Redesign of Computer Games towards Serious Motion-Sensing Games for Children with Limited Physical Skills:
A Developer Perspective

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Abstract. The paper presents an approach from a developer perspective how to redesign computer games to ensure the children with limited physical skills the possibility to play - on the one hand for the sake of the play itself, and on the other – for using the play as a functional tool for cognitive and physical skills improvement. We present several successful steps for accessibility features support, speed and difficulty adaptation, ethics, as well as the qualitative evaluation of a prototype rehabgame by an expert control panel.

Keywords: Play for children with disabilities, Motion-sensing games, Serious games, Rehabgaming, Kinect-enabled applications, Flow model, Success factors in design.

1. Introduction

The play has a leading role in the child’s early education integrating the physical and social development of the child in an implicit way. The overall aim of the ongoing research is how to ensure the children with developmental problems or disabilities the possibility to play - on the one hand for the sake of the play itself (unstructured play) and on the other – for the sake of the play as a functional tool for improvement of their motor skills (structured play). Certain computer games can be adapted to the requirements of children with limited physical skills via introducing of computerized technologies for the recognition of movements of different body parts, for instance by using a gesture interface instead of mouse or joystick controllers. The attractiveness of such games, where motion-sensing devices allow players to interact with the system through body movements, as well as their affordability at home, will motivate
and engage the physical activity of the children with limited physical skills and can serve as a structured rehabilitative therapy.

The paper presents an innovative methodology from a developer perspective how to redesign computer games into motion-sensing serious games for children with limited physical skills. A serious game is a game designed for a specific educational purpose, rather than for pure entertainment. When it serves as a rehabilitative therapy, we call it a serious rehabgame. Rehabgaming (a blend of "rehabilitation" and "gaming") is a term defined by us for any digital structured play that combines entertainment and rehabilitative activities [2].

Motion-sensing serious rehabgames rely on computerized technology that tracks body movements or gestures and uses them to interact with the objects on the screen. In this study we use Microsoft Kinect sensor [3] - a visual-based computer technology for recognition of gestures and body movements. Kinect gives life to the computer games because it is immersive, entertaining and easy to use. Some of the studies on using Kinect test children playing existing commercial Kinect-enabled games and others test their own designed structured games [4]. The game becomes accessible by inserting body part motions tracked by a Kinect sensor. We propose an innovative methodology from a developer perspective how to redesign existing computer games that are relevant for motor, speech or social rehabilitation.

The attractiveness and effectiveness are the main dimensions in the flow theory and the key component of the flow is the rehabilitative challenge according to the disabilities of the children [8]. Based on the comparison of motion-sensing game technologies for use in physical rehabilitation [7], the considerations for the design of motion exergames (computer games that combine entertainment and exercise activity) [9] and on our own experience, we tried to identify the main success factors and adapt the flow model for the serious motion-sensing rehabgame design. By kinectifying such games we enhance the children motivation to repeat controlled movements. For instance, in solving a puzzle with gestures on the screen a child repeats and repeats the same movements until reaching the goal. The main novelty in our approach is the implicit adaptation of the speed and boundaries of the play levels of difficulty during the process of rehabgaming according to the child’s present skill.

