industrial internet identification and resolution technologies facilitate the collection of both static and dynamic data pertaining to equipment or products within the AMTC 5G learning factory, including DMG machine tools, M1.4 machine tools, ZEISS CMM, and so on. This is achieved through sensors or data collection devices embedded in the equipment, which gather static data such as position, dimensions, specifications, and dynamic data like operational status, tool status, and program status. These data collection devices can be either mobile, such as smartphones and tablet PCs, or fixed, like scanning guns. During the data acquisition process, real-time calibration and error correction are applied to the gathered data to enhance its accuracy. The collected data can then be cross-referenced and verified against the data already recorded in the identification system, thereby supplementing and ensuring global consistency of the data.

## 3.2. Factory Element Connection Communication

The architecture of the learning factory's industrial internet identification application, utilizing 5G technology, is depicted in Figure 5. The top layer of the industrial internet includes the identification resolution platform and database, while the cloud layer is established on a cloud computing platform. The edge layer is constructed on a local platform, and the bottom layer comprises physical objects affiliated with the AMTC. The edge layer allows multi-site protocol access to mitigate the limitations of the industrial internet platform which relies solely on Hypertext Transfer Protocol (HTTP) and exhibits low transmission reliability. A potent combination of technologies—5G, LampSite radio coverage solution, and Mobile Edge Computing (MEC)—is formed in the realm of indoor coverage. Concurrently, through the integration of 5G and Universal Machine Tool Interface (UMATI), remote monitoring of machine tools becomes feasible, enabling real-time understanding of their operational status and performance parameters. It provides strong support for the development of the industrial internet. According to the factory element connection communication framework, the Manufacturing Execution System (MES) for data management could be implemented using MEC. Both the edge and cloud layers assist the Model Driven Architecture (MDA), which is linked to the Production Planning System (PPS). With the aid of cloud and IIoT platforms, enterprises can interconnect diverse components such as machine tools, production lines, and supply chains to achieve data sharing and collaborative work for Enterprise Resource Planning (ERP).

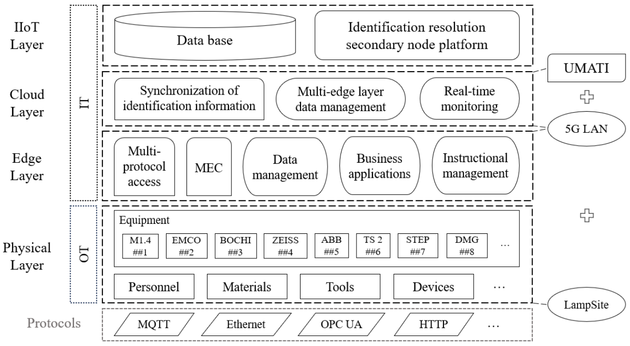

**Figure 5.** Four-layer Identification Application Architecture with 5G

Using bottom-up information synchronization as a case study, the edge equipment protocol sends a request containing identification information to the upper edge layer. The edge layer resolves this information and operates the database to complete the operational business. The edge layer takes the initiative to report the changes in the identification data to the cloud layer on the edge side and synchronizes the identification information to the cloud layer. After collecting data from each edge layer, the cloud layer checks the information differences with the IIoT layer. For the differences, the information model generator supported by artificial intelligence is applied to generate the information model of each identifier, and the request for batch registration and updating of identifiers is sent to the IIoT layer at regular intervals. The above steps achieve non-blocking completion of the operation of synchronizing information from the edge layer to the industrial internet platform, which not only facilitates multi-protocol access to the industrial internet identification and resolution platform but also guarantees the reliability of the identification data application.

## 3.3. Information Management System Scheme

Industrial internet identification and resolution technologies, driven by 5G, can manage the information of equipment or products within the AMTC via information management software and the World Wide Web. The management software can display the location, belonging, and current status of the equipment or products in the AMTC, and realize the statistics and analysis of their information. It facilitates the administrators to understand their current status and problems. Firstly, by the iSESOL BOX integrating edge computing, predictive maintenance, fault diagnosis, prediction of Remaining Useful Life (RUL), and other virtual model applications for digital twins are expected to be created. Secondly, the information management system provides business processes related to the management of digital assets, ensures that the operation actions are recorded and bound to the identification in real time, provides traceability information of all operation records, and achieves people's responsibility assignment and investigation and transformation towards digital-intelligent, environmentally sustainable, and integrated learning factories.

