Can IT health-care applications improve the medication tray-filling process at hospital wards? An exploratory study using eye-tracking and stress response

Natalia Díaz Rodríguez and Johan Lilius
Turku Centre for Computer Science (TUCS),
Department of Information Technologies,
Åbo Akademi University, Turku, Finland
Email: {ndiaz, jolilius}@abo.fi

Riitta Danielsson-Ojala, Hanna Pirinen,
Lotta Kauhanen and Sanna Salanterä
Department of Nursing Science,
University of Turku, Finland
Email:{rkdaoj, hanna.h.pirinen, anloka, sansala}@utu.fi

Sebu Björklund, Joachim Majors and Kimmo Rautanen
MediaCity Content Testing Lab, Vaasa, Finland
Email:{sebu.bjorklund, jmajors, kimmo.rautanen}@abo.fi

Tapio Salakoski, Ilona Tuominen
Turku Centre for Computer Science (TUCS),
Department of Information Technologies,
University of Turku, Finland
Email:{ tapio.salakoski, ilmitu}@utu.fi

***Abstract*—Filling medication trays and dispensing them at hospital wards is a painstaking, time-consuming and tedious task involving searching for medication in large shelves, double checking in the daily filled tray that the appearance, amount and concentration of each medication corresponds to the prescription, as well as analysing the timing conditions, among other details. Finally, if needed, finding equivalent compounds containing no secondary effects is also crucial, as well as being aware of the dynamically changing treatments in patients located, e.g., in surgery wards. Once the tray is filled, similar concerns and checks need to be done before dispensing the medication to the patient. We conducted a pilot in two university hospital wards using eye-tracking glasses and stress response to assess the tasks that take time the most and are most meticulous or stressing for the nurses. The aim is to use the findings to implement a mobile application that helps saving time and proneness to errors daily in such complex nursing procedures.**

***Index Terms*—eye-tracking, stress, filling medication tray, hospital, dispensing, nurse, eHealth.**

I. Introduction: Background on the hospital wards

Normally, physicians at the hospital order the medication for the patient during the medical round in the morning. They can change their orders during the day according to laboratory results and the condition of the patient. The nurses' duty is to transfer the information from the daily notes of the electronic patient record to the medication programme and fill medication trays for the whole ward. Since it is a time-consuming task, we observed closely the tasks executed when filling the medication tray to evaluate the possibility of developing an application for making the procedure less error-prone and efficient.

We carried out a pilot test in a Finnish hospital that has 803 beds and the amount of personnel in 2013 was of 3013. The study took place in two discretionary chosen wards. One ward, which cared for cancer patients, had 21 beds and 14 nurses dealing with the medication of the patients. The other ward, which cared for plastic surgery patients, had 16 beds and 12 nurses dealing with the medication. We performed eye tracking experiments from 6 and surveyed the stress description from 14 nurses, being in overall 20 nurses.

A. Medication administration process in most Finnish hospitals

Medication administration is a multiphase process including retrieving, preparing, administrating, documenting and monitoring [8]. Medication errors occur in all phases of the process with highest occurrence in preparing; that means when a nurse fills in the tray with pills for the patients [5]. This phase is often seen as a task belonging to the domain of pharmacists, but is typically carried out by nurses in Finnish hospitals.

The nurses fill in the medication tray for all the patients in the ward once a day at noon (or some other set time). Before the task they have to check orders from the physicians, make the changes in the medication program in the hospital information system, print and cut out medicine paper list and bring the list to the medication room. The medication of the patient in the medicine paper list is written with trade names and not according to its pharmacological name. If the medication mentioned in the list does not exist in the cabinet, the nurse has to search for another medicine from a book published by the pharmaceutical information centre or from the centre's web pages. The printed medication list is narrow to fit it in each tray slot, and all the information about one medicine is put in one row. This makes the text very small and sometimes difficult to see.

Filling the tray with medicines demands a lot of concentration from the nurse. This is often impeded by the hectic atmosphere in the ward and the use of medication room for many other tasks. Figure 1 (left) shows a nurse performing the process of filling the medication tray at the hospital ward, with different coloured glasses for the times of the day, in a medication tray.

Fig. 1. Left) Nurse performing the daily task of filling the medication tray at the hospital ward. Right) Current medication tray system

II. Related work: hospital decision-support systems and medication applications

Different errors in medication intake are common today, both at hospitals and also when it comes to automedication. A side problem is keeping treatment adherence in patients [9]. In this section we describe some applications that share these aims concerning both medication preparation and intake.

