Integrated RFID Aperture and Washing Chamber Shielding Design for Real-Time Cleaning Performance Monitoring in Healthcare Laundry System

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Abstract. A preliminary design of integrated RFID aperture and washing chamber shield for real-time cleaning monitoring in healthcare laundry system is proposed. The installation of RF based monitoring system includes sewing attachment of the RFID tags to the healthcare clothes and the setting up of RFID shield, aperture, and reader to the washing tub, and open area of the washing machine. During the wash, the clothes circulation was tracked by filtered RF transmission between the tags and reader. Software was designed to evaluate the circulation e.g. rotating, sinking, and floating of the various clothes in the batch and update the circulation level in real-time. Two types of conventional healthcare washing machines i.e. agitator and pulse flow were selected for the experiments. The Received Signal Strength Indicator (RSSI) was evaluated on each combination of RFID design, washing condition and clothes circulation level. The cleaning performance of each combination of washing condition and circulation was evaluated by using Microbiological (RODAC plate count) testing. Design of experiments (DOE) methodology of 2^5 was used to examine the relationship between washing circulation and cleaning performance on representative healthcare laundry machines. 5 trials were repeated at each experimental condition before the repeatability of RSSI was examined. The design providing best repetitive RSSI is presented.

Keywords: RFID aperture · Cleaning performance · Healthcare laundry · RFID tracking · Clothes circulation tracking

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1 Introduction

Most nursing homes, clinics, and hospitals are concerned with improving laundry infection control when the economic and reliable production is also the utmost importance. Washing a variety of items including clothes, sheets, towels, and bed pad thoroughly and consistently in one batch using properly programmed machine is one of the commonly accepted schemes [1]. Despite the popularity of the mixed wash, the investigation on its infection control quality versus the economy and speed of production has yet to be found [2].

RFID based healthcare clothing management has been widely employed by using washable RFID tags attached to the clothes and readers placement in related departments. The healthcare organization and laundry service providers perceived shared benefits in reducing staff's work load and loss of clothing assets, yet were seeking more encouragement in exchange for time and financial investment in adoption [3]. A more benefit has then been added by clothes type identification to pre-determine economic washing programs e.g. least consumption washing cycle with optimum detergent [4].

Environmental infection control is primary requirement in healthcare laundry standards [1, 2, 5]. As drying temperatures and times are dictated by materials in the fabrics, hot-air drying process may then be used to provide microbiocidal action in addition to microbial decontamination performed by the washing process. Washing process has then become the key control of environmental infection in healthcare laundry system. Microbial decontamination by using hot-water has substantial operating costs [2, 5]. Cold water (22–25 °C) wash can increase microbial decontamination with relatively low operating cost given that the clothes circulation and the type and amount of wash detergent and additive are carefully controlled [1, 5]. Given the above limitation and advantage, a simple way to improve infection control and maintain economy and reliability of the healthcare laundry production is the balance control of clothes circulation, detergent and additive. In addition to fabric identification for washing program pre-determination, the washable property of RFID tags and underwater ability of RF transmission [4, 6] can also be utilized in real-time monitoring of the clothes washing circulation which is a major key in developing real-time infection and economy washing control.

Therefore, in this research, the integrated RFID aperture, RFID washing chamber shield and evaluation software for real-time clothes circulation tracking in healthcare washing machines was developed. Two representatives of conventional washing machines i.e. agitator and pulse flow type were tested with different designs of RFID washing circulation tracking. Design of the experiments (DOE) methodology of 2^5 multiplied by 5 trials was used to examine the repeatability of Received Signal Strength Indicator (RSSI) on each RFID design and cleaning performance on the number of clothes circulation. Microbiological (RODAC plate count) testing was conducted on the washed and spin-dried sample clothes, so that the relationship between clothes circulation and cleaning performance on the representative healthcare laundry washing machines was established. The design providing best and most repetitive RSSI is proposed. Based on clothes circulation-cleaning performance relationship, the real-time cleaning performance can then be estimated on the number of clothes circulation.

