Welcome OnBoard: An Interactive Large Surface Designed for Teamwork and Flexibility in Surgical Flow Management

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Figure 1. OnBoard (left) in the main semi-public space of the surgical suite in a large hospital.

ABSTRACT

Effective management of surgical suites require teamwork and constant adaptation. Attempts to bring computer support might deteriorate information accuracy, be inflexible and turn staff collaborative tools into administrative tools. We present OnBoard, an 84" multitouch surface application to support surgical flow management. OnBoard supports multiple users, transposes existing coordination artifacts into interactive objects, and offers interactions such as free writing or addition or rescheduling of cases. As part of a cyber-infrastructure, OnBoard enables users to benefit from real-time activity sensors in the surgical suite while offering ways to mitigate potential glitches. OnBoard was installed in a surgical suite of 12 operating rooms for 2 months that performed about 300 procedures. We observed its use, ran interviews and questionnaires and tailored the interactions according to users' needs. OnBoard suggests that tailored, flexible tools might effectively support the surgical staff and be an important part of patients' health improvement.

Author Keywords

Surgical suite; interaction design; collaboration; technology probes.

INTRODUCTION

Surgical suites are a group of rooms designed to provide all surgical services to patients. They include surgery, preparation and anesthesia for the patient, sterile preparation of the surgeon, instrument and materials sterilization and storage, instrument cleaning, operating rooms (ORs) and recovery room. A key activity in a surgical suite is its management e.g. scheduling cases, allocating staff (surgeons, anesthesiologists, nurses), monitoring the status of operations, and most crucially reacting/adapting according to contingencies. Surgical suite management plays a key role in the endeavor of hospitals: patients' health at sustainable cost. Since half of the revenue of large hospitals comes from OR operations [11,13], improving capacity through better management of the surgical flow might be beneficial at all levels.

In the search of efficiency, computerization and automation of processes are conventional solutions to support resource management. However, unsuitable support might not improve the management activity, and can even be detrimental to it. Himmelstein et al. [19] estimate that so far computerization has not brought any evidence of improvement in administrative costs neither overall costs, or has brought modest improvements in quality of patient outcomes. Black et al. [7] highlight the gap between the postulated and empirically demonstrated benefits of eHealth

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technologies, as well as the lack of best practice guidelines for effective development and deployment strategies. Specific studies in the hospital field confirm the need of computerization while highlighting the potential pitfalls [2,14,31]. As noted by Grudin [17]: “Frequently we see researchers studying other researchers, developers building systems because the technology exists, and managers supporting the development of systems that will appeal to other managers”. The challenge is therefore to provide computer support for hospital management which benefits the medical staff. Our hypothesis is that usable and flexible interactivity tuned to local particularities [19] can create a working environment in which the medical staff can cope with unexpected surgery events and become the “owners” of technology.

In this article, we present OnBoard, an 84” multitouch surface application that we designed and implemented to support teamwork and flexibility in surgical flow management (see Figure 1). OnBoard belongs to a larger cyber physical system including activity sensors in every operating room of the surgical suite [15,21,26,27]. The present paper focuses on the design of the interactive part of the whole system, and the results of its installation in a real setting.

SURGICAL SUITE MANAGEMENT

Surgical suites are areas dedicated to the care of the surgical patient that are overloaded with information and characterized by short deadlines (emergencies) and missing spatial organization (*which patient for which OR at what time? Where is this laparoscopic tool or imaging device?*). A surgical suite consists of various equipment: paper notes and medical records to carry information whiteboards, phones, and emails to communicate and an information system to access patient records. In current ORs, several independent computer systems may coexist. In addition, each surgical suite has its own culture and rules. For this study, we worked within two surgical suites of a large 1700-bed hospital: DunnOR (23 ORs) and FondrenOR (12 ORs).

The surgical suite staff comprises nurses, surgeons, anesthesiologists, board runners (who are also nurses), technicians, cleaning crews, transporters etc. They work as a team to deliver the best care to the patient and need continuous access to the surgical suite information to coordinate with each other effectively (see Figure 1).

RELATED WORK

Collaboration, with focus on hospital

Lack of collaborative technologies for the hospital

The hospital field is by nature a critical environment, with constant teamwork and adaptation to new contexts. A significant contrast remains however between sophisticated healthcare technologies and the very traditional collaborative tools used in healthcare: while introducing more and more robotics for surgery activities, staff still uses paper-based communication tools such as sticky notes and whiteboards

[16]. The lack of CSCW (Computer Supported Collaborative Work) technologies in the hospital might come from the lack of deployment possibilities for clinical trials [25] due to the fact that hospitals are critical environment. Moss et al. [31] mention the danger of incidents caused by computer systems that change processes and lead to errors, the lack of evaluation tools [14], and the technology acceptance gap: many staff of the hospital environments report being worried about computerization and being forced to switch to systems that would be imposed to them [28].