The proposed methodology is illustrated with our rehabgame prototype called MotionSensingPinball (Fig.3.a). We have chosen a computer game Pinball from Cartoon Smart [10] because it can focus on hands balance and coordination by controlling the flippers by structured movements. This is done for neurocognitive rehabilitation of children with Cerebral Palsy (CP) or hemispatial neglect (people with deficits in the right hemisphere of the brain are not good at handling things in the left side). By analogy with the robotic training support system for neurocognitive rehabilitation proposed in [11] we prepared an experimental setup as a Kinect-enabled playful environment to assist rehabgaming and monitor the rehabilitation progress. After interfac- ing the pinball game by a Kinect sensor we take into account the controlled hand movements either in a seated mode or in a self-standing ability/position in a dry swimming pool (Fig. 1).
The movements of the child define the operational space for each hand, which can be the focus of rehabilitation [11]. A child controls the pinball on the screen by waving hands to move the flippers up and down. Thus the child feeds motion data into the game, being captured by the Kinect software for tracking the relations between the skeleton joints. For the purpose of not allowing the child to move the left flipper with the right hand in the left operational space, our Kinect application tracks the input hand motion and evaluates the hitting point of the left hand coordinates in a 3-D space with those of the left flipper (and vice versa). Fig.1.b. presents the cognitive and operational space at the successive stages of rehabilitation. If the game is played by a typically developing child (left), the reachable operational space for both hands has identical cover area. For a child with disability (center) the right hand helps the extension of the left operational space and the expected effect (right) is extension of the left reachable operational space to regenerate a balance between the right and left motions after appropriate rehabilitations.

To study how well the kinesiology of the rehabilitation is transferred to the context of Kinect motion-sensing and the quality of this technology for developing of serious rehabgames we use qualitative methods for evaluation such as observations, questionnaires and opinions similar to those in [9]. We first collected opinions as well as data from the control expert panel and typically developing children. Our next step will be to select children to participate form the Day care center in the city of Bansko according to their level of hand physical skills or hemispherical neglect. We are in a process of obtaining permissions from their parents and organization of the experimental session and training of the staff to get used to the experimental setup to perform the experiments. Our results can be followed on our website [2].

2 Related Work

A robotic training support system designed to address the difficulty in children with CP to perform motor skills in a coordinated and purposeful way is proposed for rehabilitation in [11]. The children with CP sit at the table because they often have a deficit in the self-standing ability. The target is to regenerate a balance between the right and left hand motions in rhythmic tasks. A robotic prototype with palm-sized buttons is implemented in the table device designed to exam and trace the hand
movements. In our rehabilitation program we use the authors’ findings that the hand movements stimulate the neuronal activity in the brain which extends the cognitive abilities in the visual area of the child [11]. Brief guidelines how to design such serious games are given in [4]. We adapted the flow model for motion exergames in [9] for the proposed in the paper rehabgaming methodology.

Although Kinect was not specifically designed for children with special needs, its numerous applications have proven being used effectively and can attract even the most isolated child to interact with teachers and peers. The creator of the motion-based video games for children with autism is Matteo Valorani from the Polytechnic of Milan University in 2011 [1]. Commercial Kinect games are used for rehabbing motor skills for children experiencing dynamic balance problems and physical fitness problems and since they do not need to carry a controller, they move like they are really playing the game. Kinect promotes the physical and emotional health of children by means of games and the possibility to learn new movements in a natural way at a subconscious level. One of the most mature approaches in the special education field is the one proposed by the Kinems team (http://www.kinems.com). Kinems develops innovative and highly configurable Kinect learning games based on traditional therapeutic protocols [4]. An extensive recent review of the technical and clinical impacts of the Microsoft Kinect in physical therapy and rehabilitation is given in [12].

A comparison of motion-sensing game technologies for use in physical rehabilitation - Nintendo Wii, Sony Move and Microsoft Kinect, is made in [7] involving a panel of experts. The expert panel consists of three physiotherapists who explore the strengths, weaknesses and challenges in using these three motion-sensing devices guided by two perspectives - the technical feasibility and the feasibility as an alternative to physical rehabilitation. They found the motion-sensing technology very promising but could not determine on a general basis which device is the most suitable since each patient has very different individual requirements to his therapy depending on the level of injury. The expert panel has found that most of the typical commercial games are too focused on the fun aspect, lacking in the concise direction of exercises, and having unacceptable adjustability to the level of difficulty for the individual user.

The Kinect-enabled applications for rehabilitation purposes, in our view, are relevant and appropriate for children, easy to be developed, with high sensing detection of compensation (when the patient achieves the result with wrong execution of the movement) because of the ability to see the detailed skeleton map.