This system is proposed for real-time clothes circulation control to improve environmental infection and economic control of healthcare laundry production.

2 Materials and Method

2.1 RFID Washing Circulation Tracking Designs

See Fig. 1.

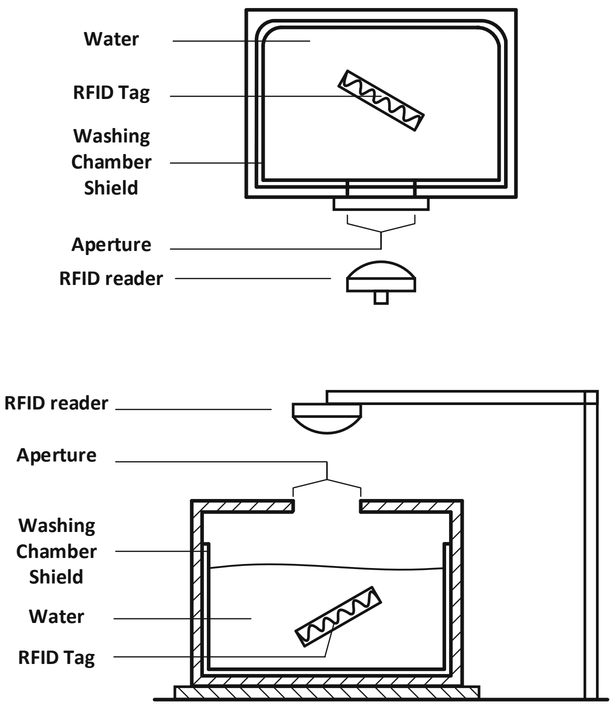

Fig. 1. Top layout of integrated RFID aperture and washing chamber shielding design in horizontal agitator (top) and side layout of pulse flow (bottom) washing machines in healthcare laundry system

2.2 Cleaning Performance Calculation

When samples of the same batch were washed in the tested washing condition and machine for a tested number of clothes circulation, the soiled area on the samples were then cut off and then collected to perform replicate organism detection and counting microbiological (RODAC plate count) test i.e. total aerobic microbial count (TAMC) to determine the hygienically cleaning performance. The calculation of RODAC based cleaning performance (c_R) for each tested washing condition and circulation can be expressed as

$$c_R = \frac{Y_t - Y_i}{Y_q - Y_i} = \frac{Y_t'}{Y_q'} \tag{1}$$

When Y_t is the total aerobic microbial count (TAMC) after the tested no. of clothes circulation, Y_i is the total aerobic microbial count (TAMC) before washing process, Y_q is TRSA [5] acceptance criterion for microbiological quality for producing hygienically clean reusable textile (20 cfu/dm^2), Y_t' is the reduction of microbial quality due to tested washing circulation and Y_q' is the required quality of microbiological reduction according to TRSA standards.

2.3 Experimental Methods

The clothes circulation monitoring was performed in two representative healthcare washing machines: horizontal agitator type with averaged spin speed of 1500 rpm and pulse flow type with averaged water pressure of 0.5 mpa. Each machine was equipped with two different integrated designs of RFID aperture, washing chamber shield and reader placement. To examine the relationship between clothes circulation and cleaning performance on different types of washing condition and integrated designs of RFID tracking, the design of experiment (DOE) of 2^5 multiplied by 5 trials was implemented. The horizontal agitator and pulse flow type was programmed to work for the duration of 45 and 30 min, respectively with given washing condition as shown in Table 2. The sample washed clothes in horizontal agitator and pulse flow type were randomly taken out of the batch at each 75 and 50 s, respectively. Before and after each cleaning performance sampling, the margin of power used to detect the tags representing the Received Signal Strength Indicator (RSSI), was recorded. All washed clothes were then spin-dried before proceeded to replicate organism detection and counting microbiological (RODAC plate count) testing [5].

