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Smart internet of things unmanned metering system design

Xuan Deng[1,*], Jiaolong Shen[2] and Honghua Liu[1]

[1] Hunan International Economics University, Changsha, 410205, China
[2] Changsha for Love Information Technology Co. Changsha, 410000, China

* Correspondence author; E-mail: 3237662410@qq.com.

Abstract: Logistics metering system is a scene that cannot be ignored in the field of manufacturing, the current metering system model architecture, each operating module to maintain a relatively independent state, did not reach a cross-module network linkage and data sharing, there are problems such as low efficiency, poor accuracy stability and so on. In order to solve this series of problems, research and design of unmanned metrology system, the integration of Internet of Things(IoT), big data and other advanced technologies, to achieve integrated design, logistics intelligence, optimize material management, and improve the efficiency of supply chain collaboration.

Keywords: IoT; unmanned metering system; integrated design; synergistic efficiency

1. Introduction

Internet of Things (IoT) technology uses digital management and intelligent empowerment to realize the efficient circulation of information and intelligent application through the interconnection of everything, which improves efficiency, precision and intelligence in the field of logistics and supply chain management.

Most of the factories in the manufacturing field have the transportation of raw materials and auxiliary materials, these transport vehicles need to stop, registration and weighing, the current system to complete these processes are mainly AVS metering system and unmanned catty checking system.AVS system belongs to the main pound separate metering system, measurement of weighing need to be used by the personnel to enter the use of simple functions, time-consuming and labor intensive, and prone to errors; unmanned catty checking system from the main and auxiliary pounds to collect weight Data and integration of the main and vice-pound measurement, support for shipping plan management, data management, vehicle number identification, reporting and other functions, and supporting equipment and facilities such as gates, vehicle number identification, traffic lights, voice intercom, etc., but the set of system operation mode is each time before weighing the need to carry out the two car scale comparison work [1] (empty car comparison), using the same vehicle for the main pound, the vice-pound pounding weighing [2], the two weighing scales weighing error is less than 20KG, in order to carry out the day's comparison work, a single vehicle measurement comparison, weighing processing and information feedback total time of about 11 minutes, in the measurement of data, all the measurement data only to the main pound measurement data shall prevail, the vice-pound only as a comparison of the use of these operational processes are complex, inefficient, and the degree of intelligence is not high. In order to solve the above problems, research and development of unmanned measurement system, a kind of integration of a variety of advanced technologies, including the Internet of Things, automatic detection, streaming media, pattern recognition, information processing and computer networks, in order to realize the automatic weighing of materials and data acquisition and processing system.

2. Unmanned metering systems and functions

The unmanned weighing system integrates license plate recognition technology [3], self-service weighing technology, PLC automatic control technology, database technology and abnormal automatic alarm technology as well as special software system. It realizes completely unattended operation and driver self-service weighing function [4]. During the weighing process, the system adopts the combination of voice prompts and LED display screen to provide drivers with clear operational guidelines to ensure that they can complete the whole process smoothly and efficiently. When the vehicle passes through the weighbridge, the system automatically triggers the image capturing device to capture the vehicle in real time, and automatically associates the acquired image information to the corresponding transportation task record.

In addition, the system is equipped with the function of automatically collecting data from the electronic weighing scales, which can accurately record key parameters such as gross weight, tare weight and net weight. This process is fully automated, which not only significantly reduces the possibility of human intervention, but also effectively eliminates the data entry errors and cheating that can be caused by traditional manual transcription. In this way, the system ensures the accuracy and reliability of the weighing data, thus providing a solid data foundation for logistics management and decision-making support.

3. Design of unmanned metering system based on IoT technology

3.1. Unmanned metering system hardware networking and enablement program

Metering equipment in the system mainly through the serial port server, Ethernet IO [5], SDK device integration three types of ways for hardware device networking and empowerment, the device signals are converted into metering business programs in the parameter information.

