Requirements Engineering Meets Physiotherapy: An Experience with Motion-Based Games

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Abstract. [Context and motivation] In the last years motion-based games have achieved an increasing success. These games have great potential to support physiotherapeutic programs, as they can guide the patients in performing the right movements for their rehabilitation. **[Question/problem]** However, on the one hand, existing games performed on commercial systems (e.g., Wii, Kinect) are not suitable for people affected by motor pathologies. On the other hand, the design of games for physiotherapy is hard, as they should meet the "physiotherapy requirements" of the medical staff, provide an enjoyable experience to the patients, and overcome the technical limitations of the systems that support their execution. **[Principal ideas/results]** These limitations can be addressed by defining a standard process, independent from the considered pathology and that starts from the requirements collection and representation, to support the development of motion-based games for physiotherapy **[Contribution]** For this reason, this paper proposes RE-FIT, a methodology to elicit and model the RE-FIT extends existing requirements elicitation (brainstorming, surveys, and direct observation) and modeling techniques (FLAGS goal model). RE-FIT was developed in collaboration with the Spinal Unit of Niguarda Hospital and the Respiratory Medicine Section of Policlinico in Milan. Our experience demonstrated that RE-FIT is not only suitable to develop new physiotherapeutic games, but also to evaluate the adequacy of existing games for people affected by a specific pathology.

1 Introduction

In the last years motion-based games have achieved an increasing success. They provide a more enjoyable experience than standard games (based on traditional gamepads), as *"they are more interactive and give a better sense of being* *there"* [1]. Motion-based games are fully controlled by the players' movements that are captured through sensors (e.g., gyroscopes, infrared cameras, body scanners) provided by the game system (e.g., Wii, Kinect). Recently, motion-based games have been used to support physiotherapeutic programs [2], since they can guide patients to perform a set of controlled movements that are both suitable for their health status and beneficial for their rehabilitation. However, some of the existing solutions [3, 4] directly use commercial games available on the market that might not be suitable for patients with limitations in motor capabilities. Furthermore, the absence of control on the correctness of movements in commercial games might even be dangerous for the patients' health. Other solutions in this direction are centered on a particular pathology [4–6] or rely on additional hardware (e.g., robots, electrical muscle stimulators) [7]. In the first case, the development of each game requires an ad-hoc process, which might not be adequate for other games that address different pathologies. In the second case, required hardware could be very expensive, making impossible to leverage the physiotherapeutic benefits of motion-based games outside the hospital.

Addressing these limitations can be crucial to facilitate the development and adoption of motion-based games for physiotherapy. However, the design of these games is hard, as they should meet the "physiotherapy requirements" of the medical staff, provide an enjoyable experience to the patients, and overcome the technical limitations of the game systems that support their execution. The cultural gap and the difference of vocabulary between medical staff and software designers makes the collection of physiotherapy requirements more prone to errors due to misunderstandings. Furthermore, existing requirements modeling techniques are not expressive enough to represent concepts that pertain to physiotherapy, such as movements and their impact on other requirements, aids (i.e., additional medical devices, such as decubitus cushions) necessary to help the patients to play, and controllers (i.e., the capabilities of the adopted game systems in detecting movements). Developed games must be able to signal wrong movements for physiotherapeutic purposes, but, at the same time, must tolerate small deviations to avoid unnecessary corrections.

This paper presents RE-FIT (Requirements Engineering For physIoTherapy), a novel methodology for eliciting and modeling the requirements of motion-based games used in physiotherapy. This methodology is the result of three years of experience on the field, in collaboration with the Spinal Unit of Niguarda Hospital and the Respiratory Medicine Section of Policlinico in Milan[5]. The elicitation process combines ad-hoc surveys, brainstorming, and direct observation. Surveys are the main technique through which the requirements of the game are identified. Brainstorming helps patients and medical staff understanding the questions that will be proposed in the survey. Direct observation allows software designers to visualize "on-the-field" how patients should perform the correct movements.

The requirements modeling process re-uses the FLAGS [8] goal model that expresses requirements as fuzzy temporal properties. This helped us developing

[5] A set of videos showing the validation of developed games with real patients can be found at `http://www.dista.uninsubria.it/~paola.spoletini/REFIT.html`.

games that tolerate small deviations of the movements performed by the patients with respect to the correct ones. FLAGS was also extended to represent physiotherapy requirements, movements, aids, and controllers as first class entities during the requirements modeling phases. RE-FIT was successfully employed to evaluate and adapt a set of new games for patients affected by different spinal cord injuries. These games detect the correctness of the movements and provide an enjoyable experience to the patient. Finally, RE-FIT was also adopted to evaluate the degree of adequacy of existing games with respect to people affected by cystic fibrosis.

