Gamification for Hand Hygiene Compliance

João Guilherme Silva da Cunha - 76440
Departamento de Engenharia Informtica
Instituto Superior Tcnico
joaogcunha@tecnico.ulisboa.pt

ABSTRACT

Hospital acquired infections are one of the major problems of healthcare in the world, resulting in increased morbidity and mortality. This problem could be minimized by simply performing good hand hygiene. However, due to factors like forgetfulness, healthcare workers still have low levels of hand hygiene compliance. The main method to monitor compliance levels, direct monitoring, is very expensive both in time and money. We propose a gamification solution capable of providing feedback about compliance levels and at the same time motivate people to improve their behaviour. This solution requires many different components working together each posing different challenges, which will be discussed in this document. In this thesis we propose a model of steps to minimize such challenges impact. The bottom layer of the model corresponds to the indoor location technology, for which we reviewed and compared some alternatives. Above that, an AMS is used to monitor hand hygiene, whose data is presented using gamification. For the gamification layer, we used the solution proposed in the OSYRISH project. This solution's interface (the upper layer of the model we propose) was evaluated using user testing, and although it still needs developing the results were considered acceptable.

Author Keywords

Hand hygiene compliance; Hospital acquired infections; Indoor location; Gamification; Automated Monitoring Systems;

INTRODUCTION

Hospital Acquired Infections (HAIs) are one of the biggest problems in healthcare around the world[16]. HAIs cause extra-days of hospital stay, increase the cost for both hospitals and patients as well and contribute to higher morbidity and mortality rates.

Preventing this particular type of infections can be done in a simple and inexpensive manner: performing hand hygiene at the right moments. Nevertheless, the compliance by Healthcare Workers (HWs) is still far from desired levels.

There are several factors leading to this low level of compliance with hand hygiene guidelines, like lack of time, forgetfulness and skin damage caused by products used in hand hygiene[5].

Despite the existence of several methods to measure the hand hygiene compliance rates, direct observation is still considered the golden standard. This method is very expensive and time-consuming.

For this reason, there is a need for new and innovative ways to monitor and improve HWs' compliance with hand hygiene guidelines. A earlier attempt at solving this problem was part of the Organizational and Informational System to Improve the Management of Healthcare Associated Infections in Hospitals (OSYRISH)[1] program[12]. The solution aimed at measuring HWs' hand hygiene compliance levels in a fun and innovative way. However, this solution had several obstacles before it could be properly deployed and tested. Several indoor location technologies were tested to track the position of HWs in order to accurately monitor their hand hygiene compliance, none produced good enough results for pilot testing.

This thesis builds on that solution's work, and proposes a way for minimizing the problems in the development of a gamification based solution of an system capable of monitoring hand hygiene compliance and presents the development of said solution.

The research was conducted using the Design Science Research Methodology (DSRM), a problem-solving process based on the understanding and formulation of a design problem[14].

The main goal of this methodology is the creation and evaluation of artefacts. These artefacts which can be constructs, models, representations, methods or instantiations must be useful. They should be able solve unsolved problems in innovative ways, or solve already solved problems in a more efficient or effective way[14].

RELATED WORK

In this section, which corresponds to the Identify problem step of DSRM, we present the results of our analysis of the literature related to our study.

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[1] OSYRISH: `http://osyrish.org` accessed January 2018

Hand Hygiene Monitoring

Monitoring hand hygiene compliance is essential to measure HWs' performance so they can improve their rates. For this purpose we need to understand the WHO 5 moments for hand hygiene[22].

As seen in Figure 1, these five moments are: **before touching a patient**; **before a clean/aseptic procedure**; **after body fluid exposure risk**; **after touching a patient** and **after touching patient surroundings**.

Figure 1. The 5 moments for hand hygiene according to the WHO [22]

There are many different ways of measuring a HW's compliance with these guidelines.

The golden standard is direct observation. Although this is the only method capable of measuring the technique used to perform hand hygiene and the most accurate method, training an observer requires has a very high cost both in time of time and money. Not only that, but this method also suffers form Hawthorn's effect as the observed HWs tend to alter their behaviour when being observed[8].