Smart TV Medicine Tracker [14] is a medicine intake support system that aims at notifying the user about the intake and keep records of all taken medicine. As any recent TV could be transformed into a Smart TV by attaching the set-top box to it, the TV setup includes what, when and what amount of medication to take. Then, the TV can display a subtle notification in top area of screen, and notify with a sound. However, the most challenging task in medicine reminder applications is how to check that the user actually takes the medication.

Life Capsule [6] is an adherence enhancing application for medication intake, based on *a pill box that tweets*. Once programmed, the box lets the followers know if the owner forgot to take the pill. Other application for medication adherence is *MediSafe* [3].

A comprehensive solution [13] is proposed to enhance adherence for the mild and moderate Alzheimer patients, involving not only the patient but also other participants, such as the nurse and/or relative, the drug store, the physician and the hospital. The solution includes the development of an automatic medication dispenser and the corresponding software applications. In [13] a description of the first hardware and software prototypes is included.

Epocrates [2] is a clinical decision support system for diagnostic and therapeutic guidance that aids the prescription procedure. It allows to visualize drugs, interactions, notifications, resource centres, FDA alerts, safety considerations, pharmacology, and to contact manufacturers.

As it can be seen, there are many solutions that already create relevant strategies that try to help remind, guide and motivate, such as [9]. However, our ultimate aim is to build a mobile application that focuses on the medication preparation procedure, previous to the dispensation process within hospital wards, i.e., filling the medication tray. In order to learn more about what kind of support application would best complement the nurses' work on their daily tasks, we realized a field work study, that is detailed in next section.

III. Experiment and analysis design

A. Focus of the study and target group

We performed a pilot study of the medicine dispensing process at one hospital, with *Tobii* mobile eye tracking glasses [4] (in Figure 2) and EDA-bracelets to measure the electrodermal activity, i.e., galvanic skin response of the nurses[1], while performing the daily task of filling trays to dispense them to the patients. The focus of the explorative pilot study was to find if there are any tasks or procedures during the medicine-filling of the tray that could be made more effective. Therefore, this process is observed without taking into consideration any future solutions. The target group consisted of nurses at two different wards at one hospital in Finland, the plastic surgery ward and the cancer care ward.

Fig. 2. Tobii eye-tracking glasses [4] employed in the pilot test

Nurses were asked to perform their usual medicine-tray preparation task while wearing eye tracking glasses for user observation. This method focuses on the realistic behaviour and relies on observation rather than the users' memory or descriptions of the process. Our pilot study was done with mixed data-gathering methods; user observation and eye tracking.

B. Methodology: eye-tracking and user centred design

1) Eye tracking: In order to follow the focus of attention of the nurses during their work, Tobii eye-tracking glasses are used. Tobii glasses are unobtrusive and are composed by a

[1]The latter data is not reported in this work.

head-mounted eye tracker (for capturing natural behaviour in qualitative and quantitative real-world research), a recording assistant and, optionally, infra-red (IR) markers for automated generation of aggregated eye tracking data from several test subjects. Accurate data and automated data mapping and aggregation is possible (requires IR markers). We chose Tobii Glasses Eye Tracker due to the demonstrated suitability in research areas such as in-store shopping research, outdoors and TV advertising, sports research, social interaction research and group dynamics, security applications and usability research, e.g. in studies of signage and control panels. As Tobii Glasses enable eye tracking studies to be conducted in real-world environments, letting subjects to interact freely with physical objects or other people, their unobtrusive design ensures the validity of capturing natural behaviour [4].

2) User centred design: This pilot study is a small part of a *User Centred Design* process [11], more precisely, part of the *User Research* phase *Data Gathering*. The user centred design process is an approach to achieve usability in interactive system development. In this model the user is the centre of focus during the whole development process [11].

During the data gathering sessions in the field at the hospital, some domain specific problems occurred. Due to the hygienic aspect of the EDA-bracelet, plastic wristbands were used instead of the original wristbands included. These plastic wristbands could not be properly adjusted for each user, they became either too tight or too loose. When too loose, the bracelet lost skin contact which resulted in data loss, while when too tight, it became painful and uncomfortable for the nurse. There was also some loss of eye tracking data at times, but it still serves the purpose of gathering necessary information for designing a future aid-supported application well.