The reminder of the paper is organized as follows. Section 2 summarizes the research objectives, the evaluation technique, and the lessons learned from our experience in developing motion-based game for physiotherapy. Section 3 presents the RE-FIT methodology and Section 4 exemplifies it through a case study. Finally, Section 5 describes related work and Section 6 concludes the paper.

2 Our Preliminary Experience with Motion-Based Games

The overall objective of our research is to identify a requirements elicitation and modeling technique that is suitable to develop motion-based games for physiotherapy. This objective can be achieved by answering the following research questions:

- **RQ1:** What is a suitable requirements elicitation technique that can be adopted for stakeholders (physiotherapists, patients, software engineers) with different backgrounds and a partial view of the problem?
- **RQ2:** How to speedup the requirements elicitation process and avoid misunderstandings among stakeholders?
- **RQ3:** How to model requirements that represent concepts that pertain to physiotherapy, such as movements or aids?
- **RQ4:** How to provide a intuitive requirement model that can be understood by people who are not software engineers?
- **RQ5:** How to formalize requirements that can tolerate small violations?

To answer these questions, in our initial collaboration with Niguarda Hospital in Milan, we investigated different ad-hoc methodologies to develop motion-based games for physiotherapy. In particular, we considered the feasibility and effectiveness of different requirements elicitation techniques, such as interviews, brainstorming, scenarios, prototypes, direct observation, and joint application development. We also evaluated the expressiveness of existing goal models in representing physiotherapy requirements. We collected the data necessary for our evaluation by developing simple games based on striking a specific target (e.g., shooting gallery, drums) or avoiding obstacles (e.g., airplane and water craft games). Developed games targeted patients affected by spinal cord injuries at different cord segments. We assumed that patients have full motor functions of hands and different levels of control of their bust. Different teams of students from Politecnico di Milano (software designers) were trained for the particular pathology, through tutorials, brainstorming sessions, and interviews. All the training sessions were hosted by a doctor/physiotherapist and supervised by a requirements engineer. Each team of students developed a motion-based game without using any systematic methodology for eliciting and modeling the requirements. The motion-based games were tested with real patients, who were interviewed to collect their impressions.

However, the lack of a systematic requirements elicitation and modeling methodology caused delays in the final realization of the games. We also observed several mismatches between the expectations of the medical staff and the game prototype and this required to modify the prototype several times before its final release. Furthermore, the time to release the game prototype was completely dependent on the availability of the medical staff that had to spend a considerable amount of time to interact with software designers to explain the problems related to the considered pathology. The time to release of the game was also influenced by the background knowledge of software designers on the considered pathology.

For these reasons, after this experience, in the last year, we investigated the development of a general methodology to engineer requirements in physiotherapy (RE-FIT). To achieve this aim, we focused also on a different pathology, such as cystic fibrosis, and extended our collaboration with the Respiratory Medicine Section of Policlinico in Milan. During this experience we learned the following lessons.

Language matters. Building a common vocabulary between medical staff and software engineers is fundamental, as these actors need to understand each other. This is challenging because doctors and physiotherapists think about games as a close reproduction of the physiotherapy programs and make the assumption that software designers have the background to understand the pathology. For example, when discussing about cystic fibrosis, they made the assumption that software designers knew about the possibility of infections, and, indeed, they did not clearly specify that playing in teams of patients should be forbidden in most of the cases. On the other hand, the medical staff often ignores technical features, such as the characteristics of developed games or the underlying sensors necessary to monitor the movements. This may be problematic for the software developers who need to associate physiotherapeutic movements with those that are permitted in the game.

Games must still be safe. Motion-based games for physiotherapy do not only require a direct mapping between physical movements prescribed in the physiotherapy program and game actions. They must also avoid situations when patients perform movements that can be harmful for their health. For example, for the watercraft game, the speed of the canoe movement should be carefully tuned to avoid the patients to incline their bust more than a maximum permitted angle.

Let them talk. Physiotherapists and doctors provide a clearer explanation of the pathology and the rehabilitation program when they are not interrupted.

