*Sensors and Materials*, Vol. 37, No. 3 (2025) 1285–1297
MYU Tokyo


S & M 3987

# Design and Implementation of a Batch Recycling and Counting System for Acupuncture Needles in Traditional Chinese Medicine

Tsung-Sheng Cheng[1] and Aaron Raymond See[2*]

[1]Department of Electronic Engineering, Southern Taiwan University of Science and Technology, Tainan 71005, Taiwan
[2]Department of Electronic Engineering, National Chin-Yi University of Technology, Taichung 411030, Taiwan

(Received November 19, 2024; accepted February 13, 2025)

***Keywords:*** acupuncture needle recycling, AIoT, medical waste management, healthcare automation

In this study, we present the design and implementation of a batch recycling and counting system for acupuncture needles, addressing safety and operational challenges in traditional Chinese medicine practices. The system incorporates sensors and relevant technologies, including infrared sensors for detecting tray or hand proximity, a high-frequency ultrasonic vibrator for needle dispersion, and an LED-illuminated imaging system for precise recognition using AI-based image processing. The closed imaging space minimizes light interference, enhancing the reliability of the image recognition process. The hardware architecture integrates these sensors with a Raspberry Pi 4 for data processing and control, while network communication employs Restful application programming interface technology for real-time data synchronization and traceability. Laboratory tests achieved a recognition accuracy of more than 95% for batches containing up to 15 needles, with a decline to 87% for batches of 25 needles due to tray saturation. Field verification on 104 patients and 552 needles demonstrated an accuracy of 100% in identifying and matching needles, with an average of 5.3 needles per session. Feedback from healthcare professionals confirmed the system's practicality, while patient interviews revealed improved confidence in medical safety. Despite some connectivity issues, this system demonstrates the potential of sensor-based technologies in enhancing workflow efficiency and safety in medical waste management.

## 1. Introduction

Acupuncture is one of the key therapeutic methods in traditional Chinese medicine. It is defined as a practice where one or more specialized needles are inserted into specific points on the body's surface, left in place for a period, and then removed to achieve therapeutic goals.(1) In 1997, the U.S. National Institutes of Health's "Consensus Conference" noted that acupuncture had received positive evidence supporting its effectiveness for a range of conditions.(2,3) The World Health Organization concluded in a 2003 review that "acupuncture has been proven" applicable for various medical conditions.(4,5) On the market side, the training and provision of

*Corresponding author: e-mail: aaronsee@gm.ncut.edu.tw
https://doi.org/10.18494/SAM5486

ISSN 0914-4935 

acupuncture care are rapidly expanding in many countries,(6) with about a quarter of physicians in the U.S. and the U.K. currently supporting acupuncture or referring patients to acupuncturists.(7,8) Beyond disease treatment, acupuncture is also widely used in professional sports settings, such as the NBA and NFL,(9) highlighting its growing recognition and widespread application. However, this growing popularity has also raised significant public health concerns regarding its safety.(10)

The increasing use of acupuncture therapy has brought about numerous medical disputes, with forgotten needles being a particularly troubling issue that can cause significant harm to patients.(11) Inserting needles into precise points on the body demands professional medical knowledge and expertise, making it a task that should be performed exclusively by qualified physicians. These needles typically remain in place for several minutes or even tens of minutes before removal. However, owing to a shortage of medical personnel, the removal process is often delegated to nurses. This division of tasks between different individuals, combined with the time gap, increases the likelihood of needles being forgotten and not removed, leading to medical disputes. To address this issue, healthcare institutions have begun implementing standardized management processes, such as maintaining detailed records before and after needling or using specialized tracking devices. Despite these efforts, incidents of forgotten needles persist,(12) sometimes with dire consequences. For example, there have been cases of needles being left in a patient's lung for as long as 17 years,(13) among other serious incidents.(14) According to data from Taiwan, the reported rate of forgotten needles stands at approximately 3.3%,(15) although the actual figure is likely higher. These incidents, while severe, are entirely preventable with proper systems in place.

In recent years, advancements in AI image recognition and IoT technologies have found widespread application in consumer electronics and beyond. Various industries are undergoing digital transformation, integrating AI solutions to streamline processes and address gaps in manual operations. In healthcare, where personnel shortages and high-stakes tasks are common, AIoT technologies play a crucial role in reducing medical disputes caused by human error. By automating critical processes and enhancing oversight, these technologies offer an innovative path forward in addressing preventable errors such as forgotten needles.