IV. Subtasks within the medicine preparation process

From the user observation, thirteen different subtasks within the medicine preparation process were identified in the current procedure to fill the trays with medication:

1) Print and cut out the patients' medicine paper list. These print-outs, in Figure 1 (right), contain the patient's treatments, dosage and administration timing information. It is worth mentioning this is regarded as a pre-step, and therefore, not considered during the eye-tracking recording process.
2) Clean work space area and hands.
3) Unlock medicine cabinets (narcotics have extra security keys in separate cabinet).
4) Organize different colour medicine cups (in Figure 3, bottom shelf, right) to be filled according to time period of the day (morning, noon, evening, night).
5) Search for medicine in cabinet (Figure 3).
6) Keep track of where on the patient medicine paper list the nurse is, which medicine has been filled and which is next.
7) Fill colour cups with medicine.
8) Halve medicine pill.
9) Look up medicine equivalences in *Pharmaca Fennica* [7] medical components catalogue.
10) Look up medicine on web page if not found in *Pharmaca Fennica*.
11) Double check medicine paper list with the amount of medicine filled in cups.
12) Put medicine cups and patient medicine paper list on tray.
13) Write information on syringe/medicine package/paper list.

Fig. 3. Cabinet

These subtasks do not occur every time the filling of the tray- process is done; in addition, there may also be more subtasks.

Table I shows tasks that are the same for every nurse and tasks that may or may not occur during the filling process. However, every nurse always has to unlock the medicine cabinet, line up or organize cups for medicine, look at the patient medicine paper list, search for medicine, fill the cups with pills and finally line up cups on tray. Tasks that are not as frequent are: to sanitize work space, print and cut out patient medicine paper list, halve medicine pill, look up medicine in *Pharmaca Fennica* and on a computer, double check the list with filled medicine cups, and write info on medicine paper lists and/or syringes.

A. Nurse expertise and experience

Taking a closer look at the data of the six recordings, we have to take into consideration the nurses' age, experience, practice, memory, custom and knack for preparing and dispensing medicines in that specific environment. With the data available through the user observation and eye tracking, we have only looked at the nurses' customs and tricks for filling the medicine tray. By adding more user research to get more information about the nurses profiles and personas, more precise task analysis and scenarios can be created to help build information architecture, primary nouns and tasks for a user centred IT-application to fill the tray for dispensing medication.

Every nurse had their own routine, custom or way of filling the medicine tray. Here are the routines that were observed during the study.

Task Analysis	Sanitize workspace	Print and cut out patient medicine paper list	Unlock medicine cabinet	Organize medicine cups	Search for medicine	Fill cups with medicine	Halve pill	Keep track of medicine paper list with pen	Search in Pharmaca Fennica	Check online version of Pharmaca Fennica	Double check paper list with amount in cup	Line up cups on tray	Write info on syringe/ list/ sticker
Rec8		x	x	x	x	x	x				x	x	x
Rec7			x	x	x	x	x					x	
Rec6	x		x	x	x	x		x			x	x	
Rec5	x		x	x	x	x		x				x	
Rec4			x	x	x	x					x	x	x
Rec3			x	x	x	x			x	x		x	x

TABLE I
TASK FREQUENCY TABLE

- Quickly looking at the patient paper list for the name of the medicine, fetching the medicine package, looking at the amount of medicine for the patient while unpacking package or unscrewing cap, placing the medicine in the tray or container glasses, double checking the amount of pills of the medicine in the coloured cup, checking the next medicine on the paper list for the patient while repacking or screwing back the cap, putting medicine back on its correct place and at the same time starting to look for the next medicine package.
- Taking a longer look on the patient medicine paper list at the medicine name and amount, fetching the medicine, opening package, extracting and placing the pill, putting medicine back, moving on to the medicine next in line, and double checking the amount of pills in each cup with the amount of pills on the list after all the medicine is put into cups. Then moving on to the next medicine on the list.
- Same as the procedure above with the modification that the double check occurs for each medicine, and not for all medicine at once as previously at the beginning of the task.
- Some nurses use a pen or tongue dispenser to keep track which medicine on the patient's medicine list they are working on.

Parts of the process where nurses tend to make most mistakes are when they take out medicine from its package (the accuracy of pushing pills out of the pill cart into a cup and taking pills out of the jar with a spoon or pliers), and putting the right amount of medicine in the right coloured cup.

