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KINOPTIM: A Tele-rehabilitation gaming Platform for Fall Prevention in the Elderly Community

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Abstract

Objectives: As our society is ageing and the elderly face loss of autonomy due to falls, rehabilitation and fall prevention in seniors has become one of the global healthcare priorities. The proposed platform (KINOPTIM) addresses the technical challenges and demands of an integrated tele-rehabilitation system through an innovative game engine.
Approach: KINOPTIM is based on three interconnected systems: a tele-monitoring subsystem (TM), a Rehabilitation and Gaming subsystem (RG) and the Medical Business Intelligence (MBI) subsystem. TM is responsible to collect the required data and process them by a threshold detection algorithm so as to evaluate the fall risk level. RG is the core of the proposed platform bearing the primary duty of providing individually tailored fun rehabilitation/training programs. These programs are games based on balance /coordination, gait, strength and flexibility exercises, enhanced by relaxing graphics, backgrounds, sound and music. Moreover each game's score relates to user performance according to their motion during the gaming sessions. Finally, the KINOPTIM platform provides an intelligent system (MBI), able to act both as repository and as a self-learning system, assisting physicians to design more efficient rehabilitation plans.
Results & Conclusion: KINOPTIM is a tele-rehabilitation gaming platform for fall prevention in the elderly community. It embraces among others an entertaining physical training program implemented in a game format based on personalised information. Furthermore, it offers some further functionality for the cares in order to help them to plan the most appropriate rehabilitation strategy and to monitor patients' performance during games' sessions.

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1 Introduction

By 2050 the proportion of people aged 65 and older will have increased in Europe, to 25% from 14% (2010)[1] leading to significant increase of health and social costs. At the same time old age dependency ratio shows increase due to falls. According to World Health Organization (WHO), approximately 28-35% of people aged 65 and above fall each year, increasing to 32-42% for those over 70 leading to explosive social and healthcare expenditures.

In recent years, game-like virtual reality exercises have been increasingly used and may redefine falls prevention among the elderly by motivating them to be active and exercise more. They automate repetitive tasks, provide passive or active movements, i.e., without or with voluntary muscular contraction by the individual, and individualized assistance, rendering them an asset for minimizing and/or retarding ageing effects

Within this context, KINOPTIM aims at developing an innovative platform for fall prevention based on serious gaming. It proposes an entertaining physical training program based on personalised information to be performed by the elderly at home, while offering to care providers games adaptation based on elderly physical status and monitoring elderly performance when playing.

Section 1 highlights KINOPTIM's approach for fall prevention with sub-sections dedicated to general concept and gaming rehabilitation approach, and closes with KINOPTIM serious game. Preliminary results and current state are presented in Section 2, while future work and conclusions close this paper.

2 KINOPTIM Approach

2.1 Ageing Process and Falls

Age effects vary in time and from one individual to another but invariants existe.g.slowness, balance and gait disorders, resulting from physical limitations e.g.Range Of Motion (ROM) alterations of lower limbs. The elderly, when walking, have a larger hip active ROM than younger people (difference 25%) and the opposite, a low knee active ROM (difference 8%) and a low ankle active ROM (difference15 %)[2],[3].The low knee flexion decreases the quadriceps demand (Figure 1) during loading response correlating with the significantly shorter step length [4].Decrease of the ankle joint flexibility is associated with weakness of the ankle plantar and dorsiflexor muscles[5].

Figure 1: Activation of the quadriceps, ankle plantar and ankle dorsiflexor muscles when walking

Intrinsic factors are responsible for 35% of falls [6]. Lower extremity muscles' weakness and limitation in lower limb joint mobility result in impaired gait pattern [7]and are significant fall risk factors, increasing the odds of falling fourfold. A falls' history and balance deficit increase the risk threefold [8]. Falls are the sixth death cause for people over 65, the second for people between 65 and 75, and the first for people over 75 (indirect costs) [9]. One solution, to confront this flail, is to follow a life course perspective: emphasis on prevention thanks to a continuous flow of enjoyable daily activities i.e. preventive support rather than reactive care.
Regular participation in physical activities is essential for maintaining good health and independence. Recently, studies suggested that exercising with mainstream home console games, e.g. Nintendo's WII Sports, can be successfully utilized for fall prevention [10], [11], [12].