Fighting these problems resulted in the creation of Automated monitoring Systems (AMS). These systems can monitor HWs' compliance without them feeling observed and extract less biased data.

Monitoring with AMS has some drawbacks as the cost associated with implementing and maintaining such systems can be high. Also, healthcare workers may sometimes feel uncomfortable with being monitored this way[20].

The main challenge when implementing an AMS is the indoor location system. Without knowing if the HW was near a patient bed or used a sink or solution dispenser we cannot calculate the hand hygiene compliance level. This is considered a challenge because in indoor environments the occlusions created by the buildings and different materials as well as the need for pin point accuracy in a small make GPS (Global Positioning System) ineffective.

There are several solutions for indoor location based on different technologies and positioning methods. This results in the need for an evaluation of the solutions before starting to build an AMS.

Indoor Location

Indoor location technologies use signal propagation properties to calculate the position of a subject in an indoor environment. Some of these properties are: Angle Of Arrival (AOA)[17], Time of Arrival (ToA)[2], Time Difference of Arrival (TDoA)[2] and Difference Time of Arrival (DToA).

Methods used to perform the indoor location can vary, some examples are: triangulation[17, 9], trilateration, proximity, scene analysis[9] and dead reckoning[9].

The most common technologies taking advantage of some of these methods are infrared (IR)[15], ultrasound[4] and the ones based in Radio Frequency (RF): Bluetooth Low Energy (BLE)[23], Wi-Fi[23, 6], Ultra Wide Band (UWB)[19] and RFID tags[18].

Considering the specificities of the problem the best approach seems to be to use proximity or triangulation. Technology based in RF is less expensive than the alternatives. This means a good approach to our problem is to find a RF based technology that uses triangulation or proximity methods to perform indoor location.

Gamification

Gamification is widely accepted as the use of game elements in non-game contexts[7].

One of the main uses of gamification is the creation or reinforcement of a particular behaviour. In another words, gamification is used in order to motivate people to behave in a certain way. This doesn't mean develop games to be played. It means using the same principals game designers use when developing a game to transform a real world experience into something rewarding so people can be intrinsic motivated to perform the desired behaviours[21, 7].

The main concepts we need to understand are those demonstrated in Figure 2. These concepts are organized as a pyramid because each level we descend its less abstract than the one before.

Dynamics are big-picture aspects of the game that we must be aware but can never directly implement into the game. Some examples of dynamics are emotions, constraints, storyline, progression, and relationships.

Mechanics are the next level of the pyramid, each one is a way of achieving one or more dynamics. They are what prompts the action forward and generates player engagement. Challenges, chance, competition, cooperation, feedback, resource acquisition, rewards, transactions, turns and win state.

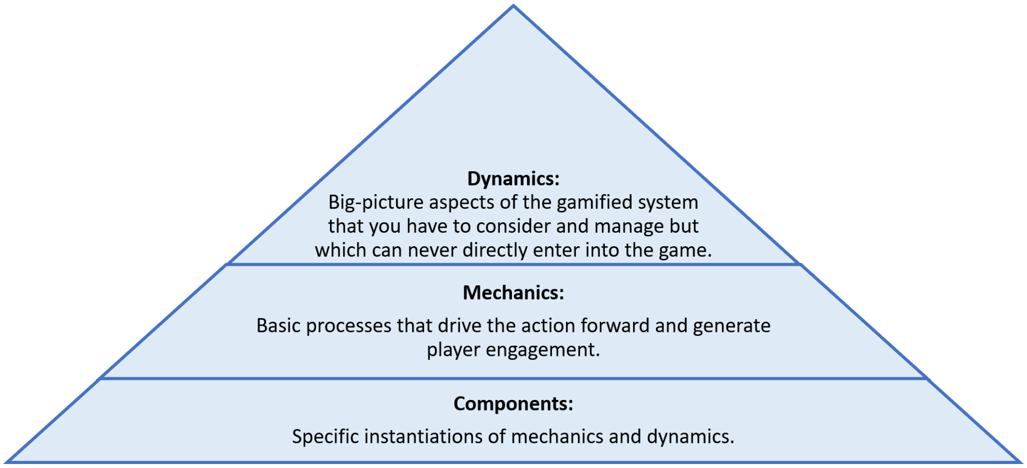

Figure 2. The 5 moments for hand hygiene according to the WHO

Components are the most specific forms of dynamics. The most commonly used components are, points, badges and leaderboards. There are many other components: avatars, teams, virtual goods, among others.