Table 1. Integrated RFID aperture and washing chamber shielding designs

Specification	Type A	Type B
Aperture size (cm) and shape	21.2, Square	15, Circle
Shielding proportion	Full	Half (porous)
Reader distance (cm)	15	10

Table 2. Washing experimental designs

Washing condition	Horizontal agitator	Pulse flow
Clothes weight (kg)	25	25
Soil type	Blood stains	
Detergent	Chlorine, Ozone	
Washing speed (rpm)	1500	–
Averaged water pressure (mpa)	–	0.5
Duration (min)	45	30
Water temperature (°C)	60,35	

3 Results

The change of margin power representing the change of received signal strength indicator (RSSI) at each sampling time during washing course is shown in Fig. 1. By using type-A design of integrated RFID system (See Table 2), the changes of margin power needed to identify the clothes tags during the washing course in agitator and pulse-flow washing machines under ozone washing condition were consistent. The summation of margin power change representing the total circulation of the clothes at each sampling time during the washing course is shown in Fig. 2. The proportional increase of the summation with the increase of washing time indicates the direct relationship between the total circulation of the clothes and the time in both types of healthcare washing machine.

The repeatability of the changes of margin power needed to indentify the clothes tags during 5-repetitive washing courses under 16 different washing conditions by using A- and B- types of integrated RFID designs is shown in Fig. 3. The comparison between the correlation coefficient representing the repeatability of RFID signal

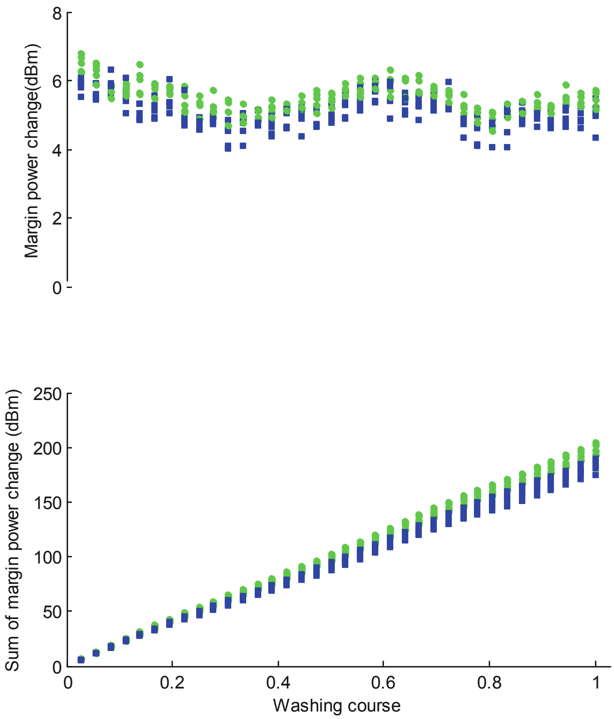

Fig. 2. The change of received signal strength indicator (RSSI) represented by margin power needed to identify clothes tags at each sampling time during the washing course in agitator (round marker) and pulse-flow (squared marker) healthcare washing machines under the condition of mixed healthcare clothes in ozone washing.

strength received by A- and B- types of integrated RFID designs (Table 1) shows that the tags circulation identified by using A-type design is more reliable in all of given washing conditions including machine type, detergent, water temperature and clothes variety (Table 2) in the batch.