2.2 The Seniors' Serious gaming Trend and Evidences

By 2015, the worldwide market for serious games will grow by almost 50% representing 10 million Euros [13]. Although not many people associate games with seniors, research shows that seniors are a target group to consider [14] since games are becoming important for healthy ageing. Nursing homes already incorporate games as the WII balance board in their activities, despite it is not delivered for older people. Health games and game assisted therapy contribute to making care more effective and efficient.
KINOPTIM takes advantage of this trend and designs a gaming platform that helps managing fall risks by taking pro-active actions based on home played serious games.

2.3 KINOPTIM's General Concept for Fall Prevention Rationale and existing Needs

Individuals and families need to prepare for old age, and make efforts to adopt positive personal health practices throughout life [1], [15]. KINOPTIM's goals for a holistic fall prevention management are the following:

- Improve seniors' quality of life,
- Support continuing independence by providing rehabilitation and support for families,
- Support via telephone or "screen to screen" communications with family and caregivers,
- Develop culturally appropriate, population-based information and guidelines on physical activity for elderly,
- Provide accessible, pleasant and affordable opportunities to be physically active,
- Inform and educate people and professionals about the importance of staying active while growing older,
- Ensure affordable quality health care for all,
- Consider seniors opinions and preferences,
- Educate informal caregivers how to care for the elderly.

KINOPTIM platform and service

KINOPTIM infrastructure (Figure 2) has three goals:

- Strengthen elderly's lower limbs to prevent fall, through gaming platforms.
- Perform tests to assess elderly fall risk, analyzing and establishing training programs to improve balance, stability strength and flexibility.
- Make elderly adhere to the training/rehabilitation programs through gaming platforms.

For this purpose, KINOPTIM is composed of three main functionalities:

- Tele-monitoring (TM)) system;
- Rehabilitation and Gaming (RG) system;
- Medical Business Intelligence (MBI) system

This paper provides insights only to the RG System.

The RG systemprovides individually tailored entertaining rehabilitation/training programs (cognition, endurance, mobility, strength, balance or gait) according to the elderly mobility capacities based on Virtual Reality (VR). Wireless optical sensors and accelerometers for pose tracking and evaluation provide inputs to the VR game and enable the elderly to control objects or the embodied agent (avatar) in the virtual environment.

The elderly receive automatic and real time motion guidance, control and supervision by the system. The seniors' computer displays an avatar representing the person moving and provides a wireframe overlay of the desired optimal posture to reach at several stages of the motion. It helps the user see what the desired sequence of postures is and make adjustments accordingly. Feedback provided by the haptic interface guides the senior through a series of desired movements by allowing him / her to feel limbs configuration errors at all times. A physiotherapist remote-supervision via "screen to screen" communication is also possible.