Gamification is not a one size fits all and each projects needs to be evaluated to understand if it is indeed gamifiable[21]. The reason why it is so important to understand what is gamification and how it can be applied is because sometimes to a poor understanding projects end up failing.

In healthcare there are some examples of the use of gamification. On example was the gamification of the study process by medical residents to improve their score in American Board of Surgery In-Service Training Examination[11]. Another used gamification to improve physical activity, health care utilization, medication overuse, empowerment, and disease knowledge of the patients affected by rheumatoid arthritis[1].

Finally, the OSYRISH project proposed the use of gamification as a mean to improve HWs' hand hygiene compliance levels. This project used indoor location technologies to monitor and measure the hand hygiene compliance levels. The information was then gamified in a platform as badges, levels, rankings, etc. to motivate the HWs to improve their behaviour. In this platform the HWs could share documents about the hand hygiene topic, review their levels across a period of time and find out the collective objectives.

PROPOSAL

The main objective of our work was to show the necessary steps to take when implementing a gamification system for hand hygiene compliance in an healthcare environment. These steps were:

- Accurately monitor hand hygiene compliance levels.
- Create a cheap, high accuracy, low battery consumption, automated and non invasive monitoring system for hand hygiene compliance.
- integrate the AMS with the gamification platform
- Validate the system prior to deployment.

Implementing a gamification based solution to improve hand hygiene compliance in HWs can be a challenging task[13]. To minimize the difficulties of developing this type of solution, and achieve the objectives above, we propose the ArchiMate model in Figure 3.

The solution consisted of five layers:

- **Indoor Location Hardware:** Indoor location technology equipment capable of transmitting raw position data (coordinates, signals for proximity detection,...)
- **Indoor Location App:** Software algorithms capable of transforming the raw positioning data into data capable of being used in the automated monitoring system
- **Automated Monitoring System:** Set of algorithms to transform the position data into hand hygiene compliance metrics
- **Gamification Platform:** Platform responsible for gamifying the hand hygiene compliance metrics
- **Gamification Platform Interface:** Part of the gamification platform the users interact with

We chose to build the solution in an incremental manner because a gamification platform can not be properly deployed or tested without the data to gamify and the data serving as input for the gamification platform is the HWs' compliance metrics, which in turn are calculated by an AMS based on indoor location data. The indoor location data is the result of filtering and extracting information from various sensors capable of monitoring HWs' actions. Another important element to take into consideration is the way the gamified information is presented to the users, that is why the gamification platform's interface is represented on the model.

As we can see each layer requires the one below to be implemented. Only when all of these layers work together can the solution be properly tested.