## 2. Related Research

Acupuncture needles commonly available on the market, as shown in Fig. 1, consist of three main components: the needle, protective sheath, and retaining pin. The needle is the primary component used for insertion into the body and serves as the core element of acupuncture therapy. To meet the requirements of different body areas and treatment needs, needles are available in various lengths. The protective sheath encases the needle, protecting against contamination and preventing accidental injury during transport or handling. The retaining pin secures the needle and protective sheath together, ensuring they remain fixed in place until use.

The typical usage process begins with removing the needle from its protective sheath. The needle is then inserted into specific points on the body as part of the acupuncture treatment. After the prescribed duration, the needle is carefully removed and properly disposed of to maintain hygiene and safety standards.

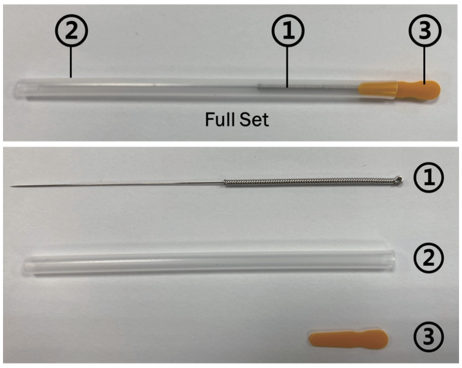



Fig. 1. (Color online) The acupuncture needle set is composed of the (1) needle, (2) protective sheath, and (3) retaining pin.

In the current medical system, the precise division of labor dictates that acupuncture needle insertion must be performed by a qualified physician, while needle removal may be delegated to nursing staff. The standard procedure, illustrated in Fig. 2, is outlined as follows:

The acupuncture procedure begins with patient identity verification. The physician must thoroughly confirm the patient's identity by cross-checking wristbands, bedside cards, and medical records, as well as verifying details with the caregiver. This step ensures that the correct patient receives the treatment.

The second stage involves preparation and insertion. The physician selects a complete set of acupuncture needles, removes the retaining pin and protective sheath, and immediately inserts the needle into the appropriate acupuncture point. In a typical session, multiple needles are inserted into various points, requiring careful tracking. An assistant or nursing staff member documents the number of needles used. At this stage, the protective sheath and retaining pin are discarded in accordance with medical waste disposal guidelines. After insertion, the retention period follows, during which the needles remain in place for approximately 20 min or longer, depending on the treatment protocol.

The final stage is needle removal. A member of the nursing staff removes the needles and disposes them in a medical waste recycling bin. At this step, it is crucial to count the number of removed needles to ensure it matches the recorded number of inserted needles, thereby preventing any needles from being left in the patient's body. Accurate needle counting during both the insertion and removal stages is paramount. This practice minimizes the risk of retained needles, mitigates potential medical disputes, and upholds patient safety standards.

In Fig. 1, we observe that acupuncture needles, retaining pins, and protective sheaths are small and inexpensive, typically costing only a few cents per set. Owing to their low cost and compact size, integrating digital management components such as barcodes or RFID tags is impractical. Consequently, the counting, recording, and verification of needles still depend on manual processes, often involving different personnel for the initial and final counts. Moreover, the dispersed nature of insertion points across various locations on the body further complicates accurate tallying, increasing the risk of errors and incidents involving forgotten needles.

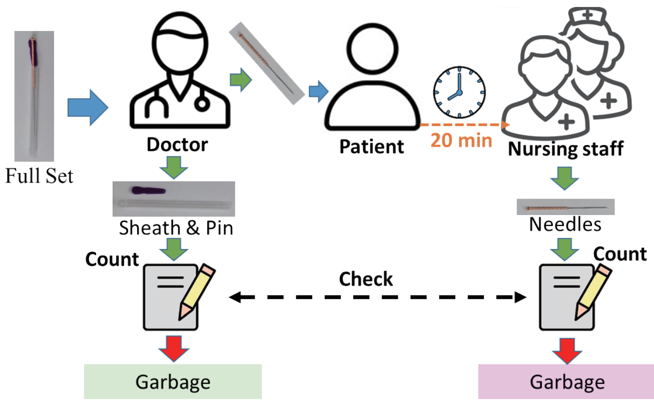



Fig. 2. (Color online) Hospital acupuncture needle usage and recycling process.