Communication needs vs. interruptions problem

The OR charge nurse primary role is communication and coordination in the OR [31]. This person coordinates the whole nurse team and is a reference in the surgical suite for any question of organization. However, Popovici et al. [33] relate the key issues of effective communication among hospital stakeholders, including interruption problems and unintuitive user interface – problem also discussed in civil aviation [20]. Indeed, the mobility of information and the relationship between information and representation [3,4] are valuable but rarely served by technology within the hospital.

Scupelli et al. [39] promote “trajectory awareness” i.e. the ability to be aware of critical events that are spatially and temporally separated from the person. They also pinpoint how lack of awareness and coordination in the OR escalates to significant problems. They claim that creating a “collaborative culture” is necessary and can be achieved by providing the staff with adapted collaborative tools. In this way, Scupelli et al. [40] endorse the view that context-aware technology can bring automated context information about the surgical suite to the staff.

Moss et al. [31] propose the integration of electronic whiteboards to support asynchronous communication. This could for instance decrease the amount of unnecessary phone calls and the number of coordination activities disruptions.

Collaborative affordances

Bardram et al. [5] defines the concept of collaborative affordances as “the relation between an artifact and a set of human actors that affords the opportunity for these actors to perform a collaborative action within a specific social context”. They define a set of core collaborative affordances: portability, collocated access, shared overview, and mutual awareness [37], and highlight that the surgical whiteboards possess some collaborative affordances.

Traditional and electronic whiteboards for surgical suite

Disconnected whiteboards

Large whiteboards are widespread centralized coordinative artifacts to support surgical team scheduling activities [18,41]. They allow flexibility thanks to the many ways information can be represented, resulting in great appropriation of information [41,46]. They also provide several collaborative affordances such as collocated access,

shared overview and mutual awareness [5]. These whiteboards are however not portable and disconnected from hospital computer systems. This hinders context awareness and the dissemination of information [3,4,31].

Computerization without degrading collaboration

Many attempts to bring computer support such as coordinative electronic whiteboards can be found in the literature [29,36]. *eWhiteBoards* [6] are an example of electronic whiteboards proposed to improve trajectory awareness. The problem stated with electronic whiteboards is that they deteriorate information accuracy, are inflexible and turn this staff collaborative tool into an administrative tool [36]. In addition, a proper appropriation requires that users be able to apply current practices [41], which is often impossible since the proposed electronic whiteboards are not as interactive as whiteboards *sensu stricto*.

Large surfaces for emergency response

ePlan Multi-Surfaces [8] is a multi-surface environment, including larger and smaller interactive surfaces for emergency response planning training. The system gathers information from multiple sources in real-time and displays an overview of the situation on a large surface. The prototype received positive feedbacks for the usability and the learnability of its interactions. The study also shows that designers should provide multi-touch interactions that avoid hard-to-remember multi-fingers gestures. The authors emphasize that technology reliability is key to user involvement and trust in the system. For instance, some users can spend a lot of time checking whether they are connected to the system instead of performing their activity.

TIPExtop [42] introduces a large multitouch display, designed to be used horizontally as a table to support decision-makers activity during emergency response. The authors designed tools to foster communication and explore alternatives around a multitouch map of the area of interest e.g. direct annotation of the map or recorded voice messages.

Large surfaces for traffic management

Air Traffic Control (ATC) research projects involves the development of new concepts that supports and improves the current way of working of the staff [22,30,43–45]. For instance, MAMMI [43–45] provides direct manipulation of “flight”, “radio message” or “action” objects on a shared surface. Teammates can freely organize those objects to communicate, support mutual awareness and dynamically allocate tasks.

Prouzeau et al. [34] describe a prototype to overview real time road traffic, including lights duration and speed limits. It also offers simulations to explore decision consequences and highlighting their impact on the current traffic. The prototype uses a very large screen to foster co-located, synchronous cooperation for two users.

METHOD

The replacement of the traditional whiteboard by an electronic one aims at providing better information to

medical staff but may jeopardize collaboration and adaptation. Our aim is to build and deploy a system that fosters teamwork and flexibility, as needed for surgical flow management. Consequently, we selected methods that focus both on users and software development.

User context analysis

Two different surgical suites of a large 1700-bed hospital have been involved in the user context analysis: DunnOR (23 ORs) and FondrenOR (12 ORs). We also as involved two board runners of a third surgical suite (Suite3) for some participatory design sessions. First, we analyzed the environment of DunnOR, through 9 interviews, two weeks of observations with about 1000 pictures of the whiteboard automatically taken every day and analyzed [35]. We then made further observations in FondrenOR. We observed that the two surgical suites were similar in their operations, basing the surgical flow management and awareness on large whiteboards maintained by board runners. From this analysis, we devised scenarios and high-level system requirements to be fulfilled by the system.