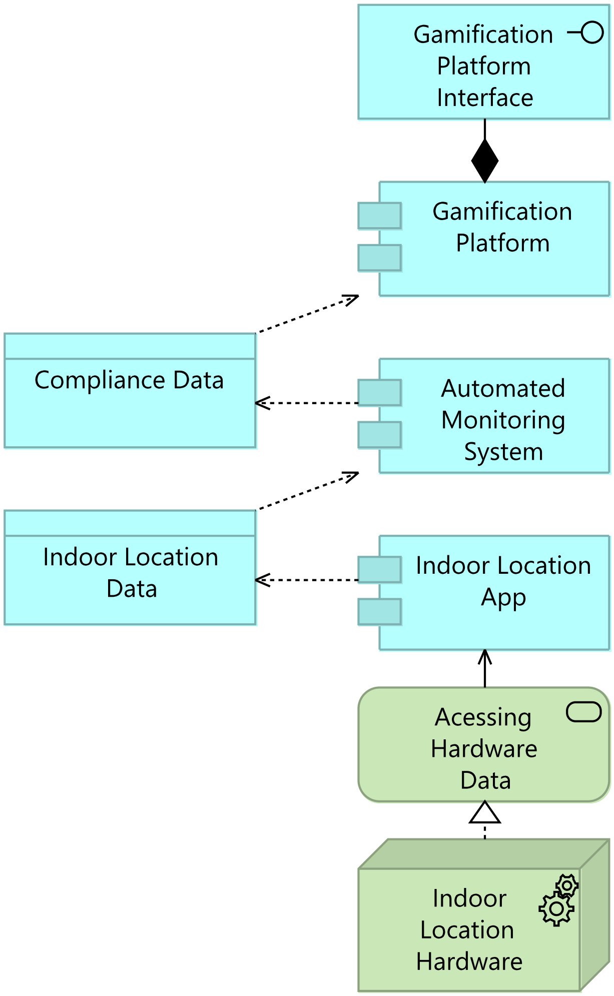

Figure 3. ArchiMate architecture model of the proposed solution

DESIGN & DEVELOPMENT

We started by considering three different technologies for the indoor location hardware. Pozyx[2], a solution using UWB and triangulation; Saninudge[3], a solution which the technology cannot be disclosed due to confidentiality agreement and Estimote[4] beacons a solution based on BLE and using proximity.

Based on the results discussed in Section , we chose Estimote beacons as our base layer for the solution.

In order to communicate with the beacons we used Estimote's Software Development Kit to build an Android app. This app handle three different triggers: *onEnter* when the mobile phone enters the beacon range; *onExit* when the mobile phone exits the beacon range and *oncontextChange* that is triggered when the number of beacons in range changes, if we are between two beds for example.

The beacons have the parameter tag to allow us to group beacons so the device can perform the same actions when it encounters the same tag. Unfortunately, if a mobile phone is waiting for the exit event of a certain tag it will not scan for different tags. This means, that if a dispenser is close to a bed and we use the tag "dispenser" the device will not detect the use of a dispenser and it will register a non complied opportunity.

To solve this problem we used the Estimote Telemetry[5] packets which act as an interruption. In particular we used the *motionState* property which describes if the beacon is moving or not and the *urrentMotionStateDurationInSeconds* that gives us the duration of the movement.

We also set the beacon to transmit only when in motion. This had to be done to avoid a flood of information to the mobile phone that would block the scanning for the tags.

After the data was collected we used it as input for the AMS to calculate the relevant metrics, opportunities to perform hand hygiene, percentage of complied opportunities, among others.

The AMS ignored each visit to a patient's bubble with a duration under 2s. We considered this interval as a HW just passing by or a wrong signal detection. If the duration of the visit was considered valid the AMS registered the opportunity. Then, the AMS checked what was the previous event detected. If it was a bed, same or other the HW had not complied with the guidelines for hand hygiene. On the other hand, if the previous event was the use of a dispenser the HW complied with the hand hygiene guidelines.

Since the dispenser for hand hygiene can be in the hallways far from the beds, we considered the interval of 30s as the maximum time interval between the dispenser use and the patient's bubble entrance. For any time interval greater than those 30s we considered the HW didn't go directly from the dispenser to the patient's bubble. All the time intervals should be adjusted on a case by case basis and further real world testing is required.

With all the metrics available the remaining step is to gamify them. This was done by integrating the AMS with the gamification platform developed during project OSYRISH as this platform was developed with the help of HWs.

An important part of gamification is the way the information is presented to the users, trough the interface. During the OSYRISH project tests were never conducted to evaluate the interface, for this reason we conducted our own and the results can be seen further in this report.

EVALUATION

In order to choose between Pozyx, Saninudge, Estimote we needed to perform tests on these technologies and see how they aligned with our solution.

