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Application of automated guided vehicle and sterilization monitoring report in disinfection and sterilization process

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ABSTRACT: Objective The present study investigates the application and effectiveness of an automated guided vehicle (AGV) and a sterilization monitoring report in the disinfection and sterilization process. **Methods** The AGV is applied for auto loading and unloading in the disinfection and sterilization process and for route planning. A reusable instrument transportation management mode and AGV instruction system are constructed. Following the requirements of the *Central sterile supply department (CSSD) - Part 3: Surveillance standard for cleaning, disinfection and sterilization* (WS 310.3—2016) for recording critical factors affecting the sterilization process and results, this study used the information tracking system in the central sterile supply department (CSSD) to automatically capture all critical points in time, temperature, and temperature from the equipment monitoring system. In addition, the actual value and the reference value items in the process flow sheet were set up using the clinical chemical examination report template to automatically determine whether the parameters comply with the requirements; parameter abnormalities are displayed with red arrows. The results of chemical and biological monitoring of sterilized items were recorded using a scanner to form a sterilization monitoring report. **Results** In comparison between before and after the application of AGV, the daily manual transportation and time consuming were reduced from an average of 5 minutes to an average of 1 minute, with a statistically significant difference (P<0.01). In comparison between the sterilization monitoring report before and after the application, the recording time of parameters and monitoring identification was reduced from an average of 3.5 minutes to an average of 1 minute, with a statistically significant difference (P<0.01). A satisfaction survey was conducted from the dimensions of environment, occupational exposure, simplicity of operation, physical exertion, time consuming, and pleasure. The satisfaction rate increased from 75% to 98.4%. **Conclusion** AGV is an intelligent logistics system that replaces repetitive and unitary manual labor and significantly improves the work efficiency of sterilization operators. It is closely connected with the Internet of Things (IOT), intelligent devices, and information tracking system to realize the intelligent construction of CSSD by reducing occupational injuries such as lowering physical exertion and simplifying operations, and to improve the satisfaction of sterilization operators. The combined application of sterilization monitoring report can not only improve the work efficiency, but also reduce the misidentification of the process flow sheet to reduce the occurrence of adverse events and improve the quality of work.

KEY WORDS: Automated guided vehicle; Sterilization monitoring report; Disinfection and sterilization process

Introduction

Automated guided vehicle (AGV) can travel automatically on a pre-set route navigated by special landmarks[1] and therefore has a safety protection mechanism. AGV is controlled by a computer and contributes to the intelligent construction of the central sterile supply department (CSSD) through the roles of network interaction, multi-sensor control, mobility, and automatic navigation. The main functions of AGV in CSSD include loading, transporting, and unloading items to be cleaned and ster-

ilized. It can replace manual handling and realize automated logistics[2], which solves the issues of occupational exposure, labor scarcity, and low work efficiency of sterilization operators. The CSSD of Nantong First People's Hospital, Nantong, Jiangsu, China has carried out reasonable planning for AGVs according to the standardized sterilization process and the existing space requirements, so as to optimize the requirements in terms of sensitivity, high efficiency, and transport weight. Sterilization is at the heart of CSSD's efforts to achieve security for sterile items. Sterilization operators are the primary performers in completing sterilization operations[3] and are in the occupational exposure of weight-bearing operations as they perform prolonged, repetitive, and singular loading and unloading of sterilized items. In addition, the *Central sterile supply department (CSSD) - Part 3: Surveillance standard for cleaning, disinfection and sterilization* (WS 310.3—2016) requires timely completion of the sterilization process and recording of critical point parameters. However, in practice, sterilization operators have different professional qualities, which results in their not being able to detect parameter abnormalities in a timely manner, greatly reducing their work efficiency. To promote the intelligent development of the disinfection and sterilization process and to improve the quality and efficiency of sterilization, the hospital has applied AGV and sterilization monitoring report to the disinfection and sterilization process since January 2023 and achieved great results, which are reported as follows.

1 Research methods

1.1 Procedure design

The procedure design and route planning of AGV is a vital part that directly affects the overall performance of the system[4]. Before putting AGV into use, it is necessary to carry out reasonable planning of the route of sterilization in CSSD, marking the routes and stations, such as starting site (idle AGV stopping point), charging site, workstation, and obstacle avoidance. Due to the limitations of goal-driven, dynamic safety, and time requirements, AGV design requires full consideration of reasonable balancing elements of safety and timeliness while planning paths under dynamic environments[5]. The AGV is equipped with voice announcements and music playback to effectively reduce collisions, to make the work area humanistic, and to increase the operator's pleasure.