Design

We performed participatory design [38] sessions with 9 surgical staff from DunnOR, to design a user interface suited to the management of the surgical flow while providing information from the cyber physical system sensors to the surgical staff. OnBoard initial design comprises whiteboard-like features, enhanced by interactions that could be only provided thanks to computer-support. We conducted several iterations [35] to refine the features with DunnOR users including: 2 board runners who were nurses by training, another board runner with a secretary background, and a nurse. We also conducted a participatory design session with 2 board runners from Suite3.

We ran design walkthrough sessions with 12 surgical staff, with 13 separate sessions. The design walkthroughs were performed on prototype versions of OnBoard. We also relied on design guidelines from the CSCW literature and previous experiences of electronic whiteboards. Finally, we performed usability inspections [32] with a focus on error prevention and recovery to prepare for deployment.

Software development and Integration

OnBoard application is developed with JavaFX. Multitouch is managed with an adaptation of SwingStates [1]. The development required careful algorithm and interaction programming to make them fast and error-free, e.g. we had to resort to QuadTrees to optimize the collision detection for erasing. OnBoard is linked to the sensors of the cyber physical system installed in every OR [15,21,26,27] and the hospital network, communicating by text files in a shared drive. One of the goals of the whole cyber-infrastructure is to gather data and analyze them to find elements of improvement in the management of the suite.

Deployment and Technology Probe approach

We deployed OnBoard at FondrenOR and the activity sensors in the 12 Operating Rooms of the suite. We have

adopted a design method that borrows some principles of the Technology Probe approach [24]. This allows us to (1) gather information while the surgical staff uses OnBoard in an actual setting in the long run (2) redesign some features and deploy them quickly.

REQUIREMENTS

Based on the user context analysis, we formulated high-level requirements to be met by our system, following the pattern "To [*achieve goal*], OnBoard shall allow [*user*] to [*perform task*]". The requirements reflect the importance of supporting medical staff collaboration by design:

R1. Enriched surgical flow: to get up-to-date information and benefit from relevant automated support, OnBoard shall allow users to visualize the surgical flow data enriched with additional information from the cyber-physical infrastructure.

R2. Multi-users and multi-roles: to face high workload situations, foster fluidity and benefit to anyone, OnBoard shall allow several users with different roles to interact with it simultaneously.

R3. Teammates' activity: to create mutual awareness, OnBoard shall provide users with means to be aware of teammates' activity.

R4. Communication and Coordination: to regulate the surgical flow, OnBoard shall allow users to communicate with each other and coordinate actions.

R5. Dynamic change: to face unexpected events, OnBoard shall allow users to change the surgical flow dynamically.

R6. Work adaptation: to appropriate technology, the OnBoard system shall allow users to continuously create and adapt new work practices.

We followed the general usability guidelines [9,32] and CSCW principles [12] and applied 5 design principles, described hereafter, to generate ideas and create prototype features and matched them with the 6 requirements:

P1. Multi-touch: Use a large interactive vertical multi-touch surface to support multi-user interaction.

P2. Reify: Reify actions and real objects into virtual objects. Since objects are displayed on a shared surface, their manipulation may enable accountability.

P3. Partial: Enable partial accomplishment of actions. An action can be separately prepared, checked and accomplished by different users, thus offering seamless task allocation.

P4. Feedthrough: Provide as much feedthrough as possible. Since activities must be accountable, it is important that appropriate feedback provide an opportunity for teammates to observe one another's actions.

P5. Robust: Interactions must be tailored to work efficiently in a high-pressure environment. OnBoard should be robust enough to be used in a real-setting or offer fallback.

INTERACTIONS

This section presents the interactions we designed, together with the requirements they fulfil and the design principles they follow [*in italic with brackets*].

Large surface in semi-public cyber-space

OnBoard runs on a large multitouch surface (84", 4k, 60hz, Figure 2) in the surgical suite corridor (Figure 1). The corridor is a semi-public, central area: the surgical staff meets there because of the presence of the whiteboards, especially during turn-around between operations. It is a place of information sharing and verbal communication. The surface is vertical in landscape orientation and is as large as one of the two whiteboards of the surgical suite. The surface is multitouch, large enough for 3 people to stand in front of it, and precise enough to allow both close-up and 5m-away reading.

OnBoard is composed of three main parts. The main one is a vertical list of white, horizontally-elongated strips that reify surgical cases. On the right a vertical list displays groups of staff members. On the top, a toolbar contains various tools such as magnets, ink color and width and an undo button. The general philosophy of OnBoard is the direct manipulation of objects [23] such as case strips, magnets and staff magnets. Objects can be physically moved on the whole board and their content can be modified. [*R2:multiusers; R6:adapt; P1:multitouch*]

Handwriting almost everywhere

Like a traditional whiteboard and for the sake of flexibility and technology transition, we wanted to preserve the ability to write/erase on the electronic board. Handwriting also naturally shows that a human (as opposed to the computer) made a modification, which fosters mutual awareness. In addition, handwriting helps users recognize who made the change. To this end, we proposed several ways to write and erase with the surface: fingers, gloves and different types of pens (see F2 in Figure 2). Up to two users can write at the same time on objects such as cases and staff magnets. We also provided empty areas as additional zones of writing, one at the top of the surface and one that can be hidden behind the staff list.