For this reason, interview is not the best elicitation technique at the beginning of requirements elicitation, when medical staff and software engineers have still not built a common vocabulary and a high degree of interaction is required. Conversely, we deem ad-hoc surveys more appropriate for requirements elicitation, after an initial brainstorming session, since the medical staff can answer questions independently, without being interrupted.

Avoid Training. Training is expensive, time consuming and the experience can be hardly transmitted to new engineers when the trained ones leave.

Understandable requirements are worth it. Modeled requirements must be reviewed and validated iteratively by medical staff. To accelerate this phase, doctors and physiotherapists must easily recognize from the proposed requirements model the elements that pertain to the physiotherapy program, such as movements, aids and controllers.

Re-use it before you lose it. The effort employed for the development of motion-based games must not be wasted. The elements of the requirements model that can be re-used to develop games for other pathologies must be recognized. This would ultimately allow software engineers to build a library of patterns of physiotherapy requirements that can be reused in the elicitation and modeling of requirements for new/different motion-based games or to evaluate the adequacy of existing motion-based games to patients affected by a specific pathology.

3 The RE-FIT Methodology

Figure 1 represents the steps of the RE-FIT methodology to elicit and model the requirements of motion-based games in physiotherapy.

Requirements elicitation is performed through steps 1-3 and leverages two ad-hoc surveys (one for the medical staff and the other one for the patients). In order to model the requirements of the game, software designers use the answers collected through the surveys. Note that surveys are independent from the considered pathology and the kind of game to be designed. Before filling the survey, a brainstorming phase on the survey (step 1) must be performed by software designers and medical staff. On the one hand, this phase allows software designers to explain the questions to the medical staff. On the other hand, it allows the medical staff (mainly physiotherapists) to express their expectation and doubts. The brainstorming also helps building a common vocabulary between medical staff and software designers, and can reduce the time required to understand the answers and identify the requirements. A brief brainstorming is also performed by software designers and patients, even if, in this case, the vocabulary is not necessarily different.

In step 2, the medical staff and the patients fill two different surveys (one each), which differ for the language adopted in their questions. Then, the software designers re-elaborate the main objectives and operations involved in the physiotherapy programs, and recognize the patients' expectations from the game. In case software designers cannot associate a movement described in the answers given in the survey with the corresponding physical movement to be performed by the patient, the direct observation "on-the-field" is necessary (step 3). In this step, software designers observe the patients performing the movements indicated in the survey, under the supervision of a physiotherapist. This phase helps software designers understanding how a specific movement is executed and its possible negative side effects. Since the observation is limited to a subset of movements of the physiotherapy program, this step is not particularly time consuming.

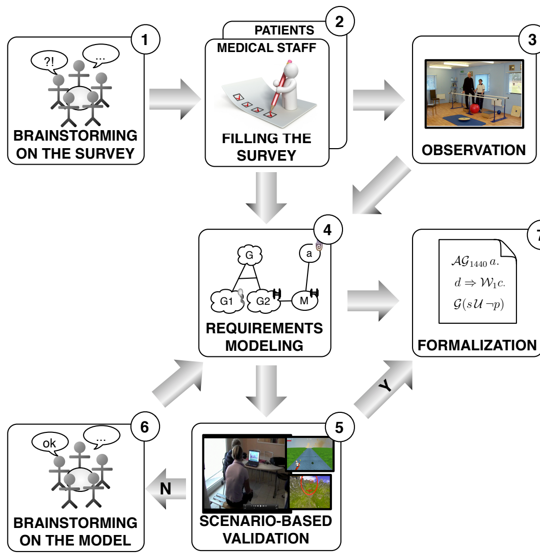

Fig. 1. The RE-FIT methodology.

Requirements modeling and validation is performed through steps 4-7. The requirements collected in the first three steps are represented through an extended FLAGS model (step 4). FLAGS provide fuzzy goals that are necessary to add flexibility to the evaluation of the correctness and speed of movements. The FLAGS model is extended to distinguish the concepts that pertain to physiotherapy (physiotherapy requirements, movements, aids) and those associated with the game system (controllers). In this way, the model is more intuitive to physiotherapists and doctors that can easily identify the elements related to the physiotherapy program. In case software designers consider the requirements model appropriate (e.g., because it reuses already validated models), they can start to formalize some of its elements (goals, operations, controllers, aids) and then start the implementation. Otherwise, the requirements model must be validated "on-the-field" by patients and physiotherapists, who provide suggestions on mockups (e.g., screenshots, images, examples, prototypes) of the game (step 5). In case the medical staff does not agree on certain parts of the mockup, a brainstorming on the goal model must be performed (step 7). In this activity, software designers review (together with the medical staff) the parts of the requirements model that have been criticized during the previous step, and the model can be updated accordingly.