1.2 Design of sterilization monitoring report

The sterilization monitoring report includes a header, main parameters, content of the sterile pack, and monitoring scanning. The header includes sterilization date, sterilization batch number, running procedure, running result, running time, total running frequency, pre-set sterilization time, pre-set sterilization temperature, pre-set sterilization pressure, sterilization operator, and reviewer. Main parameters include parameter item name, running value, reference value, and process parameter result. The content of sterile pack includes the name of the item to be sterilized, quantity, and property. The monitoring scanning includes chemical and biological monitoring.

2 Application methods

2.1 Loading, unloading, and transportation of AGV in sterilization loading racks

Combined with the information tracking system of CSSD, the central control platform of CSSD enables intelligent devices such as sterilizers, AGVs, and sites to share information within the local area network (LAN) using the Internet of Things (IOT), and to collaboratively control the automation of loading, unloading, and transportation of item loading racks, as shown in Figure 1.

2.2 Construction of auto loading, auto unloading, and transportation management modes

AGVs are set in sterilizer units. They connected each sterilizer, sterilization loading site, sterilization unloading site, AGV storage site, charging site, and starting site. The central control platform of CSSD is interfaced with the information tracking system to realize real-time data interaction. The information tracking system or hand-held PDA sends the task command, and the central control platform schedules the AGV to receive the relevant task. The

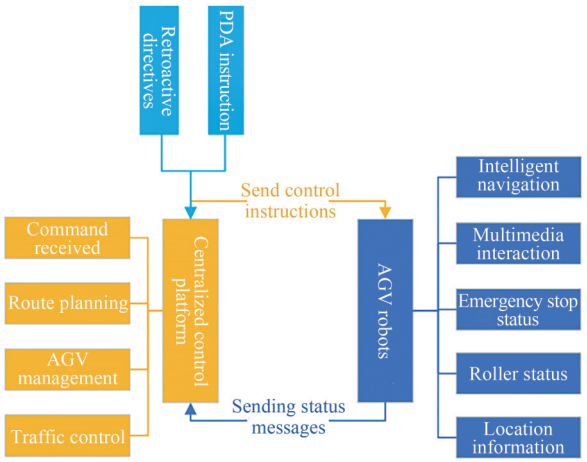

Figure 1 System structure of AGV

AGV performing the task moves to the sterilization loading site and transports the fully loaded rack to the designated sterilizer. The sterilizer starts the corresponding sterilization program according to the task instructions. After the sterilization program is finished, the AGV transports the rack to the designated sterilization unloading site to cool down for 30 minutes. After the sterile packs are unloaded, the hand-held PDA is used to send the "item loading rack return" task command again to transport the empty rack from the back door to the corresponding sterilizer, and from the front door to the corresponding sterilization loading site or AGV storage site.

2.3 Construction of AGV instruction system

The AGV instruction system is constructed based on the existing information tracking system. The system synchronizes information from the information tracking system, AGV, sterilizer, each loading or unloading site, AGV storage site, starting site, and charging site in CSSD in real-time to each port through IOT. The operator sends task instructions via the information tracking system or hand-held PDA, and then the AGV receives the task instructions and performs the task (Figure 3). The system allows transportation between sites and has one-button commands for AGVs to go to charging piles and return to the starting site, and a red emergency stop button for emergencies, as shown in Figure 2.

2.3.1 Loading and sterilization site

Instructions are sent through the sterilization registration interface of the information tracking system of CSSD or a hand-held PDA. Enter the sterilization loading module → select sterilizer → select sterilization loading site → select sterilization procedure → scan the sterilization pack → select operator → initialize → send instruction to AGV → run the sterilization procedure.