Figure 2. OnBoard interactive features.

The surgical staff promoted the use of traditional dry-erase markers that have no virtual ink in it. One advantage is that the “noise” made by a marker is preserved and participate to make people around aware that something is being done on the board. Another advantage is that writing on the board is smoother with such a pen than plastic/rubber/microfiber pens. The latter are less comfortable as they do not “glide” smoothly or make annoying tapping noise.

We also designed and implemented a multitouch erasing interaction based on the area between two or several fingers. The eraser is represented by a line joining the fingers together. Users can select the eraser size by moving one’s fingers away or closer from each other. By dragging the fingers on the screen, one erases the text which has been overflowed. Users can see what will be erased thanks to the dimming of the color of the overflowed items. Discussions with the staff led to customize a traditional eraser with several points of contact, allowing them to erase electronic items with a physical object.

Besides handwriting, there are multiple widget-based or gesture-based interactions to modify the value of some information e.g., the OR number of a case. Any modification by a human on information that was provided by the system in a first place appears with a handwritten-style font (see on the “OR” column in Figure 2) to signify that the modification was done by a human operator. This signifier might foster shared awareness among users [10,22,30].

[R1:enrich; R3:teammate; R4:coord; R5:dynachange; R6:practice; P1:multitouch; P2:reify; P3:partial; P4:feedthrough; P5:robust]

Surgical Case management

A surgical case is represented by an elongated horizontal strip containing the following information: OR number, scheduled time, hospital room number, patient name, procedure, surgeon name. The information exactly mimics the actual board. As we will see later, initial information on cases are loaded from a file at the start of the application.

Changing procedures scheduling

OR number and start time for a case may vary regularly according to the other cases and external factors such as turnover between two cases, or surgeon availability. To modify the start time, users need to press the current start time and drag the hand of the clock along the inner clock (for AMs) or the outer clock (for PMs) (see F7, F8 in Figure 2). The text of the new start time appears with a handwritten font to specify that a user changed it. As users sometimes do not know the new start time and just need to give an idea of the order of the cases, we also added the possibility to drag to a specific number (1-2-3-4). This feature illustrates how OnBoard enable users to provide partial information in a flexible way. [R1:enrich; R4:coord; R5:dynachange; P3:partial; P4:feedthrough]

Adding informative magnets

Magnets can be moved onto a strip to warn about potential mishaps: latex allergy, name confusion, contact isolation, and pre-op done (see F12 in Figure 2). These magnets are taken from the “magnet tool box” at the top of the screen and dragged and dropped onto a strip. This feature is directly inspired from the way DunnOR surgical staff manage their cases i.e., adding physical magnets on the whiteboard. [R1:enrich; R4:coord; R5:dynachange; P2:reify; P4:feedthrough]

Re-arranging cases

Users can modify the vertical layout of strips on the board, by dragging them up and down. They usually choose to order them by OR number, then by start time. We wanted to leave this free so that any surgical suite culture could be supported. Again, the OR number text is displayed with a handwritten font. [R1:enrich; R4:coord; R5:dynachange; P2:reify; P4:feedthrough]

Shifting case

OnBoard allows users to drag and shift a strip to the right (see F14 in Figure 2). This visually extracts this case from the normal flow depicted by the horizontally aligned strips. This feature was designed with no targeted use in mind, but rather to observe what would users do with it [33]. [R1:enrich; R3:teammates; R4:coord; R5:dynachange; P4:feedthrough]

Adding emergency cases

During the day, add-ons cases can be added on the board, for instance emergency cases. They are added by dragging a magnet (see F13 in Figure 2) between two strips or at the bottom of the screen. This feature answers the problem that board runners had with the whiteboard: most of the time, an add-on cannot be inserted where it logically should on the whiteboard due to the lack of space and the impossibility to erase and rewrite all the other cases. Together with free handwriting, this feature is the most important one for the handling of unplanned cases. [R1:enrich; R4:coord; R5:dynachange; P1:multitouch; P2:reify; P3:partial; P4:feedthrough]

Cancelling and deleting cases

A case can be cancelled without being removed from the board by pressing on the “trash” icon. A red triangular wave and a CANCELLED text is displayed on top of it to mimic strikethrough: this enables the staff to make sure that everybody is aware that the case has been cancelled (see Figure 3) (observations at DunnOR).

Figure 3. Cancelling a case.