To improve efficiency and minimize manual intervention, a remote centralized metering model is used. This model visualizes the topology of inter-device connections and data transmission paths by constructing an unmanned metering system with IoT [6] connectivity across the network. In this structure, the bottom layer deploys cameras as front-end acquisition devices [7] to ensure that the monitoring area has no dead-end coverage; the middle layer is configured with video recorders, which are responsible for receiving video signals from the cameras; and the core layer is the workstation, which serves as a platform for day-to-day management and operation and allows the operators to monitor the video in real time, adjust the parameters of the cameras, playback the video, and process the alarm information. All devices are interconnected by switches (e.g. Ethernet switches), which act as network hubs, efficiently forwarding data packets to ensure accurate transmission of video streams and control commands to the target terminals, which are ultimately presented on computers in the control room and on the monitor screen, realizing the efficient and accurate integrated management of unmanned metering system Internet of Things.

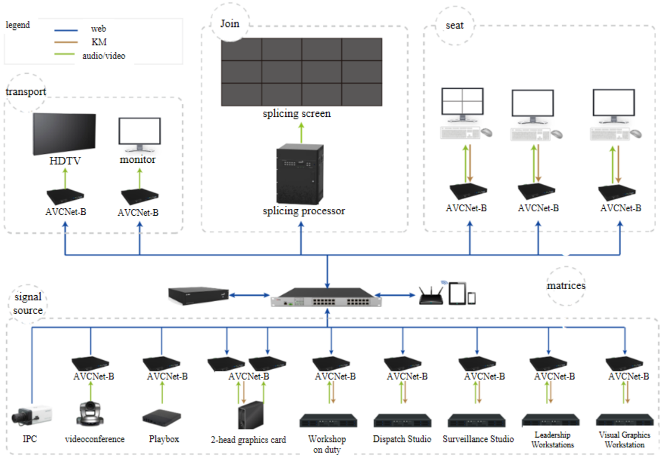


Figure 1. Network Topology.

3.2. Unmanned metering system software design

3.2.1. Unmanned metering system metering network

Cloud-based unattended metering solution, with the advanced concept of centralized management, can efficiently integrate and unify the control of metering activities distributed in multiple plants and different geographical areas in SaaS (Software as a Service) mode. Through the deployment of the cloud platform, the solution realizes real-time sharing and seamless circulation of metering data, which greatly facilitates the interconnection of information between plants [8]. On this basis, it further supports the refinement and optimization of plant operation and management, enabling each plant to carry out more scientific and reasonable resource allocation and production scheduling based on real-time and accurate metering data, thus significantly improving overall operational efficiency and management effectiveness. In addition, the solution also strengthens the ability of cross-regional and cross-plant collaboration, laying a solid foundation for the construction of an integrated and intelligent enterprise management system.

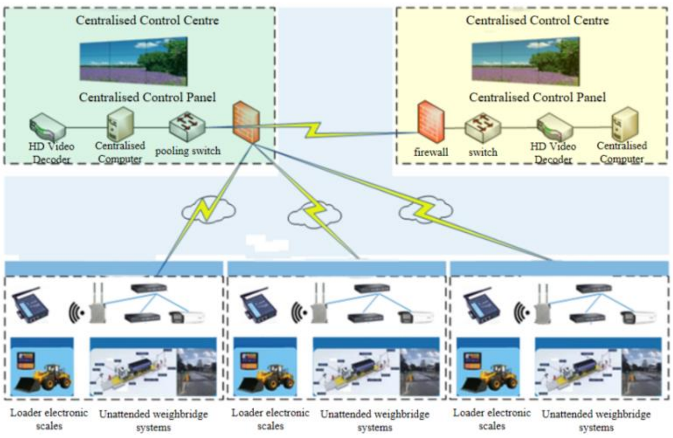


Figure 2. Cloud-based unmanned metering solution map.