The rest of the section describes the ad-hoc surveys adopted and the extended FLAGS meta-model.

3.1 Ad-hoc Surveys

As described above, the proposed elicitation technique leverages ad-hoc surveys[6] that include a set of open and multiple answer questions. The choice of the survey allows the medical staff to present the physiotherapy program without time constraints and interruptions. These surveys are the result of our experience in working with different medical departments and have been developed by a joint team of software designers and physiotherapists. In particular, we designed two types of surveys. The first one is adopted to collect physiotherapy requirements and must be filled by the medical staff. The second type of survey identifies the features that the game must provide to offer an enjoyable experience to its players, and, for this reason, it must be filled by the patients. The design of the surveys was not an easy task, since they must be complete to cover all the aspects of the physiotherapy program and the game. Furthermore, surveys should be not too long or detailed to maximize the probability to be filled in all their parts.

Before coming up with a final version of the surveys, a three months iterative review process was necessary. The surveys were validated and refined around 20 times in collaboration respectively with the medical staff having expertise on different pathologies and with patients having various age, sex, and pathology level. The validation of surveys was performed both by discussing the questions or by evaluating the degree or appropriateness of each answers with respect to its question. In addition, sample surveys have also been provided online to receive further feedback from a larger potential audience. Our surveys are independent from a specific kind of pathology, doctor's/physiotherapist's expertise, and patients' profile, and leverage a simple language that can be understood by different stakeholders. Moreover, since surveys can be re-used to develop different games, software designers do not have to attend long training sessions to acquire the medical vocabulary, as a brainstorming phase can be satisfactory.

The surveys are structured in several parts. The first part identifies the survey recipient and his/her main goals (including their priority). Sample of questions are: *"Who are you? (doctor, physiotherapist or patient)?"* or *"What are the main objectives that the game should satisfy? (List them from the most to the less important)"*. The second part is only present in the survey for the medical staff. It poses questions regarding the considered pathology and the caused physical limitations. This is also necessary to identify the additional aids needed by the patients affected by the target pathology. Samples of questions are: *"Should the*

[6] The surveys for the medical staff and the patients are available at `www.dista.uninsubria.it/~paola.spoletini/REFIT.html`.

game target patients belonging to a specific age group?"; *"Can patients with eyesight limitations use the game?"*; *"Does the patient need to use any aid to play (e.g., decubitus cushion, wrist weights)?"*. The third part contains questions regarding the environment in which the game should be performed and the type of required assistance. Note that in this case the medical staff and the patients can give contradictory answers to these questions. For example, this can happen when the doctors prefer to supervise the game in the hospital, while the patients want to have the freedom to play from home. Samples of questions are: *"In which environment the game should be played?"*, or *"Is it necessary that the patient is assisted/controlled during the use of the game? If so, indicate the minimum level of expertise required for the assistance."*.

The fourth part of the survey has questions that help identifying the required and forbidden movements that the patients must perform. Some of the questions in this part are included in all the surveys. Examples are: *"Which part of the body would you prefer to be exercised during the game?"*, or *"Which kind of movements would you prefer to be performed during the game?"*. While, more specific technical questions are only available on the survey for the medical staff. Examples are: *"For each movement listed at question 15, indicate which patient's parameters must be measured to detect the intensity/precision of the movement? (Examples can be speed and direction of the exercised parts of the body)."*

The fifth part includes questions necessary to understand the entertainment objectives that the game must achieve. In the survey for the patient, sample questions are: *"Would you like to play in team?"*, or *"Would you find interesting to visualize the score obtained by other players?"*. While, in the survey for the medical staff, questions are targeted to assess whether certain entertainment objectives should be forbidden. Sample questions are: *"Would you deem beneficial for the patients to play in team?"* or *"Is there any game configuration parameter that must only be tuned by doctors/physiotherapists (e.g., difficulty level, game duration)?"*.