A case can be totally deleted and removed from the board by pressing the trash icon, then dragging all the way to the bigger trash through each bubble, then releasing (see F4 in Figure 2). This interaction brings safety in the deletion of a case, which is considered a very critical action. This action must be done only when the staff estimates that the patient left the surgical suite. Would a mistake be made, or would the patient come back into the OR, the staff has the possibility to “undo” the deletion and bring the representation of the case (the strip) back on the board by pressing on the “undo” icon at the top of the screen. [R1:enrich; R3:teammates; R5:dynachange; P1:multitouch; P2:reify; P3:partial; P4:feedthrough]

Staff Management

Surgeon occurrence

When pressing on a surgeon name, OnBoard highlights all the cases performed by this surgeon (see **Error! Reference source not found.**). This feature allows users working with this surgeon to have a quick overview of all the patients they will work with. [R1:enrich; R4:coord; R5:dynachange; P2:reify; P3:partial; P4:feedthrough]

Figure 4. Surgeon occurrence feature.

Staff representation

An important part of the job of the board runners is to assign staff to ORs and procedures. To do so, every staff (anesthesia, nurses, and surgical technicians) of the day has a magnet with his/her name as his/her representation on the right of the board (see F16, F16.1,16.2 in Figure 2). These magnets can be moved up/down to assign them to OR numbers. New staff magnets can be created by pressing the “+” at the bottom-right of the screen and edited with a pen. Any staff magnet can also be deleted (e.g. if a staff has left) by dragging the magnet to the “-” at the bottom-right of the screen. [R1:enrich; R4:coord; R5:dynachange; P1:multitouch; P2:reify; P3:partial; P4:feedthrough]

Integration and Cyber-infrastructure

Pre-editing and Loading the surgical schedule

At the end of the day, the board runner prepares the schedule for the following day by filling up a set of preformatted spreadsheets with the details of the cases (start time, OR number, patient name, procedure name, surgeon name), the details of the surgical staff (nurses and surgical technicians names, shifts) and the details of the anesthesia staff (name and job-role). In the morning the following day, the board runner loads the schedule. Digitally prefilling the sequence of cases is an asset for board-runners, as it prevents from the necessity to transcribe by handwriting the information already available in the hospital system, thus avoiding pain and potential mistakes. In the future, the IT hospital system might be able to directly feed OnBoard: however, it is currently not possible for security and License Agreement-related reasons. [R1:enrich]

Operating room real time state

The cyber physical system comprises sensors in every OR to capture OR state in real-time [15,21,26,27]: it detects if the patient is in the OR, if the anesthesia machine is on as well as door openings. The OR state information is displayed on the board through timelines (see Figure 5). The timelines display: “Patient IN” – “Intubated” – “Extubated” and “Patient OUT” with “(time of event)”. This information is interesting to the staff: it allows them to anticipate and make decision based on unbiased and accurate data. For instance,

when the board runner sees that the patient is extubated, he/she can call post-operating room staff and announce that the patient is coming soon. This prevents from resorting to a displacement in the OR susceptible to nosocomial infection. [R1:enrich; R3:teammates; R4:coord; P2:reify; P4:feedthrough]

Multiple cases on the board are supposed to occur in the same OR (obviously not at the same time). However, the sensors are not able to decide which case is which, as the cases can be arbitrarily rescheduled. Thus, we decided that the timeline be drag-and-droppable: the board runner can manually attach the timeline to the case running in the OR. Such feature is an example of how interaction by an informed user might compensate from deficiencies of a partially-implemented or erroneous cyber-system. [R1:enrich; R3:teammates; R4:coord; P2:reify]

Figure 5. Real-time OR state timeline display (left) and number of door openings (right).

Doors openings

The cyber physical system acquires in real time the number of times a door is opened for a procedure in an OR. OnBoard displays this information on the right part of the screen, where OR are represented by numbers (see Figure 5). The number of doors openings is a measure of the infection risk mentioned above, and we wanted to see if the visibility of this information together with that of the operation state would change staff habits. [R1:enrich; R3:teammates; R4:coord; P2:reify; P4:feedthrough]

Communicating with staff with a mobile application

Though it is not the focus of the paper, we also designed and developed a mobile phone application to enable the staff to pick information about cases from OnBoard when connecting with the phone and carry it within the hospital. The MyBoard app was designed according to interruptions management guidelines [20]. However, we did not deploy it for security and privacy reasons. [R1:enrich; R3:teammates; R4:coord; P2:reify; P4:feedthrough]

Safety and Technology Probe aspects

Safety is a primary concern in critical settings such as hospitals and implies constraints on software reliability. Thus, we mitigated the risk of OnBoard failure, even if we did not expect a full replacement of the traditional whiteboard. The OnBoard software automatically saves its state every 30s. In case of failure, the user can re-launch the application and load the last save. OnBoard also takes screenshots every 30s and saved them on a shared drive to enable board runners to print the last one in case of severe failure and impossible re-launch. Screenshots are also useful for analysis, whether for research or quality monitoring. [R1:enrich; P5:robust]

DEPLOYMENT

This section describes the conditions of deployment of OnBoard in the surgical suite FondrenOR.