3.2.2. Metrological algorithms for weighing systems

The measurement algorithm precisely defines the calculation methods [9] and decision rules that are implemented in the various process steps of the weighing system. It not only defines the specific logic of data acquisition, processing and analysis, but also establishes the decision criteria at key decision points to ensure that the system is able to accurately perform the intended function at each stage of the operation. It builds a simplified logical framework to represent the process based on the given information.

Algorithm parameters:

① W is the detected weight;
② W_{stable} is the stabilized weight value;
③ ΔW is the maximum permissible weight fluctuation range;
④ $W_{recorded}$ is the final recorded weight;
⑤ $Status$ is the metering status (idle, metering in progress, abnormal, etc.)
⑥ T is a time variable to track the length of time for weight stabilization
⑦ T_{stable} is the minimum time required to determine weight stabilization

```
IF configuration loading is complete AND system is in idle state THEN
    RESET measurement status to idle

IF vehicle entry is detected THEN
    Open the gate
    WHILE detecting vehicle on scale DO
        SET measurement status to "in progress"
        WHILE (weight fluctuation > ΔW) DO
            IF infrared alarm is triggered THEN
                SET measurement status to "abnormal"
                BREAK
            ELSE
                CONTINUE monitoring weight changes
        END WHILE

        IF measurement status is "abnormal" THEN
            // Handle abnormal situation
        ELSE
            // When weight fluctuation is within controllable range and has been stable for a period of time T >= T_stable
            SET W_stable = latest W
            SET W_recorded = W_stable
            SET measurement status to "completed"
            Allow vehicle to exit
        END IF
    END WHILE
END IF
```

Figure 3. Measurement algorithm pseudo-code formula.

The pseudo-code depicts a simplified control logic framework in which a series of key steps are systematically integrated, from the entry of the vehicle, to the initiation of the weighing process, to the evaluation of the weight stability, to the handling of abnormal situations. This logical structure defines in detail the complete flow of the weighing operation, ensuring that each stage is precisely executed according to predefined norms and standards.

3.2.3. Mathematical modeling of weighing systems

The mathematical model of an unmanned metrological weighing system can be constructed based on Integer Programming (IP) or Mixed Integer Linear Programming (MILP), which is designed to optimize the scheduling process for weighing goods. The following is a simplified mathematical expression for the system to minimize the maximum time to complete the weighing of all cargoes, i.e., the "Maximum Completion Time". As shown in Table 1, the system consists of a set of goods to be weighed and a set of weighing stations to weigh them, and the corresponding program is executed at each weighing station for each of the goods to be weighed. The relevant assumptions are as follows: (i) the cargo weighing process strictly adheres to the weighing time; (ii) only one cargo can be weighed at a weighing station at any given time, and at the same time, a cargo can be weighed at only one weighing station; and (iii) the failure of the weighing station and the delay in the arrival of the cargo are not taken into account.

Table 1. Parameter Definition

Variant	Descriptive
G	Collections of goods to be weighed
S	Collection of available weighing stations
n	Quantity of goods to be weighed
m	Number of weighing stations
$W_{i.s}$	Weighing operation performed by cargo i at weighing station s
$T_{i.s}$	the execution time of the weighing operation $W_{i.s}$, i.e. the time required for the stabilization of the weighing of the load i at the weighing station s
$F_{i.s}$	Completion time of weighing cargo i at weighing station s
$F_{i.s}^{'}$	Start of the second weighing of cargo i at the weighing station
$F_{\max}$	Maximum time for all goods to be weighed, i.e. when the last goods are weighed
$X_s^{i.k}$	Binary variable. At weighing station s , this variable takes the value of 1 if good i is weighed first, followed by good k; conversely, it takes the value of 0
$Z_{i.s}$	Binary variable. Indicates whether the shipment has been weighed for the first time at the weighing station.
M	A constant large enough to ensure that this constraint does not work when $X_s^{i.k} = 0$, $Z_{i.s} = 0$
GW_i	Primary metrological weighing of cargo i from the system (gross weight)
TW_i	Secondary metrological weighing of cargo i from the system (tare)
NW_i	Net weight