2.3.2 Unloading and storage site

Sterilization procedure finishes → AGV trans-

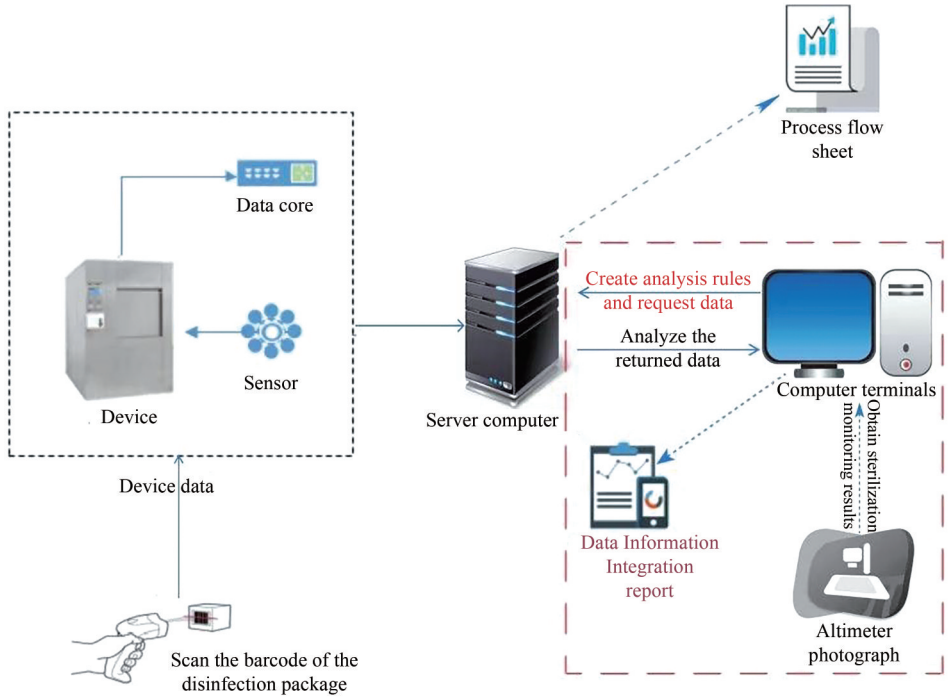

Figure 2 AGV workflow diagram

ports the item loading rack from to sterilization unloading site → AGV returns to the starting site after the task is completed.

2.3.3 Sterilized item loading rack return

Enter the empty sterilized item loading rack return module → select sterilizer → select sterilization unloading site → initialize → send instruction to AGV→AGV returns to the starting site after the task is completed.

2.4 Application of sterilization monitoring report

2.4.1 System development

The key technologies of the system include (1) relational database, Microsoft SQL Server 2019; (2) middle layer, WebService, for connecting the equipment and the backstage management system; (3) barcode scanning, i. e., automatically obtaining the information of the sterile packs by scanning the barcodes on the sterile packs and/or consumables; (4) graphical statistics and analyzing of the real-time data; and (5) connecting of the information tracking system with the quality management system, i. e. Therefore, the system can obtain the sterilization data information of the sterilization quality monitoring system through the data, so that the database of the information tracking system contains the basic information of the sterile packs and the precise corresponding sterilization quality management data.

2.4.2 Quality control in CSSD

2.4.2.1 Connection of sterilizer with information tracking system

The sterilizer is connected to the information tracking system via LAN through the device monitoring service system, and the device monitoring service system stores the device data in the information tracking system server in real time.

2.4.2.2 Connecting to item pack information

The information of instrument packs and monitoring packs is connected to the sterilization batch through the scanning gun equipped on the sterilizer.

2.4.2.3 Creation of data analysis rules

Sterilization and monitoring data analysis rules are created in the information tracking system, including parameters such as pulsation, trans-pressure pulsation, positive-pressure pulsation, internal chamber pressure, internal chamber temperature, and sterilization time during the warming sterilization and vacuum drying phases.

2.4.2.4 Data identification

The real-time data collected at each stage is intelligently screened by the equipment monitoring service system, which selects the critical point of the data at each stage and sets the reference value. The system intelligently analyzes the critical point in combination with the reference value and marks the abnormal value.

2.4.2.5 Uploading of chemical and biological monitoring results

The chemical and biological monitoring results are manually identified, and the corresponding chemical and biological indicator cards are entered into the equipment monitoring service system via an HD scanner.

2.4.2.6 Report summarization

Data was analyzed on a batch-by-batch basis. All information from the same batch (including critical data for sterilization, monitoring data, sterilization pack data, etc.) is presented in one integrated report, as shown in Figure 3.