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[2] Pozyx: `https://www.pozyx.io/` accessed January 2018

[3] Saninudge: `https://www.saninudge.com/` accessed February 2018

[4] Estimote: `https://estimote.com/` accessed June 2018

[5] Estimote Telemetry: `https://developer.estimote.com/sensors/estimote-telemetry/` accessed in June 2018

A solution based in Pozyx would consist of a slave-tag carried around by the HW which would communicate with the anchors in order to find out its position. After that it would relay this information to the master-tag connected to a computer.

For the testing 4 anchors were placed in a room near each corner but at different heights to maximize the coverage. Then a expected route was designed and a user walked along this route while a researcher gathered the information in the platform.

The first attempt resulted in a very jittery route. However, after applying filters the resulting route was good enough to be compared to the predefined route. The results of the comparison seemed good as there seemed to be no big discrepancies between the two.

Testing for autonomy, by connecting a 9V battery to the tag displayed very bad results as the battery lasted for an approximated 2h 30min. This solution was not feasible as the HWs' shifts lasted for 8h. An alternative was to use power banks, however since the HWs had already shown reluctance when using the lighter and smaller solution this was deemed to invasive.

Saninudge seemed a very good fit for our project because it was already hospital tested. However after everything was ready, bureaucracy and integration, we were informed they were no longer able to aid us in our project due to the influx of paying customers.

Finally, Estimote beacons were tested using the provided app and an Android device. The device correctly recognized the proximity zones of the beacons.

A solution developed using Estimote would consist of a mobile phone carried by the HW running a software capable of detecting the proximity to the beacons and registering the entrance/exit of the patients' bubble and the use of the dispensers.

After choosing Estimote and developing the software to interact with the beacons we needed to test it. In an large conference room we placed 2 beacons on a wall 3m apart. This was the distance between the bed centres as observed in a cooperating healthcare facility. For the same reason the bed was deemed to have 1m width and 2m length.

The dispensers were mocked using a soap dispenser with a beacon on top, because the only thing we were interested in detecting was the pumping movement.

We set the custom range of the software, running in an Android device, to trigger these events at 2.0m (length of the bed) and began to approach the first beacon. Unfortunately, at 4m the device started to detect the entrance in the beacon proximity zone. We repeated the test with the custom range set to 1m. The triggering of the events was inconsistent. The *onEnter* event would trigger at 1m and if we moved to the side of the beacon, still under 1m, the *onExit* event would trigger.

We decided to try iOS, so we repeated the test with the custom range at 2m. The results were satisfactory as the device was successfully detecting the entering and exit of the patients bubble.

We proceeded to test the scenario where the HW was between two beds. We used an improved version of the software with the *onContext* event implemented. The device showed correctly the beds in range. However, sometimes it took a few seconds to recognize those changes. Moving on to the next phase we performed the exact same test, except this time we used a neck pouch. There seemed to be no difference in the results. This meant the HWs could carry the cellphone with little interference with their work.

Finally, we moved into testing the dispenser broadcasting its telemetry data and set on transmitting only when in motion. Firstly, we used the dispenser out of the range of the beds but in range of the device. The device picked up the use of the dispenser. Then, we used the dispenser while we were in range of the beds and the device successfully picked up on the use of the dispenser while maintaining the correct bed area.

In conclusion the technology seemed to perform according to what was expected, detecting enter and exit events at appropriate times, although sometimes with a small delay and correctly identified the use of the dispensers. However, further testing in the real world should be performed.

After we had the data collected by the software we used it as an input to the AMS which ran as a script over the data. Then we compared the metrics we had observed to the ones obtained by the AMS. The comparison from between the two gave an efficacy of 100%. However, the tests were performed in a controlled environment with little to no interference and further real world testing is required.

The last layer in need of testing was the interface. For this purpose we conducted user tests starting with pilot testing and when everything was approved the real testing.

We performed all the tests in the same meeting room over two different days, according to the participants availability. Each test took about 15 minutes, 5 minutes to explain the project and an additional 10 minutes of actually testing. Only one user carried out the test at a time. The test was performed in a laptop running the gamification platform with a previously populated database containing fictitious data of healthcare professionals, levels and badges. All the users started in the home screen, after login. The test profile was the same for every user and was reset between tests. The tests were supervised by one researcher and the users were students with ages between 22 and 25.