In this paper, an integer programming model is used to describe the weighing problem of an unmanned metering system with minimizing $F_{\max}$ as the optimization objective, as shown in Eqs. (1)-(10). Eq. (1) is the objective function; Eq. (2) indicates that each cargo can only be weighed once at each weighing station; Eq. (3) indicates that each weighing station can only continue to the next one after completing the weighing of one cargo; Eq. (4) indicates that only one cargo can be weighed at a weighing station at any time; Eq. (5) indicates that a cargo can only be weighed at a weighing station at any time; and Eq. (6) indicates that the maximum completion time is not less than the (6) means that the maximum completion time is not less than the completion time of any one cargo; Eq. (7) represents the order in which the goods are weighed; Eq. (8) represents ensuring that the second weighing occurs at the same weighing station and is not earlier than the first weighing; Eq. (9) represents ensuring that the second weighing is not earlier than the first weighing; and Eq. (10) represents the net weight of the goods.

$$\min F_{\max} \tag{1}$$

$$\sum_{k\in G\backslash\{i\}} x_s^{i.k} + \sum_{k\in G\backslash\{i\}} x_s^{k.i} = 1,\quad i\in G,\quad s\in S \tag{2}$$

$$F_{i.s} + T_{i.s} + M(1 - x_s^{i.k}) \le F_{k.s},\quad i,k\in G,\quad s\in S;\quad i\ne k \tag{3}$$

$$\sum_{i\in G}[F_{i.s} \le T < F_{i.s} + T_{i.s}] \le 1,\quad s\in S \tag{4}$$

$$\sum_{s\in S}[F_{i.s} \le T < F_{i.s} + T_{i.s}] \le 1,\quad i\in G \tag{5}$$

$$F_{\max} \ge F_{i.s} + T_{i.s},\quad i\in G,\quad s\in S \tag{6}$$

$$Z_{i.s}=1\text{，}\ \text{if}\ \sum\nolimits_{k\in G\setminus\{i\}} x_s^{i.k}=1 \tag{7}$$

$$F_{i.s}+T_{i.s}\le F_{i.s}^{'}\text{，}\ \ \forall i\in G\text{，}\ \ s\in S \tag{8}$$

$$F_{i.s}+T_{i.s}+M\ \ (1-Z_{i.s})\le F_{i.s}^{'}\text{，}\ \ \forall i\in G\text{，}\ \ s\in S \tag{9}$$

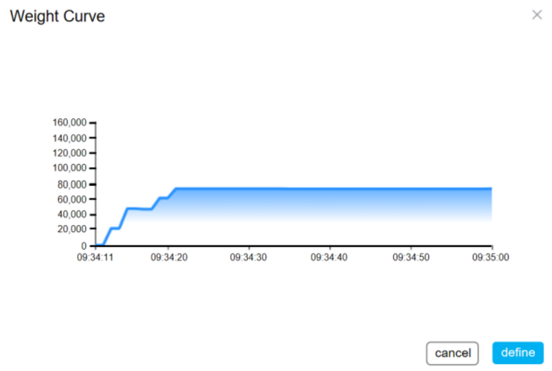
$$NW_i=GW_i-TW_i \tag{10}$$

The mathematical model of the unmanned metrological weighing system is used to optimize the operation process of the unmanned metrological weighing system to ensure that all the goods can be weighed accurately and efficiently, so as to improve the overall performance and efficiency of the system. The results of the algorithm testing are shown in Table 2, the test data are collected from the actual environment, after testing, the overall operation of the system is stable, and all the functional modules are running normally.