3 Redesign of Computer Games towards Rehabgames - the Dual Flow Model Adapted for Rehabgaming

The Kinect sensor is a controller-free system with a depth camera. The depth camera creates a skeleton map of the player in 3-D. The simplicity of the Kinect interface to the game does not require fine motor skills and, therefore, no arm or leg calibration. In addition, the new Microsoft Kinect 2 sensor has increased tracking speed, improved arm and leg tracking ability and a simplified calibration process.
We exploit Kinect as an assistive technology and software that makes easier the interaction of children with limited physical skills with a computer or a projector screen. The proposed accessibility features allow hand or wrist motions as input, analogous to a mouse, but requiring no hand contact or touching. Body parts can be tracked/traced and the interface to the game is visible on the screen instead of by using controller devices.

In positive psychology “Flow” (also known as “Zone”) is the total engagement in an activity that a person performs and presumes full involvement and joy in the process [8]. A component of the flow theory can be used to explain why one game was not successful and what might have prevented players from entering the flow state. Two are the main success factors for implementing motion sensing games in rehabilitation – the attractiveness and the effectiveness of the game. The attractiveness of the rehabgame relates to the attractiveness of computer games. In the dual flow model concerning the exergaming system from [9], the attractiveness is the combination of two independent (orthogonal) factors – skill and challenge (Fig. 2, left). The effectiveness is the combination of two independent (orthogonal) factors – fitness and intensity [9].

We propose a dual flow model for rehabgame design (Fig. 2). We have adapted the effectiveness as the most important component of the model as the combination of two independent (orthogonal) factors – rehabilitation effect and rehabilitation compliance. We use the good accuracy of the Kinect sensor for measuring the speed, intensity, repetitions and compensations of movements together with physiotherapists’ questionnaire responses to control the compliance challenge. Using the children feedback for the immersion, goals, skills, etc., we control the game play challenge.

According to the GameFlow model in the video game domain the following 8 components have to be present: concentration, challenge, player skills, control, clear goals, feedback, immersion and social interaction [13]. The balance between challenges and skills is represented in the four quadrant balance model in left half of the model in Fig. 2. The key component of the flow is the balance between the perceived skills and perceived challenge (the activity is neither too easy nor too difficult), which we achieve by the proposed in the next section implicit adaptation.

Boredom is reached when skills surpass the challenge. Anxiety is reached when the challenge surpasses the skill level and state of apathy is reached when there is a lack of both skill and challenge. A child has to be able to focus on a narrow field of atten-
tion, which can be either different motor skills being exercised or the game played. Since the purpose of rehabgaming is body skills improvement, the attention should be focused on the input body part rather than the game. Adaptation can be made regarding the actual symptoms that need correction. For instance, in our rehabgame for children with CP a set of instructions is how to enter the ball in a funnel to reach the goal with the left hand and to get a higher score. In other cases, by using Kinect technology for the purpose of children with ASD (autistic spectrum disorder) we have to focus their attention on learning new movements in the game in a natural way at a subconscious (unattended) level.

The second half of the model – the **effectiveness** - expresses the physical balance between the rehabilitative effect and the compliance to the game (as a type of treatment). In medicine, **compliance** is the degree to which a patient follows correctly the medical advice. We refer the term mainly to the self-directed exercises and therapy sessions. A positive physician-patient relationship is the most important factor in improving compliance (teacher-child in the present model, respectively). The balance between **compliance** and **effect** (represented by similar four quadrants) shows that **rehab flow** is reached when the expected effect of the child is improved with continuing the controlled movements. When the compliance to the movement program far surpasses the effect on the child, a state of failure occurs - the child is unable to continue the movements or enters a state of compensation. A state of no benefit is reached when the child has a low difficulty level for movement and low intensity. If the effect exceeds the level of difficulty, there is a potential for entering a state of deterioration or compensation of the current state of the psycho-motor system.