Participants

The surgical team of FondrenOR comprises 124 persons: average of 10 surgeons per day, 15 anesthesiologists., 2 board runners (BR), 40 nurses, 14 surgical technicians (ST), 10 perioperative nursing assistant (PNA), 12 anesthesia technicians (AT), 21 certified registered nurse anesthetists (CRNA) and (+2 high school interns at the end of the study). Among them the 2 anesthesiologists, 2 BR, 2 nurses (including a BR) were deeply involved in the study. The 2 BR volunteered to use OnBoard and encourage others to do so. The 2 anesthesiologists provided feedback on the use of the board by the anesthesia staff.

Equipment and setting

OnBoard was installed in FondrenOR right next to the whiteboards, in the corridor (see Figure 1). OnBoard is running on an 84" 60Hz multitouch 4K display, on a computer installed on a cart, connected to the intranet network of the hospital. Every users' input on OnBoard was recorded in a CSV file on a shared drive of the hospital network as soon as the input was performed. In addition, OnBoard took and stored screenshots of itself every 30s for further analysis. The sensors systems were installed in the 12 ORs of FondrenOR prior to the study. The communication between OnBoard and the sensors systems were made via csv files on the shared drive located on the hospital network. OnBoard was watching the csv files and reloaded them whenever the sensors modified them.

Training

The main users (2 BR and 2 other nurses) quickly tested and informally trained on OnBoard prior to the installation: training was thus minimal.

Procedure

OnBoard was used from 7.00am to 3.00pm (time during which the involved BRs were working), Tuesdays through Thursdays and occasionally Mondays/Fridays/Week-ends. OnBoard was mostly used between 7.00am and 12.00pm as mornings are typically busier than afternoons. The Board Runners were asked to make updates first on the whiteboards then on OnBoard for safety reasons.

A member of the research team was present the first two weeks every morning from 7.00am to 11.30am and often during an hour at around 2.00pm, at the time of the afternoon shift. She was also present twice a day during the rest of the study, from 9.00am to 10.00am and from 2.00pm to 3.00pm. She updated OnBoard during the deployment to improve its usability or robustness. Most of the software updates were made in the evening when the surgical suite was less busy. She would also answer occasional questions about OnBoard to curious members of the surgical team that were not directly involved with its use.

Data collection means

During the study, we collected various data, including videos/photos (subject to patient privacy restrictions), observations, and interviews in the surgical suite when the staff had time, questionnaires and logs.

We used the technology probe method to get inspiration, create new features or better understand the surgical flow needs. Many features and ideas came from talking with the surgical staff in their environment, in front of OnBoard. The fact OnBoard was physically in the surgical suite changed the users' way of seeing it and they started to have much more ideas of features than during the participatory design sessions with the first team in the laboratory.

RESULTS

Different teams

The participatory design of OnBoard was performed with surgical teams (DunnOR and some staff from a third surgical suite), which are different from the surgical team that used the board during the study (FondrenOR). Even if they share the same goals and concern, every surgical suite has its own culture and specificities. Nevertheless, the first design allowed the FondrenOR team to perform most of their daily activities with only minor customizations due to a slightly different way of managing anesthesia and staff. The rest of the interface was satisfying to the FondrenOR team, which allowed us to deploy the system at their facility to run the study. This suggests that OnBoard is not too specific to a OR suite.

We also ran training sessions with nurses. They consisted in a 10min session in a laboratory environment and a 30min class with all the nurses. The nurses were able to perform most of the interactions. Furthermore, the main users did not report difficulties to perform the interactions during the study. This suggests that OnBoard interactions are not too difficult to learn and to perform.

A successful management of surgical cases and staff

Surgical cases

OnBoard enabled the staff to visualize updates and make the necessary case modifications. The BR were able to load up to 21 cases per day on the electronic board during the 2 months of study in the surgical suite. Users provided comments such as “Easy to use, clear information” (Board Runners), or “The board gives the ability to have a better visual work flow assessment” (Anesthesia staff). A nurse also commented “I love this electronic board because I love our whiteboard, and it is a good compromised between what we already use and the hospital system”.

However, a single OnBoard can display 21 cases only for one day: if there are more cases, the supplemental ones are hidden until there is room again. There were a few days when the board runner had to load 22+ cases on the board (the surgical suite usually uses 2 whiteboards, but we could provide only 1 electronic board).