The sixth part aims to understand which data can be stored for further use and how they can be manipulated. Sample of questions are: *"Which data do you want to be stored?"*, or *"Would you like the game to show statics about the overall scores of other patients?"*. Additional questions are also included to understand what can be the privacy concerns of the medical staff/patients regarding the data to disclose. Examples are: *"What are the privacy concerns regarding the data stored by the game? Which information do you want to disclose?"*.

3.2 The Extended FLAGS Meta-Model

As described above, identified requirements are represented through a goal model. Goals provide a very intuitive representation of the system, as they decompose high level goals into sub-goals, until a specific requirement of the system is identified. Furthermore, representing goals at different levels of abstraction makes easier to re-use its parts when similar requirements are common in different games and pathologies. We chose the FLAGS goal model that formalizes requirements in terms of fuzzy temporal propositions. This allows us to tolerate small requirements violations (e.g., when a movement is not perfectly executed) that are not harmful to the health of the patient and partially contribute to satisfy physiotherapy requirements.

However, the current version of FLAGS is not satisfactory to represent the main concepts used in physiotherapy programs (e.g., physiotherapy requirements, movements, aids, controllers) and their relationships. In this respect, the model is not even intuitive for the medical staff that cannot easily discriminate the physiotherapy concepts from the other functional and non-functional requirements of the system. For this reason, we extended the FLAGS meta-model, as shown in in Figure 2, to make it suitable to be used in physiotherapy.

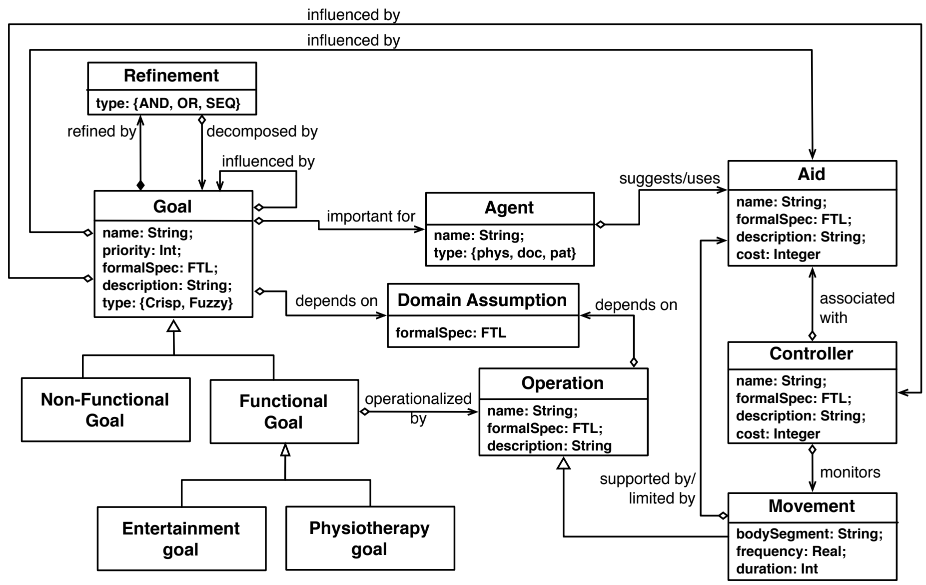

Fig. 2. The extended FLAGS meta-model.

Agents represent physical persons who express a sub-set of the goals and the requirements of the game. An agent is identified by a *name* and can be a doctor, physiotherapist or a patient (*type*). In case an agent is a doctor/physiotherapist, it can *suggest* one or more aids to support the patient during the game. While, in case an agent is a patient, it can *use* suggested aids. *Aids* represent external devices that can facilitate the movements of the patients during the game. They are identified by a *name* and have a *cost*, as they can be more or less expensive. They are also characterized by a *description* and a specification (*formalSpec*). These describe how the aid must be used during the game (informally and formally, respectively).

Physiotherapy and *entertainment goals* explicitly extend functional goals. Each goal is identified by a *name*, has a *priority*, and is characterized by an informal *description* and a specification (*formalSpec*) that formalizes the property that measures the satisfaction of the goal. Goals may also be positively or negatively *influenced by* the satisfaction of other ones. Goals can also be valid when certain *domain assumptions* hold. In physiotherapy, these express a set of conditions on the environment where the game will be used. Goals can be *refined by* sub-goals necessary for their achievement. *Refinements* not only aggregate subgoals through traditional *AND* and *OR* operators. For physiotherapy, we need to add the *SEQ* operator, to explicitly state that a goal can only be satisfied through a set of sub-goals, achieved in a specific order. This is fundamental to represent sequences of movements whose order can affect the success of the rehabilitation program of the patient. For example, if we consider a physiotherapy goal that concerns the maximization of the rotation speed of an arm. This goal will always require a warm up phase, the execution of specific movements (e.g., rotation of the chest), and a slow down phase.