V. RESULTS

The nurses spent from 4 minutes up to 22 minutes on the tray-filling process during the study; depending on how many patients they dispense medicine to and if they have to look up medicines in *Pharmaca Fennica*.

A. Patient medicine paper list

In the pilot study the nurses spent about 30 – 60 seconds on each individual patient's medicine paper list. The time varied depending on the nurse's experience, expertise about the medicine, familiarity with the environment, and the amount of medicine on the list. There may be issues with the patients' medicine list, which are hard to see through an eye tracker video, but which could be time consuming by not enabling easy visual scanning of the paper list. For instance, the design of the patient medicine list, such as the typeface used. Key questions are: How is the information presented? What draws the nurses attention? What visual strategy they follow to optimize the search process? These are also questions that need to be considered when designing an IT-application.

Recording	# of Patients	Time for whole process	Searching for medicine	Going through patient medicine list	Pharmaca Fennica	Double checking medicine and paper list
Rec8	4	00:21:33	00:03:09	00:02:18	-	00:03:56
Rec7	4	00:17:56	00:02:46	00:02:45	-	-
Rec6	3	00:12:26	00:02:41	00:02:52	-	00:00:46
Rec5	2	00:04:24	00:00:27	00:00:57	-	-
Rec4	4	00:15:27	00:02:30	00:03:49	-	00:08:67
Rec3	3	00:21:47	00:06:26	00:03:22	00:02:51	-

TABLE II
TIME SPENT ON THE MEDICINE-TRAY FILLING PROCESS

A task driven digitalized patient medicine list with a wizard navigation model (step-by-step) could reduce the time for the whole process. For example, on one screen patient, it could show:
John Smith: Fill medicine A into cup z, x and y. ⇒ *Next medicine* (new screen).

Nurses with good routine and much experience could be hindered by the application, but it would help new nurses or nurses in training to keep track of which medicine and which amount goes into which cup.

Searching for medicine and fetching the medicine are sub-tasks that could be made more efficient with help of an IT-application. The tasks are time consuming, especially when the medicine is not available. An IT-application with an extra feature to the example above, where the name of the medicine is presented clearly with information about where to find it, could help. For example:
Medicine X, cabinet C, shelf 2, row 34

VI. Which subtasks are the most time consuming?

The most time consuming subtasks during the whole process were scenarios when the nurse did not find a specific medicine listed on a patient's medicine paper list. In this situation the nurse had to look up the medicine in the *Pharmaca Fennica* catalogue [7]. This subtask takes the longest, especially if the nurse cannot find the medicine there but must go to a different room to look up the medicine on a computer. This scenario happened in video Recording 3. For the nurse in Recording 3 the whole process took approximately 22 minutes, where she filled in medicine for 3 patients.

6 minutes and 26 seconds (out of 22 minutes) were spent searching for a specific medicine. 3 minutes and 22 seconds took to look at the patient medicine list, and double check the names and quantities of each medicine. 2 minutes and 51 seconds were spent on searching for the medicine in *Pharmaca Fennica* [7] and then looking it up on the computer.

Approximately 45 % of the whole process time was spent on searching for the medicine and looking it up in *Pharmaca Fennica* and on the computer. 29 % of the time was spent on looking at the patient medicine paper list and leaves 26 % of the time for dispensing medicine into cups and putting the medicine back into its place in the cabinet.

A good scenario where an IT-application would be beneficial for the nurses would be, for example, by having applications that will automatically recognize from the digital patient medicine list that the specific medicine is not available, but a substitute is, and will be then listed in the patient medicine list. This solution would save all the time spent on looking up medicine in *Pharmaca Fennica* [7] and on the computer.

Another solution would be that the application has a built-in search function where the nurse can type in the name of the drug, and the application will search through a medicine database. This solution would save the time spent physically looking through a book for the information and going to a different room to log in on the computer and to the online medicine database. This alternative would not save as much time as the previous solution but it would save time for the nurses if they could type in a medicine name to get the required information on the spot.

VII. How stressing and tedious is the task of filling the medicine tray daily?

Affectiva stress meter sensor [1] was worn by the nurses to measure their stress response. However, as results did not turn out to be 100 % reliable due to hygienic reasons mentioned earlier, we therefore only relied on interviews realized to the nurses after executing the noon task of filling the tray.