We observed that OnBoard transcended the whiteboard in the following dimensions:

1. *Flexibility*: the staff appreciated and benefited from the flexibility offered by the addition of emergency cases (or no-elective cases), and the ability to insert it anywhere, move it around and change its OR number and its start time. The reification of physical objects into digital instruments (strips, magnets) enabled users to move elements faster (no need to erase a case and rewrite it completely elsewhere – action that is also prone to human copy errors) while preserving flexibility. We observed partial accomplishment of action when inserting a new case in the flow during an emergency. The user would bring the add-on magnet to the bottom of the list for instance, creating a whole empty strip. The user would then start to fill patient name, procedure title and surgeon name, leaving the OR number and start time of the procedure blank. Indeed, the user did not know yet in which room nor at what time he could schedule this emergency case. Case shift was also straightforwardly adopted and appropriated: FondrenOR team used this feature to signify a “hold on” on a patient, meaning that the surgeon requested that everything about this patient must be stopped until further notice.

2. *Semi-public overview*: OnBoard preserved a collocated access of the whiteboard by remaining a large, central information surface. Users found the overall visualization clearer than the whiteboard when written with computer fonts (once we increased the size after a request from the staff), affording a better shared overview. However, it is not possible to conclude on the effective support of mutual awareness from OnBoard alone, since the traditional whiteboards were still in place and filled up with the same information for safety reasons.

3. *Cross-Interactivity*: OnBoard displays new types of information coming from the sensors and enables the BR to quickly load all cases for the day from a spreadsheet file. Board Runners and Anesthesia reported being more able to anticipate and deal with the surgical flow by having a better idea of where the procedure is at. They also reported less need to physically enter the ORs to check the state of the surgery if they have the information on the electronic board. The mobile timelines helped them compensate the system for not being fully automatic.

Staff management adaptation

Associating staff (anesthesia and nursing) with ORs is as important as case management: who will work in what room after the shift, who already took his/her break, who will replace who etc. To do this, the team from DunnOR only relies on hand writing on the whiteboard. We designed magnets with this surgical team during participatory design to improve efficiency.

When we installed the system at FondrenOR with the second surgical team, we observed that they already use magnets for the staff. Indeed, we were able to automatically load

everyday all the surgical staff with their shift information by creating individual magnets. However, we observed that digital magnets lack flexibility, compared to tangible magnets (see Figure 6). The staff was not able to signify some information the exact way they were doing it: for instance, rotating by 90° a staff magnet to signify to others that this person is covering another person during his/her break (as observed with the DunnOR team). Also, the fact that all magnets stay at any time on the board was difficult for major re-organization of staff activities: with tangible magnets, the BR is able to pick them up, keep them in hand or in the pocket, and then place them on the whiteboard. With OnBoard, the BR could only drag and drop them. This suggests that these magnets need improvements on their design to reach the level of flexibility of tangible magnets.

Figure 6. Example of use of tangible magnets on the whiteboard at FondrenOR.

Handwriting fosters flexibility

The ability to free-write/erase anywhere on OnBoard is an addition to the electronic whiteboards in the literature. Indeed, writing adds extensive flexibility and allow users to support actions that were not planned by designers. We observed the ability of the users to write/erase notes on cases and magnets, just like they would on the whiteboard. For instance, the inability to rotate by 90° a staff magnet was compensated by writing on the magnet the name of the person that is covering for the other person. The users also used it to fix an error from the users at the launch of the application: a wrong surgeon's name input (see Figure 7). This suggests that providing handwriting on OnBoard mitigates some of its limits.

Figure 7. Manual writings and corrections on strips.

The three colors (black, red, and blue), were mostly used with the same purpose as on the whiteboard: black for regular information, blue for anesthesia information, red for special/important notices. On Figure 7, the modification made was on the surgeon name was made in blue: an Anesthesia staff noticed the problem and he made the modification with “the anesthesia (blue) color”.

As said before, users found the computer font “clearer” than handwriting. Indeed, the quality of the graphic rendering of handwriting may have an impact on users’ satisfaction. JavaFX only provides event coordinates rounded to the

closest integer. The result was that the writings seems wobbly. The users were particularly annoyed by the rendering during a day when they filled OnBoard entirely with writings.

To improve the look and feel of handwriting, we adapted an existing java library for Windows Real-Time Synchronous pen events to use the full resolution of the input. Combined with a library we wrote to build dynamic, pressure-variable Bezier curves, we obtained much better results. Because both JavaFX and Windows technologies cannot cohabitate, we had to provide the better input mechanism through a 5x5cm translucent overlay window on top of the main application. The handwriting interaction necessitates now a semi-temporal and spatial mode. To handwrite, the user needs to click on a strip first. This makes the overlay appear centered on the position of the click for a couple of seconds before fading away (see Figure 8).

Though adding a mode seems cumbersome for the user, it brings two benefits. First, we observed that users would leave unwanted traces when failing to properly move a strip and unexpectedly starting a handwriting interaction. The new mode helps prevent such artefacts. Second, we took advantage of this overlay window by moving writing parameters from the top bar to the overlay, making them closer to the writing context.