4 **Operational Safety of the Play and Ethics**

We have prepared an experimental setup, which consists of a PC or laptop, Kinect sensor, playing area, projector and projector screen. Since there are spatial movements, we take into account spatial safety measures – the playing area is especially designed in the Day care centers with one option to be a dry swimming pool and another - a desk. If a child becomes angry, s/he will not break the computer or the Kinect sensor because these are far away from him. The setup will be used only in prescheduled sessions as a therapeutic means and after that will be taken away. The device can be taken at home only after clinical training and instruction. Therefore developers have to be guided by simple access to the devices and easy preparation for the game. The space requirements should be considered in day care centers, as well as at home. The therapists will often need to do a home visit to ensure proper setup and adequate space and to monitor the flow states. The need for feedback on correct exercises and progress tracking is important so wireless connection is desirable at home.

Measures how to balance the compliance and the expected effect are proposed, like assessing whether the rehabgame is attractive, not mentally overloading and guarantees that it does not make the child angry. The possibility to play with others is important from a social perspective and this has to guide the developers for multiple-player options.
The parents will sign a consent form for their child’s participation in the study. The Parent Informed Consent form will be accompanied by an information sheet containing the project’s details, and the name and the address of the responsible scientist who will sign declarations, based on ethical principles and requirements for working with children with disabilities. Medical data for the progress tracking are stored for a certain period complying with strict regulations.

5 **Personalization of the Rehabgame**

The proposed in the present paper approach to design of rehabgames involves explicit and implicit personalization. To engage the child’s attention in the game different backgrounds, music and format of the reward are used if correct movements (points, apples, speech, etc) are performed according to the child’s choice. Implicit personalization is implemented to help the child enter the flow state by balancing the compliance and the expected effect (still under development as internal algorithm of the game).

![Fig. 3. The MotionSensingPinnBall rehabgame a) explicit background personalization (left); b) implicit personalization - invisible ‘dummy’ squares (right)](image)

By monitoring the individual physical skills of the children and the progress of the hand interaction with the flippers the rehabilitation effect guides the developers in the process of deciding what to adapt implicitly in the game, like intensity, velocity of the pinball, the level of difficulty, etc. The main novelty in our approach for personalization, relevant for the physical rehabilitation, is the implicit adaptation of the boundaries of the levels of difficulty to the expected skills of the child, aiming to extend or improve the hand operational space. We put a specifically designed invisible ‘dummy’ squares defining to what extend to facilitate the achieving of the game goals.

For instance, when the kid hits the horse and the pinball enters the funnel (Fig.3. b), the child gets many score points. There is a specific ramp animation that is started when the ball hits the invisible square. Exiting the ramp in another square directed to some extend the pinball to lighten the yellow bumpers. Calculating how often the
pinball is on the ramp leads the developer what to adapt during the run. If the pinball goes often into the funnel we give a positive feedback in an explicitly chosen way and at the same time decrease the size of the invisible square defining to which extend to facilitate entering the funnel. If the new level is unreachable for the kid, the invisible area is extended implicitly a little back in order the kid to enter the flow state.

5.1 Getting started with interfacing the existing commercial Flash games with the Kinect sensor

A commercial Actionscript 3 (AS3) source code of a computer game “Actionscript 3 Pinball” from Cartoon Smart [10] is redesigned in our Lab [2]. The game was selected according to the 8 components of the GameFlow model presented above. We connected the Kinect sensor to the pinball using Kinect Native Extension for Adobe AS3 software – AIRKinect allowing light level functions that provide an abstraction layer with a generic interface to IR and RGB sensors. More information can be found on our web page [2] on how to get started with installation of Kinect drivers and application libraries for the MS SDK version of the Kinect sensor for interfacing Kinect with Flash&AS3, as well as the algorithm of changing the interface from mouse and keyboard controllers to hand gestures (kinectifying) by replacing the mouse or keyboard events with Kinect events for processing raw depth data and skeleton joints. Development and distribution of applications with Kinect Windows SDK is free. Our Kinect-enabled program uses child hands/wrists motion to interact with the pinball objects on the screen. The ball comes on the ramp after child waving the right or left hand above the head. These motions are made to initialize the skeleton map for the player(s). One of the programmed rules for the controlled movements is that the right hand is not allowed to move the left flipper. We have designed a different configuration of flippers and bumpers (fig.3.a) by tuning their number and places in order to personalize the complexity of the current scenario. The speed is adapted by changing the x and y velocity values in a BoundaryObject class.