As acupuncture continues to gain popularity, new methods have been proposed to address the issue of forgotten needles. Table 1 provides a comparative summary of the technical characteristics and functions of these new methods alongside the system developed in this study.

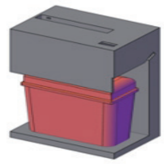
In the traditional workflow utilizing a needle counting box, physicians employ an acupuncture needle counting form as demonstrated in Fig. 3 to minimize the risk of forgotten or unremoved needles. During the procedure, the physician records the specific locations and the number of needles inserted on this form. Upon removal, the needles must be manually counted and cross-verified with the recorded numbers for each location. Despite its widespread use, this method heavily relies on manual counting and recording, which is prone to errors and contributes to a relatively high error rate.

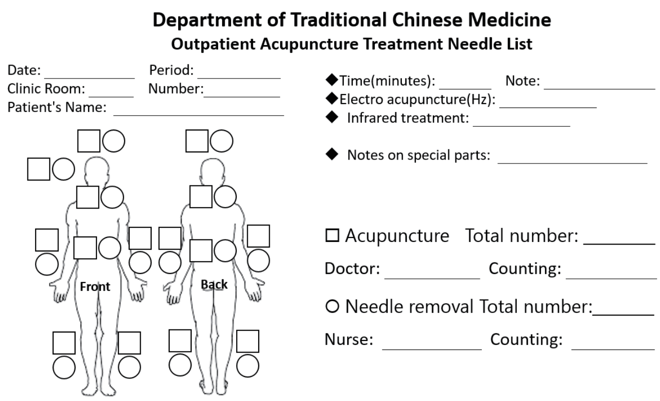
To address potential errors introduced by human handling, automated needle counting devices have been developed, often employing optical interruption technology. These systems detect needles as they pass through a channel, incrementing the count accordingly. However, this approach faces two major challenges.

First, there is a mismatch with existing medical workflows. To improve efficiency, current practices typically involve removing multiple needles simultaneously, placing them on a tray (Fig. 4), and disposing them collectively into a recycling bin. Devices designed to handle needles one at a time fail to accommodate this workflow, reducing their practical utility. Second, there are issues related to convenience and functionality. Acupuncture needles, being thin and elongated, are prone to becoming stuck in narrow channels. To ensure smooth passage, the channels must be widened, but this increases the likelihood that needles bypass the sensors without being properly detected, leading to inaccurate counts.

As a result of these challenges, the adoption rate of such devices in practical healthcare settings remains low. These limitations underscore the need for a more advanced solution. In this study, we propose the development of a needle counting system that integrates AIoT and electronic technologies with image processing. The proposed system is designed to align seamlessly with existing workflows, mitigate current limitations, and incorporate networking capabilities for generating traceable historical records.

Table 1
(Color online) Comparison of existing needle counting methods.

| Feature/Function | Traditional needle counting box | Automated needle counting products | System developed in this study |
|---|---|---|---|
| Appearance |  |  |  |
| Counting Method | Manual counting | Channel-based with infrared interruption | Image recognition combined with electronic actuation |
| Drawbacks | Manual counting, difficult to ensure accuracy | Infrared interruption; channels may not fit longer needles, prone to jamming | High cost, requires network system integration |
| Operating Principle | Manual collection and recording | Insert one needle at a time, counted via infrared sensor interruption | Can handle multiple needles simultaneously |
| Traceability | Manual tallying + notebook | Screen display + notebook | The server records images and data for analysis |
| Needle Box Capacity Alert | None | None | Alert medical staff when the needle box is full |


**Department of Traditional Chinese Medicine**
**Outpatient Acupuncture Treatment Needle List**

Date: ____________ Period: ____________
Clinic Room: ______ Number: __________
Patient's Name: ____________________

◆Time(minutes): ______ Note: ____________
◆Electro acupuncture(Hz): ___________
◆ Infrared treatment: ___________

◆ Notes on special parts: __________________



☐ Acupuncture Total number: ________
Doctor: ___________ Counting: __________
○ Needle removal Total number: ______
Nurse: ___________ Counting: __________

Fig. 3. Acupuncture procedure needle counting form.

Fig. 4. (Color online) Using a tray to collect needles after acupuncture.