3 Results

3.1 Before and after the application of AGV, the daily sterilization workload and time consuming to complete loading, unloading, and transportation of items were observed and recorded. According to the data from the equipment monitoring, the average daily sterilization is about 25 pots. The entire manual process includes taking out the item loading rack, transferring the item loading rack to the appropriate sterilizer and starting the sterilization process, taking out the item loading rack after the operation and transferring it to the sterilization unloading site for cooling (approx. 5 minutes). After applying AGV, the operator spent most of time on sending task instructions using PDA, and it took about 1 minute per pot to complete the whole process. The difference in operating time required between the two groups was statistically significant (P<0.01), as

Sterilization Monitoring Characterization Statement

disinfectioner: _____

Review personnel: _____

The date of sterilization	Batch	Run the program	Results
2024-03-31T16:45:54	2ST240331-4-2718	P19 custom-defined 1	Unnormal end
disinfectioner	Review personnel	total number of runs	Runtime
Shen Xiao	Zhao Jie	2718	4398
Setting the sterilization time 480' S	Setting the sterilization temperature 134℃	Setting the sterilization pressure 212Kpa	
Sterilization parameters	runtime value	reference value	Results
number of negative pressure pulsations	3	3	
Negative pressure pulsation upper limit (kPa)	-0.1	⩾ -5	
lower limit of negative pressure pulsation (kPa)	-91.9	⩽ -85	
Number of cross-pressure pulsations	1	1	
upper limit of cross-pressure pulsation (kPa)	40.2	⩾ 40	
lower limit of cross-pressure pulsation (kPa)	-87.7	⩽ -50	
Number of pressure pulsation	3	3	
upper positive pressure pulsation limit (kPa)	90.3	⩾ 90	
lower limit of positive pressure pulsation (kPa)	-50	⩽ 10	
Sterilization start time	17:10:55		
Sterilization end time	17:18:55		
Sterilization run time (seconds)	480	480	
Upper pressure limit for the sterilization phase	217.8	⩽ 229.3	
Lower pressure limit for sterilization phase	207	⩾ 201.7	
Maximum value of temperature during the sterilization phase(℃)	135.4	⩽ 137	
Minimum value of temperature in the sterilization phase(℃)	134.6	⩾ 134	
Vacuum fast drying run time (seconds)	1372	⩾ 900	
Minimum value of lower vacuum drying pressure limit	-87.5	⩽-89	⬆
Sterilized items 2 LDR cervical spine tools; 2 Kangmeisheng's joint instrumentation kits, 1 Kangmeisheng's borrowed tool; 1 Kangmeisheng's hollow nail instrumentation kit; 2 Kangmeisheng's nail removal tools, 1 Kangmeisheng's lower extremity instrumentation kit; 4 Medtronic lumbar solera; 1 Shanghai Renying upper extremity instrumentation kit; and 5 ophthalmic dressing kits;			

Batch	Run the program	type of monitoring	Monitoring legend	Results
2ST240331-4-2718	P19 custom-defined 1	chemical monitoring		Qualified
2ST240331-4-2718	P19 custom-defined 1	Biomonitoring		Qualified

Figure 3 Sterilization monitoring report

shown in Table 1.

3.2 The quality control intelligent module of the information tracking system automatically obtains, analyzes, and identifies the data to form the sterilization monitoring report. The recording time of sterilization parameters, monitoring interpretation, and sterilized items per pot was reduced from 3.5 minutes to 1 minute. The difference was statistically significant (P<0.01), as shown in Table 2.

3.3 After the application of AGV and sterilization monitoring report, a satisfaction survey was conducted in terms of environment, occupational exposure, simplicity of operation, physical exertion, time consuming, pleasure, error probability, and professional. The overall satisfaction increased from 75% to 98.4%, as shown in Table 3.

4 Discussion

4.1 AGV is a product of intelligence and automation of logistics and transportation. It can replace the repetitive, unitary, labor-intensive manual labor[6], providing CSSD with a more optimized and convenient workflow, reducing operating costs and operator's physical exertion, and improving sterilization efficiency, so as to meet the high-quality development needs of quality enhancement and efficiency of modern hospitals.