In order to assess the nurses' feelings about the procedure realized every noon, we used the PXLab Self-Assessment-Manikin (SAM) Scale [10]. This scale, shown in Figure 4, consists of continuous scales for valence [12], as to study affective judgement in relation to visual stimuli, and a dominance and arousal scale, as a 5-, 7-, and 9-point scale. In order to measure mental stress, the pictorial assessment model (SAM) is used for the subjects to describe pleasant/unpleasant effect (valence) and arousal/calmness effect during medicine disposal (arousal).

Figures 4 and 6 reflect the answers of the fourteen nurses which were observed doing the task of filling of the tray. The nurses told us (observers) which "man" image in the scale described their feelings best when they were filling the tray. Thus, the survey results were not the observer's opinion.

It is visible that average values of the arousal scale reach 3 out of the maximum (5), whereas valence, regarding positive and negative feelings associated to the process of the task, average under 3. Results show in this way the error-proneness of the medicine tray-filling, as well as how painstaking and meticulous it requires it to be with the current procedure being followed. Results indicate the need for an IT solution that can help guide the procedure.

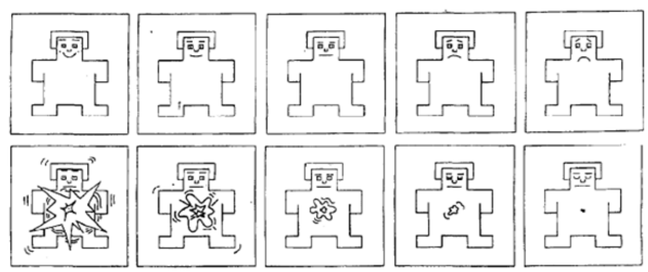

Fig. 4. Valence (upper row) and arousal (lower row) scales for the PXLab Self-Assessment-Manikin (SAM) Scale [10].

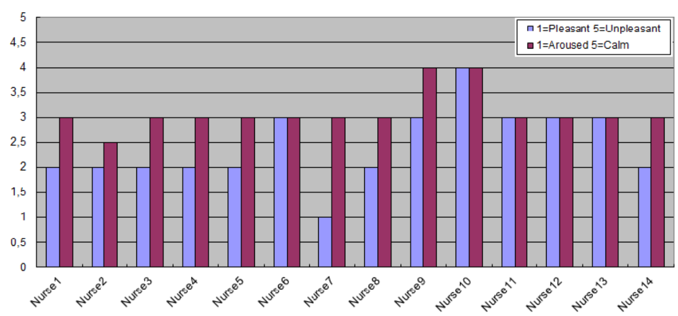

Fig. 5. Valence (purple) and Arousal (dark red) chart for assessing the tray-filling task by the 14 hospital nurses.

A. Practical usability problems within the process

In the cases where nurses did not have to look up the medicine in *Pharmaca Fennica* or on the computer, the most time consuming subtask that were of a practical nature, and where IT-application may not directly help or be possible (when not considering a fully automated solution) are:

1) Searching for medicine
2) Writing information on syringe packages and on specific medicine packages
3) Opening medicine package, taking out the pills and placing them in cups
4) Putting medicine package back to its place

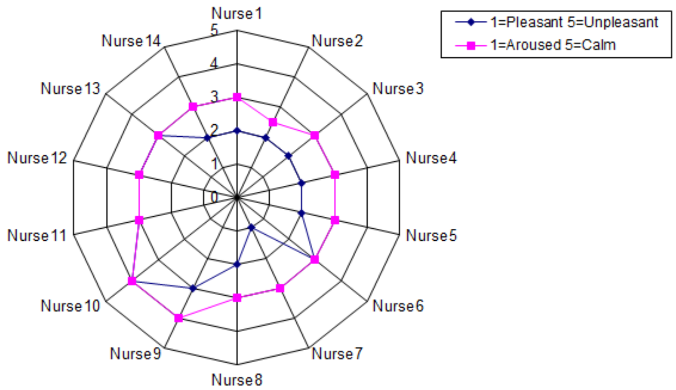

Fig. 6. Spider chart for assessing the tray-filling task by the 14 hospital nurses.

5) Organizing the coloured cup for the patients
6) Halving the medicine pills
7) Unlocking medicine cabinets

Having into account the tasks that take the most time during the tray preparation, there are several practical solutions that can be done to make the medicine tray filling process more time effective. Some ideas of solutions are:

1) Unlocking medicine cabinets; they could be open all the time if there was a room for the medicine dispensing process only (the room should be locked for the same reason the cabinets are locked).
2) Having medicine packages stored so that specific brands can be found without having to open drawers and lifting up medicine jars to see if it is the right one. This may require more practical design cabinets.
3) Having a bigger workspace for preparing the medicine tray and aligning medicine cups. Tight spaces hinder movement and mistakes are more easily made.
4) The medication room should be meant only for medication purposes to guarantee a peaceful situation for the nurse filling the medication tray.