The tasks to be carried out were:

1. View the game objectives;
2. Check the requirements to obtain the badge: "Vedeta de Turno" nvel 2;
3. Change the profile description to "Hello!";
4. View the percentage of hand hygiene compliance on 2015/09/29;
5. Edit the profile to not display the number of badges.

These tasks considered successful only when either the user pointed out the task was finished or read out the required information. After each test we also asked every participant to answer a small questionnaire regarding the platform usability. This form was fully based on the System Usability Scale (SUS) as it the standard when measuring a system's usability[10]. The SUS consists of 10 statements where the user uses a scale from 1 to 5 (1 meaning that the user strongly disagrees and 5 meaning the user strongly agrees with the statement).

The results can be seen in Table 1

Comparing these intervals to the optimal number of clicks needed to accomplish each task we can see a big difference for tasks 3 and 4. This was consistent with the values for the times, as these were the tasks with the highest values. During the tests both tasks 3 and 4 were also the tasks were the users gave the highest number of suggestions for improvement. The main problem detected in both of these tasks was described, by the users, as not intuitive interface design.

Regarding the SUS we observed an average score of 70.38, this would result in a C score which meant that the interface was just acceptable when considering the work of Bangor et al [3].

Having an interface with a just acceptable score is a problem for a gamification based solution as the main way of communicating the metrics, engaging the HWs and change their behaviour would be this interface.

CONCLUSIONS

We built on the work of the OSYRISH project, we started by addressing the problem of HAIs and their negative impact on both patients and healthcare facilities. HAIs impact could be minimized if the HWs complied with the guidelines for hand hygiene by the WHO.

Monitoring this compliance can be an expensive process as direct observation is still the golden standard. This compels healthcare facilities to invent new and innovative ways of performing hand hygiene monitoring.

Learning from the difficulties of implementing a gamification solution to monitor hand hygiene compliance and provide feedback to the HWs, faced in the OSYRISH project, we developed a model to structure the development of this solution and tackle these challenges.

By following the steps of the model, we developed a solution however, we were not able to deploy the system in the real world, because it seems there is still no indoor location technology suitable for solving this problem.

From the first steps of the solution's development we understood that it's very difficult to perform indoor location. Finding a indoor location technology that is both accurate cheap and has good autonomy is a challenge. By compromising and finding a balance between the parameters, and making sure it still fitted our needs we were able to develop a pilot that gave us very good results in the tests.

Developing a solution in an incremental manner allowed us to have a better grasp on the specificities of the bottom layers and make sure the choices we made for the top layers fitted the solution in the best way possible.

However, there is still much work to be done in the indoor location department if we wish to have a reliable AMS and be able to test the gamification solution in an healthcare environment.

Table 1. User tests number of clicks by task (confidence level of 95%)

	Tasks				
	1	2	3	4	5
Confidence interval	[3 - 5]	[3 - 8]	[11 - 21]	[11 - 16]	[4 - 6]
Optimal number of clicks	2	2	6	3	4