We suspect that slow and ugly handwriting may refrain users from updating the board. The new technique improved latency and the quality of the graphical rendering. Though we did not gather enough supporting data that it helped improve users’ satisfaction and incentive to using it, we at least eliminated a potential barrier to its use.

Figure 8. A handwriting overlay captures more accurate inputs from the touch screen than the main window.

Collaboration

OnBoard fostered synchronous and asynchronous collaboration among the surgical staff

We observed that the positioning around the boards (whiteboard and electronic board) are similar at FondrenOR and DunnOR. Many people gathered in front of the board to check the information they need: two people talking about a patient using the board as a support; one person making a change on the board; people gathering in front of the board just waiting; people texting information from the board to someone; people taking notes on paper from the board etc. However, conversely to DunnOR, people at FondrenOR tend

to write on the whiteboard one person at a time only, while having more asynchronous communication. Some collaboration patterns were observed e.g. the updates made by a board runner were later read by other staff (change of ORs number, change of cases order, staff information). We therefore could observe that OnBoard, even if it can support two users at a time, was principally used by one person only. This might be because people wanted to be cautious with the technology and were worried to break it.

Still, every person of the different surgical suites has their own objectives and uses the whiteboard/OnBoard to achieve it. Anesthesiologists write to inform other anesthesia staff of the anesthesia team organization, the charge nurse writes for the nurses, nurses update cases state etc. Overall, every displayed information may have a value for anyone who can read it and has value to be displayed to everyone. The large size of OnBoard both provides space for putting information and, as a semi-public screen, draws the attention of the staff.

OnBoard fostered collaboration between surgical staff and design team

We were able to test on the fly new types of interactions during the study, based on our own observations or requests from the staff. The first request consisted in customization due to the fact the participatory design was done with a different team: the creation of an anesthesia information space on the board with another color, so that the anesthesia team could be linked to an OR instead of a case. Two additional magnets “Pre-Op Anesthesia Done” and “Pre-Op Nurse Done” were provided to mimic FondrenOR staff practice on the traditional whiteboard. The second type of request came from the visibility of the public displays in general and many people asked right away for bigger font, as well as different colors to differentiate people by their job-roles on the board. We also got a request of customization of a staff magnet (representing a person), with an avatar. The third type of requests was functional. We were asked first to remove a note area that potentially could be hidden: the staff was worried that important things could be written on it, then hidden and overlooked. We were also asked if we could make it easier to follow staff magnet assignments to ORs while moving them up and down, which we did by highlighting the OR number when hovering with a staff magnet. Another request was to “make a copy by clicking on a staff magnet”. Indeed, some people, represented by a magnet, must be assigned to several ORs. We answered quickly by loading directly in the morning several magnets of the same person.

The request to connect the electronic board to phones was made many times by every job-role staff, emphasizing the need for information mobility. The prototype of the phone application was designed to explore this need. All these changes and additions suggests that the technology probe principles succeeded in fostering rich exchanges and offering new design perspectives.

Finally, three documents were left on the cart of the electronic board during the study, one among them with clear intention to be found and reused later (an anesthesia staff calendar). Also, we observed a lot of paper notes were taken from the board, but also that things were written on the board from paper notes. This suggests that there is a need for even more flexible ways of inputting on and outputting from the board.

CONCLUSION & FUTURE WORK

The objective of OnBoard is to propose a computerized environment for surgical flow management that supports both the hospital management in cost performance and the medical staff in patient care. To do so, we used participatory design and continuous improvement from users’ observations and feedback in a real setting. The resulting system is a large shared surface that displays the surgical cases associated with highly interactive features. Observations and interviews “in the wild” showed that users were able to get up-to-date information from the sensors (R1), especially through the timelines, with the help of their direct manipulation to correct sensor deficiencies. We did not observe high workload situations and several users interacting simultaneously (R2). However, several roles (surgeons, anesthesiologists, nurses) were able to use OnBoard, thanks to handwriting. We did not evaluate the level of mutual awareness (R3) and how interactions may contribute. The large surface displaying coordination artifacts (surgical cases and staff) with hand writing everywhere is definitively a good means to support communication and coordination (R4), as shown in figure 1. Direct interactions to change time, fix incorrect information and add new cases in the flow allowed users to face unexpected events (R5). Finally, users were able to appropriate technology (R6), with the use of colors, handwriting and object shift. However, we observed that some users are still reluctant to technology, turning away from using OnBoard.

The OnBoard experience suggests that the design of interactions is paramount to provide the medical staff with an efficient collaborative environment. Of course, there remains usability issues, and the application is not robust enough to completely replace the traditional whiteboards. We still need to explore how to enhance mutual awareness. The continuity between the large shared surface and the private mobile phones is a promising way forward.

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