4.2 In October 2021, the National Health Commission of the PRC and the National Administration of Traditional Chinese Medicine of the PRC jointly issued the "Actions to Promote High-Quality Development of Public Hospitals (2021—2025)". Many hospitals in China responded to it and gradually promoted the construction of intelligent hospitals with the three-in-one mode of intelligent medical care, intelligent service, and intelligent management[7]. CSSD, as an important part of hospitals and a key department of nosocomial infection control, also responded positively to it by updating its concepts and advancing the construction of an intelligent CSSD. Instead of relying on information tracking systems alone, intelligent construction must be closely linked to information tracking system, equipment monitoring system, intelligent devices, and AGV, which provide modernization, automation, and refinement of logistics management solutions for CSSD.

4.3 The disinfection and sterilization process involves a large number of weight-bearing operations such as loading, unloading, and transferring. During weight-bearing operations, if the operator exerts improper force, has incorrect posture, or is overload-

Table 1 Comparison of time consuming before and after application of AGV (min/batch)

Mode of transportation	Average number of transportation batches per day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	*P* value
Manual	30	5. 03	5. 07	5. 01	5	4. 99	4. 97	4. 93	<0. 01
AGV	30	0. 96	1. 01	0. 99	1. 02	0. 98	1. 04	1	

Table 2 Comparison of time consuming before and after application of the sterilization monitoring report (min/batch)

Application status	Average number of transportation batches per day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	*P* value
(Before) Manual record	30	3. 48	3. 55	3. 51	3. 45	3. 52	3. 49	3. 5	<0. 01
(After) Sterilization monitoring report	30	1. 03	0. 97	1. 06	1. 01	1	0. 94	0. 99	

Table 3 Satisfaction survey before and after application of AGV and sterilization monitoring report

Application status	Number of participants	Number of satisfied								overall satisfaction (%)
		environment	Occupational exposure	simplicity of operation	physical exertion	time consuming	pleasure	professional	error probability	
Before	24	18	16	17	17	20	18	18	20	75
After	24	23	23	24	24	24	24	23	24	98. 4

ed, he or she is prone to sprains, strains, or impact injuries[8], which may lead to occupational injuries such as tennis elbow and lumbar muscle strain. In addition, the timely misidentification of physical, chemical, and biological monitoring at the end of each pot run and the recording of parameters and sterilized items at each critical point takes a lot of time. After the hospital moved to the new campus, all the equipment was updated and upgraded. The sterilization process has been optimized to improve the sterilization quality. For example, the pulsation mode and number of pulsations are updated from the original three cross-pressure pulsations to a total of seven pulsations, including three negative-pressure pulsations, one cross-pressure pulsation, and three positive-pressure pulsations. The drying method was updated from the original vacuum drying method to vacuum drying plus pulsating air-drying method. Therefore, although the process was optimized to ensure the quality of sterilization, the workload of reading and recording parameters at critical points was greatly increased. In the above sterilization process, reading and recording may make sterilization operators fatigue or burnout, thus reducing satisfaction. In addition, the differences in the parameters at each critical point cause potential misidentification, thus increasing the safety risk of not being able to detect abnormal parameters in time and raising the possibility of sending unqualified packs to the clinic. After the application of AGV and sterilization monitoring report in the disinfection and sterilization process, the optimization of the process and change of working mode greatly reduce the intensity and workload of sterilization and improve work experience and professional value, especially in the environment, occupational exposure, simplicity of operation, physical exertion, time consuming, pleasure, error probability, and professional. In addition, the sterilization monitoring report quickly, timely, and accurately captures the parameters of each critical point and accurately identifies them, reducing the occurrence of adverse events related to misjudgment.

Conclusion

In conclusion, AGV and sterilization monitoring report in the disinfection and sterilization process effectively improve the quality and efficiency of disinfection and sterilization. Under the requirements of high-quality development of public hospitals, the role of information technology has gradually transformed from technical support to an important engine[9]. The informatization construction of CSSD has effectively improved the efficiency of multipurpose instrument handling and standardized the instrument handling process. However, the limitations in terms of professional connotation enhancement have become increasingly prominent, so the transformation and upgrading from informatization to intelligence is urgently required. AGV and sterilization monitoring report pioneer the construction of intelligent CSSD to promote the high-quality development of sterilization supply.

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