Physiotherapy goals can be operationalized by *movements*. A movement extends an operation and is characterized by the part of body segment exercised (*bodySegment*), a target *frequency* and a *duration*. Each movement can be supported or even limited by an *aid* and this will also be reported in its formal and informal specification. Each *controller* (e.g., mote, board, and sensors) *monitor*s one or more movements and may be used in *association with* an aid (in case an aid is adopted). The interaction of the controller with the aid must be informally described in its *description* and formally described in its specification (*formalSpec*). Finally, the satisfaction of any goal can also be influenced by the usage of aids and controllers and this must also be stated in its description and formal specification.

The language provided in FLAGS [8, 9] to formally specify goals and operations is called FTL (Fuzzy-time Temporal Logic) and is obtained by extending the traditional linear temporal logic LTL with fuzzy constructs, embedding vagueness both at propositional and at the temporal level. The formalization of the requirements provides a detailed and mathematical formulation of the elements of the model. This specification can be used to derive part of the game logic, by combining , for example, the controller and the movement description. Moreover, using a formal specification could be very helpful at run-time [10] to monitor the current satisfaction level of goals and the correct usage of aids and controllers.

4 A Case Study

This section describes how RE-FIT can be applied to elicit and model the requirements of a water craft game aimed to improve the chest control in patients with spinal injuries in the lumbar region. We previously developed the game without applying RE-FIT. The requirements elicitation was time consuming due to several misunderstandings between software designers and the medical staff or the patients. The final prototype of the game, only partially satisfied the goals of doctors, physiotherapists, and patients. Using RE-FIT, it was necessary to perform a smaller number of iterations to validate collected requirements. This confirmed that the methodology can help software engineers to produce requirements models that better conform to the objectives of medical staff and patients.

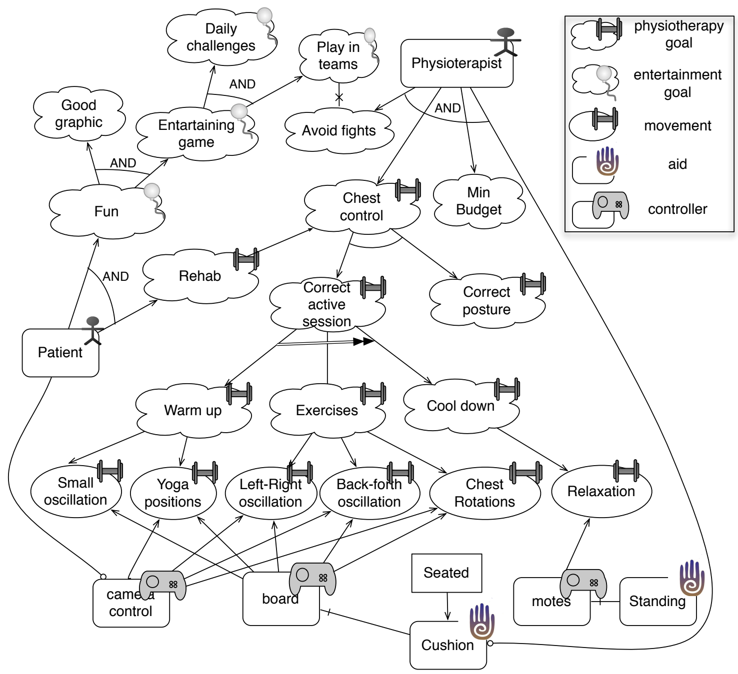

Fig. 3. A simplified version of the requirements model for the case study.