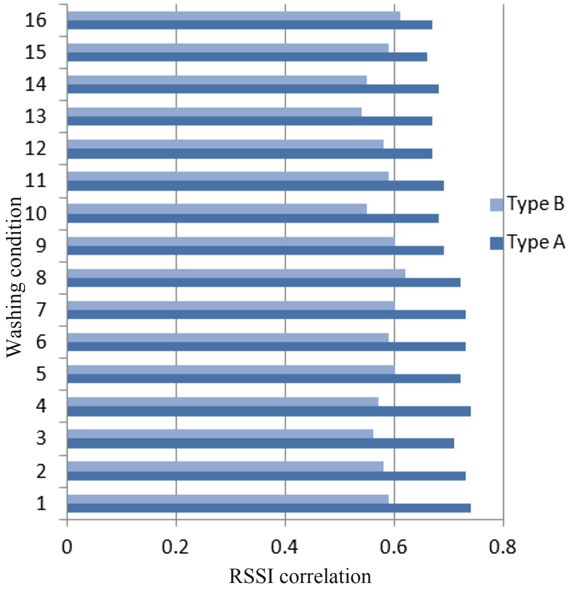

Fig. 3. The correlation coefficient of the RSSI (change of margin power needed to indentify the clothes tags) during the five repetitive washing courses under 16 washing conditions monitored by using A- and B- types of integrated RFID designs

The relationship between cleaning performance and clothes circulation level under the representative washing condition in two representative washing machines is shown in Fig. 4. The increases of cleaning performance with the increases of clothes circulation level were found in both representative washing machines. The relatively high cleaning performance of the pulse flow washing machine in the beginning of the clothes circulation course possibly represented the performance of the pulse flow water pressure in the initiation of microbial decontamination. Despite the differences in washing duration and technique, the consistent relationships between cleaning performance and clothes circulation level in horizontal agitation and pulse flow washings were found. The decreased rate of change of cleaning performance after the middle of the circulation course indicates the requirement of clothes circulation monitoring to optimize the washing course for the best cleaning performance.

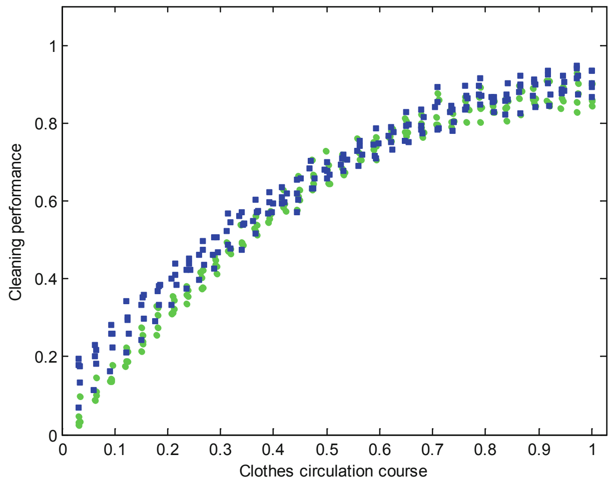

Fig. 4. The cleaning performance during the course of circulation of the mixed healthcare clothes in agitator (round marker) and pulse-flow (squared marker) washing machines under ozone washing condition identified by A-type RFID integrated design.

4 Discussions

In this research, the real-time cleaning performance monitoring in healthcare laundry system was performed by using integrated designs of RFID aperture and washing chamber shielding. The repeatability of signal strength received by the designed system indicates the reliability of clothes circulation monitoring in the various washing condition and machine. The proposed calculation of cleaning performance for healthcare laundry system provided the measures of healthcare clothes cleanliness after a specified level of clothes circulation under a given washing condition following TRSA [5] acceptance criterion for microbiological quality for producing hygienically clean reusable textile. The non-linear relationship between the cleaning performance and clothes circulation level in both of agitation and pulse flow washing machines indicates that the clothes circulation monitoring is crucial in microbial decontamination as the longer washing course does not necessarily produce the greater effect on microbial decontamination. Unlike the evaluation method of cleaning performance for household washing machines [7] considering stain removal perception as a basis, the evaluation and monitoring method of cleaning performance for healthcare laundry machines are on hygienical bases in which the microbial decontamination is the major priority followed by the microbiocidal action in drying process. The clothes circulation level will, therefore, assist in washing course determination not only for the purpose in maximizing the microbial decontamination but also minimizing the washing and drying durations or the energy costs.

Conflict of Interest. The authors declare that they have no conflict of interest.

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