Table 2. Measurement test data

Task No.	Material Name	GW_i (kg)	TW_i (kg)	NW_i (kg)	$F_{i.s}$	$F_{i.s}^{'}$
GHYY-202501-00367	Aluminum ore 1#	87810	19570	68240	2025/1/1 21:41:31	2025/1/2 9:35:34
GHYY-202501-00376	Aluminum ore 1#	87510	23670	63840	2025/1/1 22:15:28	2025/1/2 9:35:32
DY-202404-0025	Cinder	76030	20510	55520	2025/1/2 9:34:25	2025/1/2 10:36:03
GHYY-202501-00527	Ammonia	51050	16020	35030	2025/1/2 8:10:39	2025/1/2 9:45:07
GHYY-202501-00463	Ammonia	78710	18320	60390	2025/1/2 2:32:34	2025/1/2 9:34:21
GHYY-202501-00533	Aluminum ore 1#	51100	15520	35580	2025/1/2 8:15:51	2025/1/2 9:35:30

The single weighing time of the above experimental procedure includes the total time of the up-weighing phase and the down-weighing phase. At the beginning of the weighing phase, the weight readings experienced a short period of instability, which was characterized by fluctuations or jerks in the measured values, mainly caused by mechanical shocks and delayed system response when the vehicle was parked. Subsequently, the readings gradually converge to a stable interval, with fluctuations significantly reduced and maintained within an acceptable error range; when getting off the scale, as the vehicle leaves the weighing platform, the weight value detected by the sensor shows a decreasing trend, which is non-instantaneous, accompanied by time delay, and ultimately reaches a zero equilibrium state. During this period, the rate of change of the weight reading varies with time, decreasing rapidly at the beginning and then slowing down until it reaches zero. This phenomenon reflects the system's response to load removal and the role of its internal reset mechanism. From the dynamic characteristics of the weighing process in the figure below, it can be seen that, for example, in the case of transporting cinder goods, the vehicle weighing time is 9:34:11 on January 2, 2025, and after a period of fluctuating and unstable period, 9:34:25 maintains stability, that is, it begins to time; after the completion of the timing of the vehicle weighing, the value decreases to zero, and the end of the measurement is 9:35:17, and the whole process of a single measurement time is within 2 minutes. The whole process is within 2 minutes.



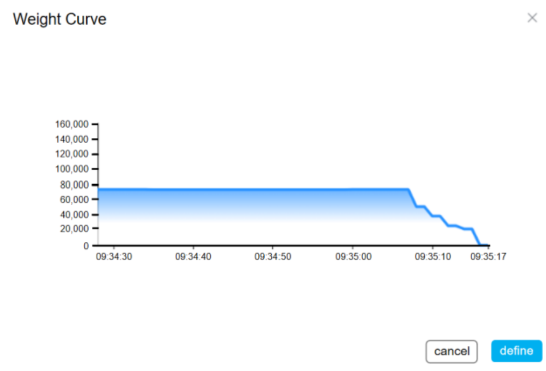


Figure 4. Upper dynamic properties **Figure 5.** Lower dynamic properties

3.3. Measurement models for unmanned measurement systems

The Metrology Model is designed to ensure the efficiency, accuracy and safety of the vehicle weighing process through a series of highly integrated and automated steps. The model combines state-of-the-art hardware facilities and software services to automate the entire process from vehicle entry to exit.