## 3. System Design

The system developed in this study is designed to closely align with the existing workflow of acupuncture healthcare personnel. Featuring an add-on design, it can be easily attached to existing recycling bins without requiring significant modifications to current practices. The system allows multiple needles to be introduced simultaneously from a tray and efficiently counts the total quantity. Furthermore, it incorporates networking capabilities, enabling the generation of traceable historical records for enhanced accountability and process management.

### 3.1 Hardware architecture

The system was developed and designed on the basis of insights gathered from multiple interviews with nursing staff and a week-long observation in a clinical setting. Once the design was finalized, it was fabricated using a 3D printer. To accommodate the dimensions of existing medical waste recycling bins, the design required a relatively large size. As a result, the printing process was divided into several components, which were printed separately and subsequently assembled. The fully assembled model is represented by the gray-shaded area in Fig. 5.

The system integrates several technological components: an LCD display, an RFID reader, an infrared sensor, an LED light source, a microcamera, two stepper motors, and an ultrasonic vibrator. These devices are connected to a Raspberry Pi 4 (4 GB) via GPIO pins for data processing and control. The Raspberry Pi's built-in Wi-Fi functionality enables the transmission of all images to a server, while data exchange is facilitated using Restful application programming interface technology.

### 3.2 Software architecture

This system utilizes image processing for counting, primarily operating on a Raspberry Pi 4. The system runs on Raspberry Pi OS (Debian Bullseye with Raspberry Pi Desktop, release date: July 1, 2022, 32-bit system, Kernel version: 5.10, Debian version: 11). The primary development tool is Python (version 3.8.10), with OpenCV and YOLO V7 serving as the main image processing and analysis frameworks. To establish the image processing database, 200 images of each needle and protective sheath were initially labeled using a labeling tool, forming the foundation for accurate detection and analysis.

### 3.3 Exterior design

Acupuncture needles are classified as medical waste (sharp and infectious waste) and require special handling and disposal in most countries.[16] The standard practice involves collecting these needles in dedicated medical waste recycling bins, as illustrated in Fig. 6, which are subsequently processed by professional waste management companies. This approach has become the norm, with healthcare facilities adopting standardized recycling systems. Given this context, the design principle of the proposed system is to allow external attachment to existing

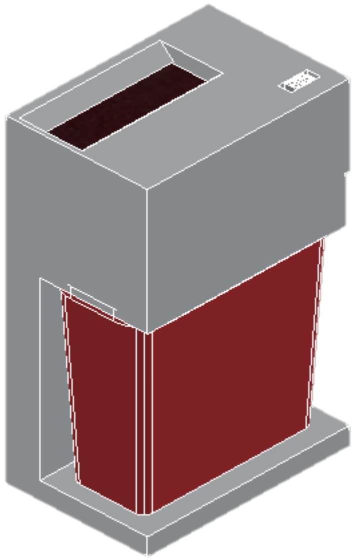


Fig. 5. (Color online) The system design is illustrated as an attachment to a medical waste recycling bin.

Fig. 6. (Color online) Medical waste recycling bin and 3D diagram.

recycling bins. When a bin becomes full, the system can be easily detached and reattached to an empty bin, enabling seamless integration with the existing waste management process. The filled bin continues through the standard disposal workflow. This design ensures full compatibility with current practices, while also being reusable and cost-effective.

### 3.4 System architecture and workflow

In the hardware architecture design illustrated in Fig. 7, the functionality of each component is explained through its role in the operational workflow.

First, the system begins by reading the patient's RFID tag using the RFID reader at 7 to associate the process with the corresponding patient record. When the physician or nursing staff collects needle caps or needles on a tray, they can pour the contents in bulk into the input port at 1 as shown in Fig. 7. To enhance usability, the input port features a larger opening design for user convenience.

Next, the infrared sensor at 2 detects the approach of the tray or hand, triggering the automatic closing device to open and allow the needles to drop onto the needle counting platform below (3). At this stage, the ultrasonic vibrator is activated to disperse the needles, improving their distribution for accurate image recognition. The LED light source and camera at 4, positioned above the platform, capture images of the needles. The closed design of this section, combined with a fixed light source, minimizes environmental interference and ensures optimal conditions for image sampling, which benefits AI-based analysis.