Taking equipment management as an example, regular repair, maintenance, and usage records are primary. Industrial internet identification and resolution technologies can efficiently and conveniently manage industrial equipment. It can also be extended to typical application scenarios such as collaborative Research and Development (R&D) design, remote device control, on-site auxiliary assembly, machine vision quality inspection, unmanned intelligent patrols, etc., as well as key industry practices like electronic equipment manufacturing and equipment manufacturing. The architecture of integration and sharing of factory resources based on industrial internet identification and resolution systems within the AMTC is shown in Figure 6.

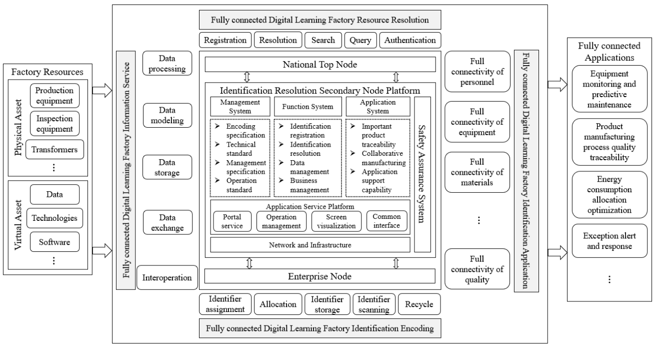

**Figure 6.** Integration and Sharing of Industrial Factors

# 4. Training Courses of the AMTC

## 4.1. Theoretical Learning

### 4.1.1. Basic Knowledge of 5G and Industrial Internet Identification and Resolution

The objective of theoretical learning is to equip students with a comprehensive understanding of the fundamental concepts, technical principles, and application values associated with 5G and industrial internet identification and resolution technologies. The courses commence by presenting an overview of the communication network architecture, key performance indicators, and technical characteristics intrinsic to 5G. It emphasizes the transformative impact of 5G's low latency, high reliability, and extensive connection on the industrial internet. Afterward, the courses methodically elucidate the system architecture, encoding specification, and resolution process inherent to identification and resolution technologies. The use of compelling case studies aids students in comprehending the pivotal role that industrial internet identification and resolution technologies play within the industrial internet.

During the training process, the courses emphasize the seamless integration of theory and practice. For instance, in the explanation of 5G network slicing technology, Students are given an intuitive experience of how end-to-end network slicing addresses diverse business requirements through the construction of a 5G private network. Meanwhile, we employ multimedia teaching techniques, including videos, animations, and virtual simulations, to enrich the interactivity and engagement of the training content.

### 4.1.2. Analysis of Typical Application Scenarios

Upon establishing foundational knowledge, the courses delve into the analysis of typical application scenarios for 5G-driven methods based on industrial internet identification and resolution technologies. By examining real-world cases in sectors such as intelligent manufacturing, smart logistics, and digital twins, we aim to foster a profound understanding of the practical utility and innovative potential of industrial internet identification and resolution technologies among students.

In the context of a smart learning factory's production line traceability, we illustrate the application of 5G + RFID for accurate identification and real-time positioning of materials, semi-finished products, finished products, and other objects. This approach overcomes the efficiency limitations inherent in traditional barcode scanning. Through visual data analysis interfaces, students gain a clear understanding of anomalies in working conditions and quality issues during the manufacturing process, thereby enhancing their capacity to oversee the entire procedure. In the realm of digital twin scenarios, we showcase the deployment of 5G-driven industrial internet identification and resolution technologies to facilitate real-time mapping and synchronization between physical entities and their digital counterparts. This enables functionalities such as remote equipment operation, maintenance, and product performance optimization.

## 4.2. Practical Training

### 4.2.1. Equipment and Product Identification Encoding Practice

The practical training component of the courses is central to fostering students' capacity to employ industrial internet identification and resolution technologies in settling real-world challenges. Initially, we direct students to engage in equipment and product identification encoding exercises. They are required to assign distinct identification codes to various equipment and products within the learning factory, adhering to the Global Standard 1 (GS1). Additionally, they must select suitable carriers (e.g., RFID tags, QR codes) for attaching these identifications.

In this process, we underscore the importance of standardizing and scaling identification encoding. Students must take into account factors such as length, structure, verification, and others to ensure that the encoding scheme not only adheres to industry standards but also accommodates the future developmental needs of the factory. Furthermore, we organize students to conduct performance tests on identification carriers. These tests evaluate various indicators such as reading distance, recognition speed, and anti-interference ability under actual working conditions. This provides data support for the selection of optimal solutions.