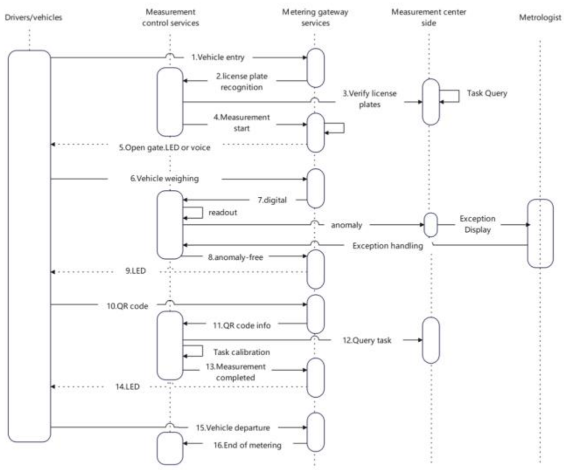


Figure 6. Measurement model

3.4. Hardware implementation of unmanned metering systems

The hardware implementation of the metering system demonstrates a bi-directional metering configuration that integrates a variety of advanced technology components to optimize operational processes and ensure high accuracy. Cameras are used for license plate recognition, supplemented by fill-in lamps to compensate for the lack of light at night, thus significantly improving the accuracy and reliability of the recognition. Infrared sensors form a virtual fence [10], effectively preventing cheating during the metering process and enhancing the stability of the metering results. As the core component of the system, the MFP integrates a number of functional modules including, but not limited to, printing, code scanning, network exchange, and flat-panel information display, aiming to comprehensively address the operational needs of the entire metering process [11]. Through this integrated design, it not only simplifies the deployment and maintenance of the system, but also improves work efficiency and service quality. It not only provides users with convenient and accurate measurement services, but also effectively prevents measurement cheating and safeguards the fairness and impartiality of measurement results. The whole system process single automatic measurement processing time <5 minutes, operational efficiency of more than 50%.

Table 3. Main Hardware Configuration

Name	Type	Quantity
LED display screen	220VAC power supply module：BQ-4.5V40A X4(Plus) V2.1 control board	2
Edge Server	ARK-1221L	1
Two-dimensional code scanner	LV4500L:Serial 232 communication port	2
IP Network Intercom Terminal	RT-NT-02	3
Thermal paper printers	KP-300H	1
Hemispherical camera	DS-2DE2402IW-DE3/W	1
License plate recognition camera	DS-TCG405-E	2
License plate recognition fill light	CXBG-1-CX-DS-TL2000CS	2
Infrared	ABI10-1106	2
Ethernet IO	C2000-A2-SDD8080-BC1	1
Relays	JZX-22F(D)4Z	6

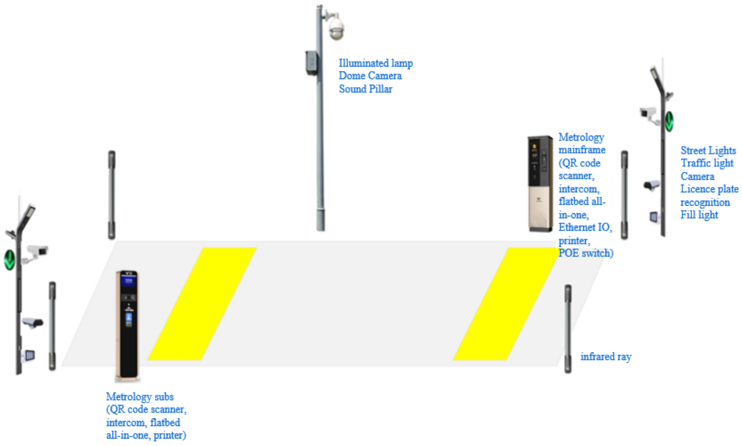


Figure 7. Hardware Implementation Diagram

4. Conclusion

Based on the Internet of Things technology unmanned measurement system research to achieve unmanned measurement of digital, networked, intelligent, build a service system based on data collection, convergence, analysis, support there are enterprises intelligent construction process ubiquitous connection, elasticity of supply, high-efficiency configuration of the carrier. Unmanned metering management system, to the logistics operation of the intensive, efficient as the basic goal, to sales of factory logistics, into the factory material logistics, internal production logistics as the main line, through the optimization of business processes, the effective use of space, equipment, personnel and energy; minimize material handling; simplify the workflow, reduce manual labor, improve efficiency, reduce logistics costs; reduce inventory capital consumption; improve customer satisfaction; for the convenience of employees, and to improve the efficiency and efficiency of the logistics system.

Customer satisfaction; provide employees with a convenient, comfortable, safe and hygienic working environment.

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