As a first step, we collected the requirements from a few physiotherapists and around ten patients affected by the pathology under analysis. A brainstorming step was not really necessary with the patients, who only needed a brief explanation of some of the questions. Physiotherapists attended two brainstorming sessions of 2-3 hours. Then, both patients and physiotherapists received their survey and completed it within one week. From the analysis of the surveys, we identified two movements that were not clear for the designers: small and normal oscillation. To understand the difference of the impact of these two movements, we observed a session in the unit gym. This observation helped the designers to better understand the characteristics of the movements that were unclear and facilitated the choice of the controller to monitor the movements. For example, small oscillations can be tiny and difficult to be observed with a camera. Hence, this movement must be measured with a board on which the patient should sit. Note that the camera controller is not appropriate in this case, even if the majority of the patients identified it as the preferred controller. The overall elicitation of physiotherapy requirements took around three weeks and was highly dependent on the availability of the medical staff.

The requirements collected in the elicitation phase are modeled by using the extended version of FLAGS. A simplified version of the model is shown in Figure 3. To make the model more intuitive, we chose different symbols to differentiate entertainment goals (small balloon), physiotherapy goals, movements (weight), controllers (joystick), and aids (hand) from the other elements of the FLAGS model. The patient aims to complete part of the physiotherapy program (*rehab*) and have *fun*. The latter is achieved by providing a *good graphical interface* and by making it *entertaining*. Note that goal *fun* and its decomposition can even be re-used across different games for different pathologies. To make the game entertaining it is necessary to provide *daily challenges* for each gameplay and by allowing the patients to *play in teams*. This goal might be in conflict with another physiotherapist's goal, that requires to *avoid fights* between patients.

The main physiotherapy goal is aimed to improve the chest control, as required by the physiotherapists, who can also have budget constraints for buying possible aids and controllers. Moreover, the physiotherapists prefer that the patients use a decubitus cushion during the game. This aid can change the capability of sensing of the board. The chest control is achieved through goals *Correct active session* and *Correct posture*. To correct active session it is necessary to achieve a sorted sequence of subgoals: *Warm-up*, *Exercise* and *Cool-down*. Each subgoal is operationalized through movements (i.e., rotations and oscillations), that may be executed using different controllers (camera control, board, motes). For example, the left oscillation movement can be formalized as

$$\mathcal{AG}(\neg(\mathcal{L}_k(left\_oscillation))).$$

The evaluation of the formula is as higher as lower is the duration of the patient left oscillation (*left_ oscillation*). In particular, temporal operator $\mathcal{AG}$ stands for almost always and evaluates a property by avoiding at most a fixed number of worse cases (i.e., where a property is minimally satisfied). A penalization will be assigned according to the number of avoided worse cases. If more worse cases are avoided, penalization will be more severe. $\mathcal{L}_t$, instead, stands for "lasts for k time units" and expresses that a property should last for k consecutive time units. In case the property does not hold from a certain time unit $n \in [0, k]$, a penalization is given depending on the difference between n and k. Notice that, we use the Zadeh's interpretation for connectives [11], since it is very intuitive and well known. In particular, we interpret $\wedge$ as the minimum value of operands, $\vee$ as the maximum value of their operands, $\neg$ as the complement of the value of its operand w.r.t. 1, and $\Rightarrow$ as the maximum between the negation of the antecedent and the consequent.

The following formula represents the behavior of the board

$$\mathcal{G}(move\_left(\alpha) \Rightarrow p\_move\_left(x)).$$

In case the patient moves the chest on the left of an angle α, then the player on the screen should move x mm to the left. This formula uses the temporal operator $\mathcal{G}$, that stands for "Always". The value of $\mathcal{G}$ at the current instant corresponds to the minimum of the values of its operand over the time.
The behavior of the board can also be influenced by the usage of the cushion, as indicated in the following

$$\mathcal{G}((move\_left(\alpha) \wedge cushion(t)) \Rightarrow p\_move\_left(x/2)).$$

In this case, the cushion reduces the movement of the player on the screen by half (i.e., the player on the screen will only move $x/2$ mm to the left).

Note that there is a mismatch between the controller suggested by the physiotherapist (board) and the one desired by patients (camera controls). All the aids and controllers influence the satisfiability level of the *Min Budget* goal, depending on their cost. However, these links are omitted in the figure for readability reasons.

The obtained goal model has also been used to evaluate the limitations of existing games in training patients with lumbar spinal injuries to better control the chest. As an example, we considered the watercraft game developed without applying RE-FIT. In this game, the patients have to control the navigation of a canoe in a river by moving their chest left and right to avoid obstacles or collect rewards, and back and forth to slow down and accelerate, respectively. The patient is sat on the board that measures the changes of weight to capture the player movements, independently on whether he/she is using a decubitus cushion. The game is single player and the bending angle of the oscillations can be customized depending on the players capabilities.