The captured images are processed in real time by the computational processing unit at 8, which utilizes a Raspberry Pi 4 for both computation and control. A buzzer provides auditory

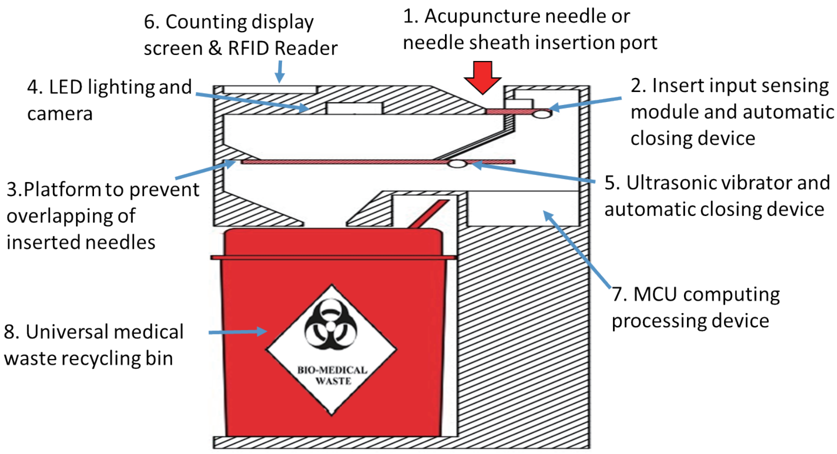



Fig. 7. (Color online) Design diagram of the hardware architecture.

alerts during operation. Upon completing the recognition and counting, the results are displayed on the counting screen at 7 and simultaneously synchronized and stored in a cloud database for traceability.

After processing, the automatic closing device at 5 activates, opening the needle-carrying platform (3) and triggering the ultrasonic vibrator to drop the needles into the medical waste recycling bin at 9, thereby completing the cycle. During operation, the LED at 5 indicates system functionality, and the input port at 1 is temporarily disabled. Each cycle takes approximately 8 s to complete, after which the system resets for the next input.

Additionally, the system cross-references and records the number of needle caps and needles inputted using RFID numbering, ensuring consistency and traceability throughout the process.

## 4. System Implementation

### 4.1 Reducing false positives

Optical recognition systems are typically sensitive to variations in light sources. To mitigate this issue, the design incorporates a closed space with a fixed light source for image capture, effectively eliminating light interference. However, during the initial implementation of the system, specific challenges arise owing to the structural differences between needle caps and acupuncture needles. Needle caps, being larger and shorter, are less prone to overlap, whereas acupuncture needles, owing to their thin and elongated structure, tend to overlap when multiple needles are poured simultaneously. This overlap complicates accurate counting by the image recognition system.

For instance, as shown in Fig. 8, two overlapping needles may be mistakenly identified as one, a limitation that cannot be resolved through algorithms alone. To address this issue, the design integrates a high-frequency ultrasonic vibrating motor, which activates when the needles drop onto the platform, dispersing them to minimize overlap. Additionally, diagonal grooves were incorporated into the platform's surface, guiding the needles to fall into separate grooves.

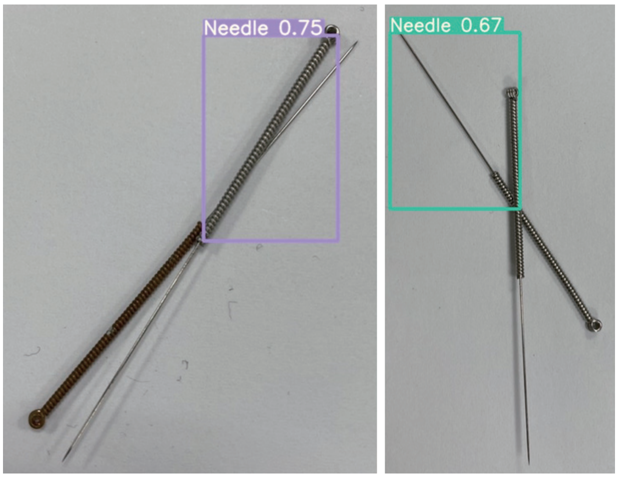



Fig. 8. (Color online) System error due to overlapping.

This alignment helps prevent overlap and positions the needle heads approximately parallel, as illustrated in Fig. 9.

Experimental results confirm that this approach effectively reduces needle overlap, ensuring more accurate recognition. However, when more than 25 needles are processed simultaneously, overlap can still occur, leading to misjudgments by the system. This limitation underscores the need to refine the standard operating procedure to ensure optimal system performance and accuracy.