VIII. Conclusions and Future Work

Our main motivation for this eye-tracking driven pilot study was to lower risks and increase patient safety in order to decrease the number of medication errors that are common today in hospitals. The work presented let us conclude that there is room to do that.

A concrete aim of the pilot study was firstly to describe the medication process, and secondly, to find what kind of tasks within the medicine dealing process are more tedious and therefore, could be made more efficient with IT-applications. Results show that affirmatively, some subtasks within the medicine tray filling process may become more efficient with the help of an application, for example showing the medication active components equivalences next to the patient's treatment, or indicating interactions among medications when substituting a medication by its equivalence. Some insights for making the task more efficient were proposed.

There are, however, some aspects that need to be taken into consideration. 1. The workspace: the nurses work in very tight spaces during the tray filling process. A tablet-based solution would require more free space to not become a hindrance to the process. 2. The nurses' experiences, routine in using tablets and other devices. 3. The use of *examination gloves*. Some nurses use gloves during the process, which can hinder the use of a touch screen.

We conclude after the realization of the pilot test in the two hospital wards that a task-driven digitized mobile application with a wizard navigation model (step-by-step) can be implemented as future work to reduce the time and increase the safety of the whole process of filling and dispensing medication trays at hospitals. As a rigorous daily task that takes time and attention daily, nurses would surely benefit of a mobile application to assist on the procedure.

Acknowledgments

This work was funded by Academy of Finland, TUCS (Turku Centre for Computer Science), Finnish Cultural Foundation and Nokia Foundation. We also thank Susanne Hägglund from MediaCity for her help, and our voluntary nurses which allowed us to perform the pilot test at the hospital.

References

[1] Affectiva Q Sensor 1.0. http://www.qsensortech.com/q-analytics-beta/.
[2] Epocrates. http://www.epocrates.com.
[3] MediSafe. http://www.medisafeproject.com/.
[4] Tobii Eye Tracking Technology. Eye tracking glasses. User manuals. 2011. http://www.tobii.com/en/eye-tracking-research/global/library/manuals/.
[5] HaiPro statistics of Hospital District of Southwest Finland. 2013.
[6] LifeCapsule: www.lifecap.coi. 2014.
[7] Pharmaca Fennica 2014 - Lääketietokeskus. www.laaketietokeskus.fi. 2014.
[8] D. Battisto, R. Pak, M. A. Vander Wood, and J. J. Pilcher. Using a task analysis to describe nursing work in acute care patient environments. volume 39, pages 537–547. Journal of Nursing Administration, 2009.
[9] J. García-Vázquez, M. Rodríguez, A. Andrade, and J. Bravo. Supporting the strategies to improve elders' medication compliance by providing ambient aids. *Personal and Ubiquitous Computing*, 15(4):389–397, 2011.
[10] P. J. Lang. Behavioral treatment and bio-behavioral assessment: computer applications. In J. B. Sidowski, J. H. Johnson, and T. H. Williams, editors, *Technology in Mental Health Care Delivery Systems*, pages 119–137. Ablex, Norwood, NJ, 1980.
[11] J. Rubin. *Handbook of Usability Testing: How to Plan, Design, and Conduct Effective Tests*. John Wiley & Sons, Inc., New York, NY, USA, 1994.
[12] H. Suk. *Color and Emotion: A Study on the Affective Judgment Across Media and in Relation to Visual Stimuli*. 2006.
[13] G. Urzaiz, E. Murillo, S. Arjona, R. Hervás, J. Fontecha, and J. Bravo. An integral medicine taking solution for mild and moderate alzheimer patients. In C. Nugent, A. Coronato, and J. Bravo, editors, *Ambient Assisted Living and Active Aging*, volume 8277 of *Lecture Notes in Computer Science*, pages 104–111. Springer International Publishing, 2013.
[14] M. Yusufov, I. Paramonov, and I. Timofeev. Medicine tracker for Smart TV. In *Open Innovations Association (FRUCT), 2013 14th Conference of*, pages 164–170, Nov 2013.