REFERENCES

1. Allam, A., Kostova, Z., Nakamoto, K., and Schulz, P. J. The effect of social support features and gamification on a web-based intervention for rheumatoid arthritis patients: Randomized controlled trial. *Journal of Medical Internet Research 17*, 1 (2015), e14.
2. Amundson, I., and Koutsoukos, X. A survey on localization for mobile wireless sensor networks. *Mobile entity localization and tracking in GPS-less environnments* (2009), 235–254.
3. Bangor, A., Kortum, P. T., Miller, J. T., Bangor, A., Kortum, P. T., Miller, J. T., Empirical, A., Bangor, A., Kortum, P. T., and Miller, J. T. An Empirical Evaluation of the System Usability Scale Usability Scale.
4. Casas, R., Cuartielles, D., Marco, Á., Gracia, H. J., and Falcó, J. L. Hidden issues in deploying an indoor location system. *IEEE Pervasive Computing 6*, 2 (2007), 62–69.
5. Chassin, M. R., Mayer, C., and Nether, K. Improving Hand Hygiene at Eight Hospitals in the United States by Targeting Specific Causes of Noncompliance. *Journal on Quality and Patient Safety 41*, 1 (2015).
6. Chen, Y., Lymberopoulos, D., Liu, J., and Priyantha, B. FM-based indoor localization. *Proceedings of the 10th international conference on Mobile systems, applications, and services - MobiSys '12*, September (2012), 169.
7. Deterding, S., and Dixon, D. From Game Design Elements to Gamefulness : Defining Gamification .
8. Hagel, S., Reischke, J., Kesselmeier, M., Winning, J., Gastmeier, P., Brunkhorst, F. M., Scherag, A., and Pletz, M. W. Quantifying the Hawthorne Effect in Hand Hygiene Compliance Through Comparing Direct Observation With Automated Hand Hygiene Monitoring. *Infection Control & Hospital Epidemiology 36*, 08 (2015), 957–962.
9. Jeffrey Hightower, G. B. A Survey and Taxonomy of Location Systems for Ubiquitous Computing. *IEEE Computer 34* (2001), 57–66.
10. Kortum, P., and Peres, S. C. The Relationship Between System Effectiveness and Subjective Usability Scores Using the System Usability Scale. *International Journal of Human-Computer Interaction 30*, 7 (2014), 575–584.
11. Lamb, L. C., DiFiori, M. M., Jayaraman, V., Shames, B. D., and Feeney, J. M. Gamified Twitter Microblogging to Support Resident Preparation for the American Board of Surgery In-Service Training Examination. *Journal of Surgical Education 74*, 6 (2017), 986–991.
12. Marques, R. Using Gamification for Reducing Infections in Hospitals.
13. Marques, R., Gregório, J., Pinheiro, F., Póvoa, P., da Silva, M. M., and Lapão, L. V. How can information systems provide support to nurses' hand hygiene performance? Using gamification and indoor location to improve hand hygiene awareness and reduce hospital infections. *BMC Medical Informatics and Decision Making 17*, 1 (2017), 15.
14. Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems 24*, 3 (2007), 45–77.
15. Petrellis, N., Konofaos, N., and Alexiou, G. P. Target localization utilizing the success rate in infrared pattern recognition. *IEEE Sensors Journal 6*, 5 (2006), 1355–1364.
16. Safdar, N., Anderson, D. J., Braun, B. I., Cohen, S., Donskey, C., Drees, M., Henderson, D. K., and Huang, S. S. HHS Public Access. 480–493.
17. Soganci, H., Gezici, S., and Poor, H. V. Accurate positioning in ultra-wideband systems. *IEEE Wireless Communications 18*, 2 (2011), 19–27.
18. Tesoriero, R., Gallud, J., Lozano, M., and Penichet, V. Using active and passive RFID technology to support indoor location-aware systems. *IEEE Transactions on Consumer Electronics 54*, 2 (2008), 578–583.
19. Venkatesh, S., and Buehrer, R. Non-line-of-sight identification in ultra-wideband systems based on received signal statistics. *European Space Agency, (Special Publication) ESA SP 626 SP*, 6 (2007), 1120–1130.
20. Ward, M. A., Schweizer, M. L., Polgreen, P. M., Gupta, K., Reisinger, H. S., and Perencevich, E. N. Automated and electronically assisted hand hygiene monitoring systems: A systematic review. *American Journal of Infection Control 42*, 5 (2014), 472–478.
21. Werbach, K., and Hunter, D. *For the win: How game thinking can revolutionize your business*. Wharton Digital Press, 2012.
22. World Health Organization, W. Report on the Burden of Endemic Health Care-Associated Infection Worldwide. *WHO Library Cataloguing-in-Publication Data* (2011), 40.
23. Zhao, X., Xiao, Z., Markham, A., Trigoni, N., and Ren, Y. Does BTLE measure up against WiFi? A comparison of indoor location performance. *20th European Wireless Conference* (2014), 1–6.