### 4.2 Mechanism for handling discrepancies in counted recycling quantity

Although the system has been optimized to minimize misjudgments, it cannot entirely eliminate errors. To address this, protective measures have been incorporated into the implementation process, as outlined in the operational flow shown in Fig. 10. During the acupuncture process, both the needle cap and the needle entering the recycling system are identified using RFID for patient identification, forming the basis for accurate counting and comparison. As shown in Fig. 10, the system counts the needle caps as Result A and the needle heads as Result B. When the system detects an input as a needle head, it indicates the completion of the patient's acupuncture session. The system then compares the current count of needle caps with the previous input. If the counts do not match, suggesting a potential missed needle, an alarm is triggered. The LCD panel displays images from the last two inputs for user interpretation.

If manual inspection finds that the quantities in the two images are inconsistent, it is flagged as a system error, requiring confirmation via the system's confirmation button. These discrepancies are logged on the cloud server to aid future AI system improvements. Conversely, if a missed needle is confirmed, a manual needle search is initiated until the needle is located and entered into the system. This process, including discrepancies and resolution steps, is recorded in the cloud server, providing a traceable record that can serve as evidence in the event of a medical dispute.

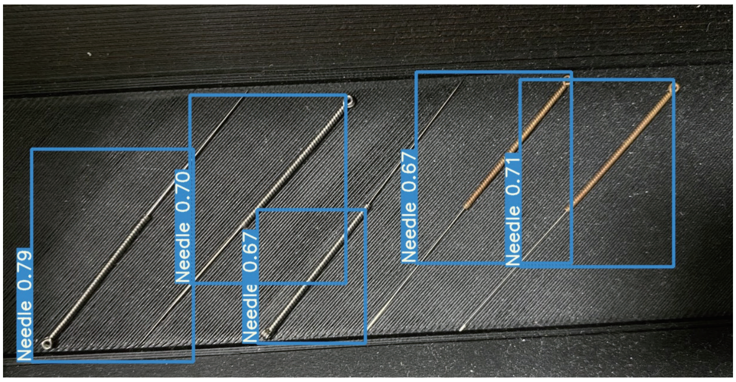



Fig. 9. (Color online) Using grooved design to individually disperse needles for accurate identification.

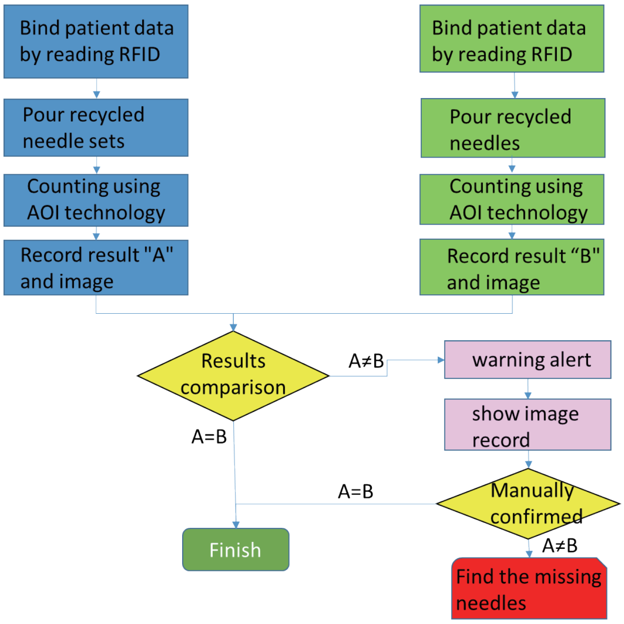



Fig. 10. (Color online) Process for handling discrepancies in counted recycling quantity.

## 5. System verification

### 5.1 Verification in the laboratory

After the system was constructed, accuracy experiments were conducted in the laboratory to verify its feasibility. The experimental method simulated the actual hospital workflow. The tests started with one needle per batch and gradually increased to 25 needles per batch. Needles were first placed on a tray and then poured into the needle counting box in a single motion.