### 4.2.2. Data Collection and Application Development

Upon completion of the identification encoding process, as shown in Figure 7, students are introduced to the utilization of 5G networks and smart terminals for the automated collection and cloud uploading of equipment and product identification data. We furnish an open Application Programming Interface (API) coupled with an edge computing platform, facilitating rapid integration of RFID readers, cameras, and other data collection devices to establish real-time and dependable data collection links. At the same time, students have access to big data analysis, machine learning, and other tools offered by the platform to develop intelligent applications predicated on identification data. These applications encompass equipment health assessments, product traceability inquiries, and inventory forecast optimization.

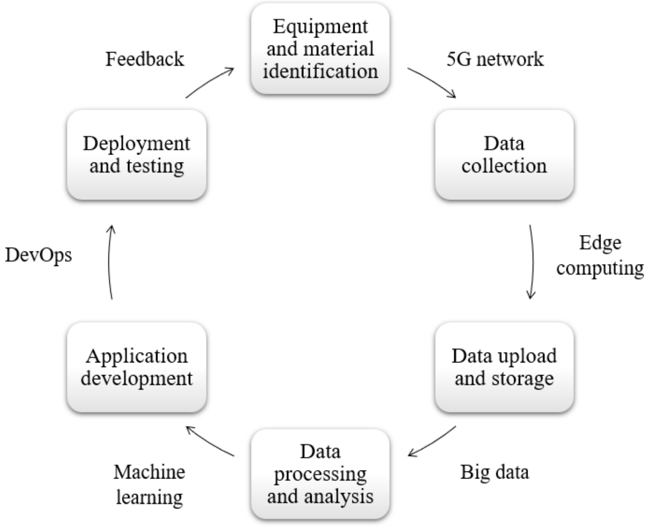

**Figure 7.** Data Collection and Application Development Process

In applied projects, we utilize a "learning by doing" training model. We collaboratively design the "equipment full life cycle management" project with our partner companies. Students are required to employ the 5G-driven industrial internet identification and resolution platform to achieve comprehensive digital management of specific equipment throughout its lifecycle, from entry and installation to operation, maintenance, and eventual scrapping. This process culminates in the formation of a visual equipment archive and knowledge base. Through this project practice, students' hands-on skills and innovative thinking have been fully honed.

In summary, the AMTC 5G learning factory's industrial internet identification and resolution training program is underpinned by the principles of ‘5G + identification and resolution’ and is tailored to the practical applications of intelligent manufacturing. This program has established a comprehensive training system that seamlessly integrates theoretical instruction with hands-on practice. Through rigorous coursework and project-based exercises, students not only acquire advanced knowledge in industrial internet identification and resolution but also hone their problem-solving skills, including critical thinking, analysis, and innovation. Such training lays a robust foundation for their future development as pioneering talents in the emerging field of engineering.

## 5. Conclusion and Outlook

This article creatively proposes a concept of asset management in 5G learning factories based on industrial internet identification and resolution systems, which is convenient for instructional management and digital asset management. Industrial internet identification and resolution, combined with 5G providing superior data transmission capacity and lower latency, significantly improves the whole life cycle management of equipment, devices, people, materials, and tools in the fully connected AMTC 5G learning factory. Based on this, students’ teaching, equipment, items, and environment management and application extension enhance students’ command of knowledge, strengthen lectures’ understanding of students’ learning degree; provide researchers with more private and convenient experimental conditions; avoid the confusion of unqualified and qualified parts; avoid waste of time during the assembly process of equipment by classifying products; efficiently prevent machine breakdowns by cleaning and maintenance; increase safety by sorting and cleaning; prevent wastage of products, tools and materials; improve the AMTC and its environment.

Since industrial internet identification and resolution systems are the foundation for breaking information silos, achieving data interoperability, and mining massive data, the technologies are essential for 5G learning factories to achieve highly intelligent management through digital platforms for digital twins. This article provides a reference for other learning factories. Further research will focus on the establishment of a global network of learning factories for information resource exchange and sharing.

In the future, the subsequent research on integration and sharing of industrial resources would facilitate collaborative design and ubiquitous perception of millions of production resources, including finished parts, structural components, and chemical materials. This would enable more precise assembly and processing capabilities, as well as quality inspection methods. It would also stimulate the development of digital research and development, network collaboration, intelligent manufacturing, lean management, and other models for the manufacturing industry. The potential benefits include the realization of remote collaborative design and modification, a reduction in experimental costs, an improvement in research and development and assembly efficiency, and a shortening of the design cycle.

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