According to the model in Figure 3, the game does not completely satisfy the patients' and physiotherapists' goals. One of the main issue for patients is that the game does not include the possibility of playing with others. However, this goal is in conflicts with the one of the physiotherapist (no fights between patients), since competition in the game could be a source of tension. Alternative solutions can also be identified to satisfy the goals of both the agents, such as group navigation or meter relay. Furthermore, the water craft game does not consider a "Warm up" and a "Cool down" goals. While the "Warm-up" can partially be satisfied by incrementally increasing the difficulty of the game, the "Cool down" cannot be satisfied by using the current functionalities of the game. Finally, we can observe that the "Exercise" goal is identified and operationalized in terms of movements in the same way in both games. However, the formal description of the movements in the model must always be compared to the implementation of the movements in the game.

5 Related Work

Designing video games is an activity guided by market analyses and by the vision of the development team. In general, the direct interaction with the users, if present, is confined in the final phase of testing and validation. In [12], the video games production process is analyzed, by taking into account the emotional factors that can influence it. Similarly, Hunicke et al. ([13]) study the production process of games, trying to bridge the gap between design and development, game criticism, and technical game research. Unfortunately, none of these papers address the problems related to the elicitation of requirements of video games. Despite other approaches ([14, 15]) have focused on the impact of the user's amusement on the requirements, they only consider general purpose games and neglect games for physiotherapy.

Requirements engineering has been widely applied in the health care domain, for the elicitation of medical requirements, to validate medical processes and analyze the behavior of medical devices. For example, in [16], classical requirements elicitation techniques are adapted to take into account the political and legal issues of the health care domain. Other work ([17]) applies requirements analysis to identify new constraints that must be satisfied by the medical devices to avoid violations of the medical process. In [18], instead, usability and user acceptance issues are considered in the early system development phases. To achieve this aim, the user satisfaction is explicitly considered in the requirements model. Finally, Garde et al. ([19]) start from the assumption that communication between different health care professionals of different institutions is unusual. For this reason, they provide an evolutionary prototyping approach that constantly develops and refines the generic domain model, depending on the interactions between different health care professionals.

In physiotherapy, similarly to the generic health care domain, the domain under analysis is complex and the interaction with the stakeholders cannot be frequent. Few attempts to use video games for physiotherapy ([20, 21]) focus on their adaptation. They propose to continuously control the gameplays using a fuzzy system to avoid that patients assume wrong postures or perform wrong movements, which can be harmful for their health. However, despite this work is valuable, they did not investigated how to design motion-based games in a systematic way.

6 Conclusions

This paper introduces RE-FIT, a methodology to engineer the requirements of motion-based games for physiotherapy. This methodology is the result of a three-year collaboration with the Spinal Unit of Niguarda Hospital in Milan and a one-year collaboration with the Respiratory Medicine Section of Policlinico in Milan. Our experience allowed us to answer the research questions stated in Section 2 as follows.

- **RA1:** Requirements elicitation is mainly performed through a brainstorming session, the compilation of ad-hoc surveys and direct observation. The adoption of surveys is an effective choice as it minimized the interaction between software engineers and the medical staff.
- **RA2:** Long training sessions are avoided to speed-up the requirements elicitation. To avoid misunderstandings, requirements elicitation is conceived as

an iterative process, where requirements are constantly validated and refined through mockups and brainstorming sessions, respectively.
- **RA3-RA4:** After different interviews with the medical personel, we identified an intuitive way to embed physiotherapy requirements into existing goal models. The adoption of a goal model also allowed us to re-use the common subsets of requirements to develop games for different pathologies.
- **RA5:** We employed a fuzzy language to represent requirements that can be partially satisfied and to tolerate small violations.

We were able to assess the external validity and the reliability of our results [22]. In particular, we generalize our findings by applying our methodology on a different set of pathologies, such as spinal injuries and respiratory pathologies. Furthermore, we assess the reliability of our procedure by testing it with a different set of students and medical personel. Despite our preliminary attempts to apply RE-FIT were very successful, it is still necessary to further validate it on other pathologies. Additional experience is also necessary to consolidate the methodology and gives it more respectability. As a future work, we will also investigate the applicability of the methodology in the elicitation and modeling of requirements of other health care domains.

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