Initially, the anti-overlap mechanism was not activated. The system used image recognition to count the needles, and the number of matches between the results and the actual number of needles poured was recorded. Subsequently, the same procedure was repeated with the anti-overlap mechanism activated during the process. The recognition and counting results were recorded, noting the frequency of matches with the actual number of needles poured. The results are shown in Fig. 11, where the *X*-axis represents the number of needles poured in each batch and the *Y*-axis represents the accuracy rate (%) of the system's needle recognition after input. When the needles poured per batch are fewer than five, the needles can be evenly distributed on the tray, and no errors were observed. However, when six needles were poured in a single batch without vibration processing, errors began to occur. With vibration processing, errors did not appear until 17 needles were poured in a single batch. Beyond 17 needles, the system essentially reached its saturation point owing to the tray's limited capacity, making needle overlap more likely and adversely affecting image recognition accuracy. This issue cannot be fully resolved through vibration or similar methods alone. That said, in most traditional Chinese medicine clinics, the average number of needles used per acupuncture session ranges from 4 to 12, with sessions rarely exceeding 15 needles. Within this range, the solution proposed in this study effectively addresses the needle-counting issue.

## 5.2 Verification in actual application fields

After the system was completed, a verification test was conducted in the traditional Chinese medicine department of a medical center in Taiwan. The test involved two doctors and four nursing staff performing practical examinations, divided into two sessions: one in the morning and one in the afternoon. Each session included one doctor and two nurses. During the process, the doctors inserted the needles while the nurses were responsible for their removal.

A total of 104 patients received acupuncture treatments, utilizing 552 needles, all of which were disposed of in a recycling bin for collection. On average, 5.3 needles were used per patient, with a minimum of 3 needle caps and a maximum of 9 needle caps per session. Throughout the verification process, both needle heads and needle caps were successfully identified and matched, with no incidents of missing needles reported during the experiment.

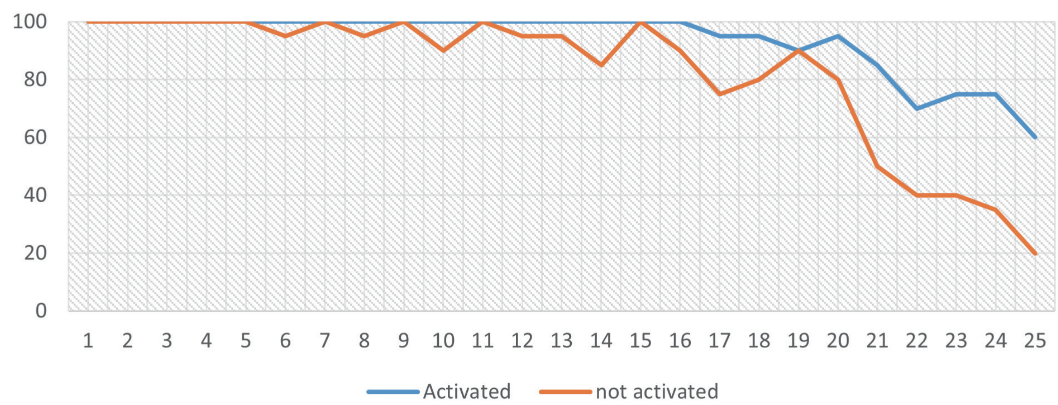



Fig. 11. (Color online) Accuracy rate of input needles number identification.

## 6. Discussion and Conclusions

Following the experiment, interviews were conducted with doctors and nursing staff, who indicated that the system significantly reduced the likelihood of missing needles. They also noted that, compared with other similar products, this system had minimal impact on their original workflow and expressed a willingness to adopt it once it entered mass production.

Additionally, 10 patients or their family members were randomly surveyed to explain the system's operation and design purpose. While none had personally experienced missing needles, four were aware of similar incidents and expressed concerns about the possibility of it happening to them. All participants agreed that seeing the system in use would increase their confidence in the medical procedures.

Feedback for future improvements was also provided. A doctor suggested further miniaturizing the system to enhance portability and better align with doctors' work habits. Nurses recommended replacing the plug-in voltage regulator with a rechargeable power bank to facilitate easier use on nursing carts.

During the experiment, it was observed that Wi-Fi connectivity was occasionally disrupted by interference from multiple devices and medical equipment, resulting in poor connection stability. Consequently, some data (five records) were not accurately recorded. This finding underscored the importance of integrating the operator directly into the medication box and exploring alternative network transmission methods to enhance data stability in future iterations of the system.

## Acknowledgments

T. S. C. gratefully thanks the financial support from the National Science and Technology Council under grant no. NSTC 113-2222-E-218-001.