The implicit adaptation of the boundaries of levels of difficulty is programmed as follows: when the child hits the funnel, s/he receives 500 points, while for hitting the bumper – 10 points. When s/he accumulates 5000 points, s/he gets a reward and goes to the next level with decreasing the size of the ‘dummy’ square (fig.3.b). If s/he can’t get 2500 points in the next 100 frames, the level goes back to a level in between the current and the previous implicitly and the size of ‘dummy’ squares is increased a little. The process is repeated till reaching the flow state for level 2. In this way the child receives positive feedback mainly, and the difficulty adjusts without displaying any regress in the game. The tuning of the difficulty can be made in various ways, including by training neural networks on game prehistory for the current child.

5.2 Preliminary Results and Discussion

Two typically developing children of age 7 (boy) and 10 (girl) played individually for 40 minutes with the MotionSensingPinnBall rehabgame. The children response to the game was quite positive and they were successfully engaged in the play. They said
that controlling objects on the screen by gestures is a kind of magic for them. At the beginning the boy waved with both hands chaotically, however after only 10 minutes started controlling and coordinating his movements to force the pinball into the funnel. Both children preferred the score type of reward instead of being rewarded by music, cheering etc. The rehabgame was tested by a child-psychiatrist, a speech therapist and a physical therapist forming our control panel of experts (CP). Thus we obtained a feedback in a form of interviews on the strengths, weaknesses, and challenges of the game from a technical point of view and how well the kinesiology of rehabilitation is transferred to the context of Kinect motion-sensing. CP found that the sensing quality for movement compensation of Kinect is very accurate. They liked the implicit adaptation of the speed and levels of difficulty as a success factor helping the child exit the state of boredom. CP found that the graphic design is a minor factor in rehabgaming - a fun scenario of playing by body parts is more important. CP considers a child with disabilities would prefer a kind of ovations (hand clapping) or objects running on the screen as rewards. An avatar or an animal is an option but only when it represents the child skeleton performing some exercise, for instance the child to walk with knees raised high like a stork. CP would like speech directions like “up, bottom, back, forward, in front of…” to assist them in the rehabgame. They proposed sorting games for developing strength, agility and speed after grasping (or kicking) different objects with similar colors, shapes, types or sizes and sorting objects on the left and right of the screen. CP assumes that the rehabgame can support social interaction by different competitions. They fully support the idea for home playing to strengthen the skills in compliance with a preliminary prepared safety procedure and strict therapist monitoring. CP gave several recommendations about the questionnaire prepared by us. They also propose that the application libraries for MS Kinect (SDK) to allow quantitative methods for evaluation of the adapted Dual flow model. In the future the Kinect application will measure data from the movements, such as number of repetitions, time to reach, accuracy and precision of the movements.

6 Conclusions and Future Work

Motion-sensing serious games and their implementation in physical rehabilitation have not become part of the comprehensive research yet because they require multidisciplinary collaboration of researchers and practitioners in psycho-pedagogical sciences, health and rehabilitation, humanities, enabling technologies and robotics. The paper proposes an attractive and interesting way for rehabilitating children in a form of motion-sensing serious game in which the motions of the body parts are the interface to the objects on the screen and children with motor disabilities can learn new movements at a subconscious (unattended) level. A novel implicit personalization of game parameters according to the child’s physical and perception abilities was proposed. After measuring the balance of compliance and rehabilitation effect the success factors will be further reported to guide developers in designing effective serious games for physical and cognitive rehabilitation.
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