## References

1 L. S. Nasir: Prim. Care - Clin. Off. Pract. **29** (2002) 393. https://doi.org/10.1016/S0095-4543(01)00007-0
2 E. Ernst: J. Intern. Med. **259** (2006) 125. https://doi.org/10.1111/j.1365-2796.2005.01584.x
3 C. Marwick: JAMA **278** (1997) 1725. https://doi.org/10.1001/jama.1997.03550210021013
4 J. S. Han and Y. S. Ho: Neurosci. Biobehav. Rev. **35** (2011) 680. https://doi.org/10.1016/j.neubiorev.2010.08.006
5 K. VanderPloeg and X. Yi: J. Acupunct. Meridian Stud. **2** (2009) 26. https://doi.org/10.1016/S2005-2901(09)60012-1
6 T. J. Kaptchuk: Ann. Intern. Med. **136** (2002) 374. https://doi.org/10.7326/0003-4819-136-5-200203050-00010
7 A. R. White, K. L. Resch, and E. Ernst: Fam. Pr. **14** (1997) 302. https://doi.org/10.1093/fampra/14.4.302
8 B. M. Berman, B. B. Singh, S. M. Hartnoll, B. K. Singh, and D. Reilly: J. Am. Board Fam. Med. **11** (1998) 272. https://doi.org/10.3122/jabfm.11.4.272
9 C. Chapleau: Korean J. Food & Health Convergence **6** (2020) 23. http://dx.doi.org/10.13106/kjfhc.2020.vol6.no2.23
10 J. Wheway, T. B. Agbabiaka, and E. Ernst: Int. J. Risk Saf. Med. **24** (2012) 163. https://doi.org/10.3233/JRS-2012-0569
11 H. Yamashita, H. Tsukayama, Y. Tanno, and K. Nishijo: J. Altern. Complement. Med. **5** (1999) 229. https://doi.org/10.1089/acm.1999.5.229
12 H. Yamashita and H. Tsukayama: Evid.-Based Complement. Altern. Med. **5** (2008) 391. https://doi.org/10.1093/ecam/nem086

13 P. Lewek, J. Lewek, and P. Kardas: Acupunct. Med. **30** (2012) 229. https://doi.org/10.1136/acupmed-2012-010191
14 B. Penugonda, J. Kaplan, and G. Goddard: Med. Acupunct. **23** (2011) 115. https://doi.org/10.1089/acu.2011.0799
15 W.-C. Lü, S.-K. Lin, and C.-T. Chen: Taipei City Medical J. **11** (2014) 24. https://doi.org/10.6200/TCMJ.2014.11.1.04
16 K. K. Padmanabhan and D. Barik: Energy from Toxic Organic Waste for Heat and Power Generation, Health Hazards of Medical Waste and its Disposal. (Woodhead, 2019) 1st ed., Chap. 8. https://doi.org/10.1016/B978-0-08-102528-4.00008-0

## About the Authors

**Tsung-Sheng Cheng** received his B.S. (2001) and M.S. (2005) degrees from National Taiwan Normal University, Taiwan, and his Ph.D. degree from National Cheng Kung University, Taiwan, in 2015. From 2016 to 2022, he was an engineer at the Taiwan Industrial Technology Research Institute. Starting in 2022, he has been serving as an assistant professor in the Department of Electronic Engineering at Southern Taiwan University of Science and Technology. His research focuses on AI & Internet of Things (AIoT) technology and its applications. He is also a key member of the school's smart medical center and smart manufacturing projects. Additionally, he serves as a technical consultant for several large medical centers and has extensive experience in technology development within the medical industry. (tscheng@stust.edu.tw)

**Aaron Raymond See** (Member, IEEE) was born in Manila, Philippines and received his B.S. degree in electronics and communications engineering from De La Salle University, Manila, Philippines in 2006. He obtained his M.S. and Ph.D. degrees in electrical engineering with a major in biomedical engineering from Southern Taiwan University of Science and Technology in 2010 and 2014, respectively. Subsequently, he did his postdoctoral research in neuroscience at the Brain Research Center, National Tsing Hua University, Hsin Chu, Taiwan. He is currently an associate professor in the Department of Electronic Engineering at National Chin-Yi University of Technology. His research interests are in assistive device development, haptics, and visuotactile sensors. (aaronsee@gm.ncut.edu.tw)