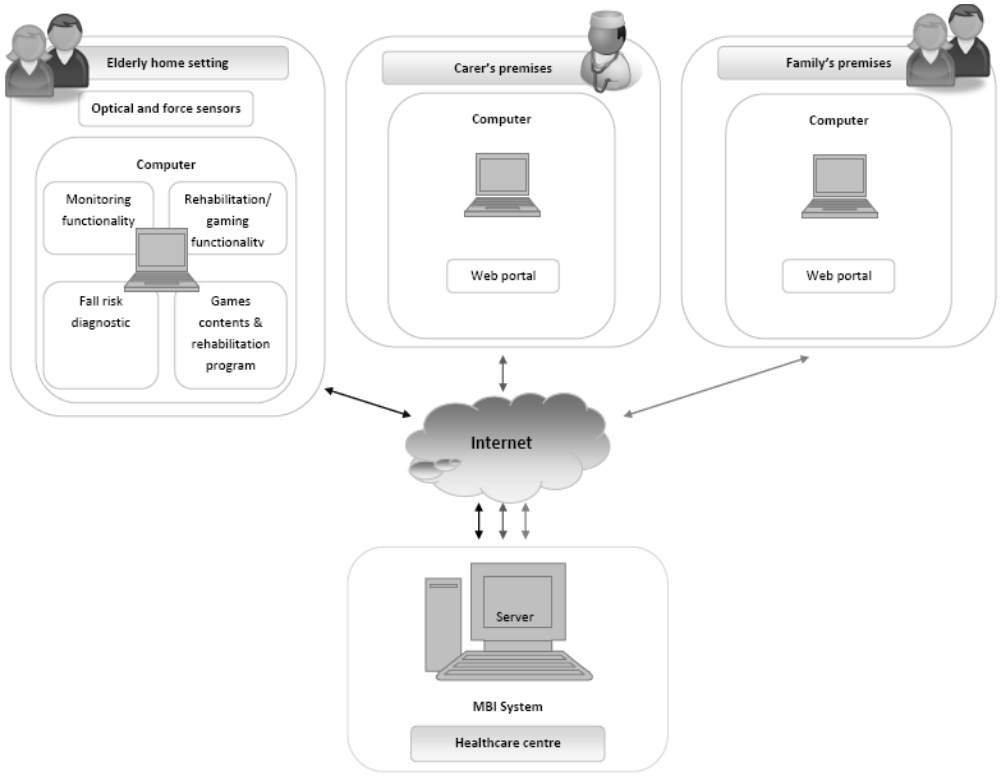

Figure 2: Final platform Architecture.

2.4 KINOPTIM Rehabilitation Approach

Evidence in preventing fall by training/rehabilitating motion capacities

According to WHO [1], access to appropriate, early and affordable actions can significantly impact health and quality of life as well as decrease the likelihood of falling. More than 60 randomized controlled trials have been published [16] investigating the exercise benefits for reducing fall risk and incidence rates in theelderly. Although the interventions varied according to exercise type, intensity, frequency and duration, the combined outcomes demonstrated a significant reduction in the risk of falling for the interventions that included exercise as a core component (13% reduction).This risk was further reduced (24% reduction) if the intervention included specific balance and gait activities [17] thus commitment to exercise should be maintained throughout lifetime.

KINOPTIM program

KINOPTIM is a home based, individually tailored training/rehabilitation program including:

- first assessment of the person.
- daily monitoring and follow-up
- games helping enforcing a person's physical capacities and skills

First assessment's objective is to establish a good working relationship, explain KINOPTIM's rationale, demonstrate equipment functionalities, record clinical history and assess factors influencing safety and adherence to the program.

Specific gait analysis determines the senior's fall risk level. After 5 minutes warm-up, at least 6 steps will be performed for evaluating:

- Mean gait speed(mean/variance);
- Chest acceleration during gait;
- Length of steps (right/left);
- Steps' width;
- Steps' regularity (variance of steps length);
- Steps' symmetry(difference between the length of left/right step);
- Elevation against the ground of left/right feet when walking;
- Chest oscillations when walking;
- Ankles flexion angles;
- Knees flexion angles;
- Time of double and simple support;
- Deviation from prescribed path.

Monitoring and follow-up of the progress is directly done at home in the form of "semi-self-management". Strength and balance tests (similar to first assessment) will be repeated periodically and progress will be assessed against the first results. The monitoring sessions allow the care giver to upgrade the program in order to match the senior's new skills by increase/ decrease number of the training sessions, repetitions/duration of the exercises and each exercise's intensity.

Balance/coordination, gait, strength and flexibility exercises are part of the program as they are the most readily modified and have great impact on fall prevention. They will be integrated in KINOPTIM's gaming module in an entertaining way to offer motivation for exercising. The exercises selected (based on fall prevention efficiency) are tabulated below:

Table 1: KINOPTIM's core exercises

Training objectives	Type of exercises	Exercises description and expected effects
Balance& coordination 	**Bending left/right legs on the side**	**Description:** 1- Stand behind a steady chair with knees slightly bend and feet flat on floor, hands on back of the chair (if necessary). 2-Keep back and shoulder straight, breathe in slowly. 3- Bend slowly left leg up on the side then put foot flat on the floor. 4- Bend slowly right leg up on the side then put foot flat on the floor. **Expected effects:** Enhancement of the lateral balance, person's awareness and reactive capability as well as better spatial orientation.
	Bending /extending legs backward	**Description:** 1- Stand behind a steady chair with knees slightly bend and feet flat on floor, hands on back of the chair. 2-Keep back and shoulder straight, breathe in slowly. 3- Bend slowly left leg in front of you then put foot flat on the floor. 4- Extend slowly backward left leg then put foot flat on the floor. 5- Do the same with other leg **Expected effects:**Enhancement of the longitudinal balance, person's awareness and reactive capability as well as better spatial orientation.
	Heel to toe walk	**Description:** 1- Adoptastanding posture with the heel of the left leg in contact with the toe of the right one 2-Start walking keeping all the time the toe of your backward leg in contact with the heel of the front leg. 2- Spread your both arm apart while walking. 3- Breathe in and out slowly **Expected effects:**Enhancement of the general balance, person's awareness and reactive capability as well as better spatial orientation..
Gait 	**Forward and backward walking**	**Description:** 1-Legs extend, back and shoulder straight, both arms spread apart. 2-Walk forward (at least 5 steps) 3-Walk backward (at least 5 steps). 4- At the same time, breathe in and out slowly. **Expected effects:**Improve muscle-activation timing, better walking abilities, better safe ambulation and maneuvers.
	Walking in place raising the knee	**Description:** 1-Stand behind a steady chair with legs extended and feet flat on floor, hands on the chair's back (if necessary). 2-Walk in place by raising as high as possible and alternatively your knees (at least 10 steps in place). 3- At the same time, breathe in and out slowly. **Expected effects:** Improve muscle-activation timing, better walking abilities, better safe ambulation and maneuvers.
	Toe Walking	**Description:** 1-Stand up tall and look ahead 2-Come up onto your toes 3-Walk 10 steps on your toes **Expected effects:** Improve muscle-activation timing, better walking abilities, better safe ambulation and maneuvers.
	Heel walking	**Description:** 1-Stand up tall and look ahead 2-Come back onto your heels, raising front foot off the floor 3-Walk 10 steps on your heel **Expected effects:** Improve muscle-activation timing, better walking abilities, better safe ambulation and maneuvers.

Strength 	**Sit to stand 1**	**Description:** 1-Sit on chair with knees bend and feet flat on floor. 2-Keep back and shoulder straight, breathe in slowly. 3-Breathe out and take support with your arms on the armrests. 4-Get up. 5-Breath while slowly seating down. **Expected effects:** improve skeletal integrity and muscular performance
	Sit to stand 2	**Description:** 1-Sit on chair with knees bend and feet flat on floor. 2-Keep back and shoulder straight, breathe in slowly. 3- Cross your arms on your chest, and breathe out. 4-Get up. 5- Breath in while slowly seating down. **Expected effects:** improve skeletal integrity and muscular performance
	Sit to stand 3	**Description:** 1-Stand behind a steady chair, hands on the chair's back. 2-Spread feet apart for balance (natural spread). 3-Breathe in when you bend your knees and go down slowly. 4- Breathe out when you stand up slowly. **Expected effects:** improve skeletal integrity and muscular performance
Joints mobility 	**Hip mobility 1**	**Description:** 1-Stand up on the chair's left side, with right hand on the chair. 2-raise right knee up at hip level 3-In this posture, open right knee laterally on the right 4- Keep back your knee in front of you and put foot on the ground. **Expected effects:**Achieving better coordination and muscle control as well as keep the person mobile and less susceptible to fall
	Hip mobility 2	**Description:** 1-Stand up on the chair's left side, with right hand on the chair. 2-raise right knee up at hip level 3-In this posture, open right knee laterally on the right 4- Keep back your knee in front of you and open it again as you were drawing some circle. 5- After 10 repetitions put foot on the floor **Expected effects:** Achieving better coordination and muscle control as well as keep the person mobile and less susceptible to fall
	Ankle mobility 1	**Description:** 1-Seat on a steady armless chair, keep feet flat on the floor. 2-Stand right leg in front of you, foot off the ground 3-Draw slowly a circle from your ankle in the clockwise direction. 4- Then in the counterclockwise direction. If your knee moves, block it with your hand. **Expected effects:** Achieving better coordination and muscle control as well as keep the person mobile and less susceptible to fall
	Ankle mobility 2	**Description:** 1-Seat on a steady armless chair, keep feet flat on the floor. 2-Stand right leg in front of you, foot off the ground 3-Write the letters of your first name and last name from the ankle in the space **Expected effects:** Achieving better coordination and muscle control as well as keep the person mobile and less susceptible to fall

3 KINOPTIM Serious Game

3.1 KINOPTIM Game Approach

The exercise's gamification process engages people and optimizes the physical activity's efficiency. KINOPTIM uses games where their mechanisms (scores, rankings, challenges, etc.) relate touser performance according to their motion during the gaming sessions (Figure 3)so objectives can be determined, just like in normal games. This approach is applied in Wii Sports, Just Dance, Guitar Hero, etc and it has completely different effects than classical rehabilitation hence more adherence is expected from the seniors to the program with finally better health outcome and less falls.

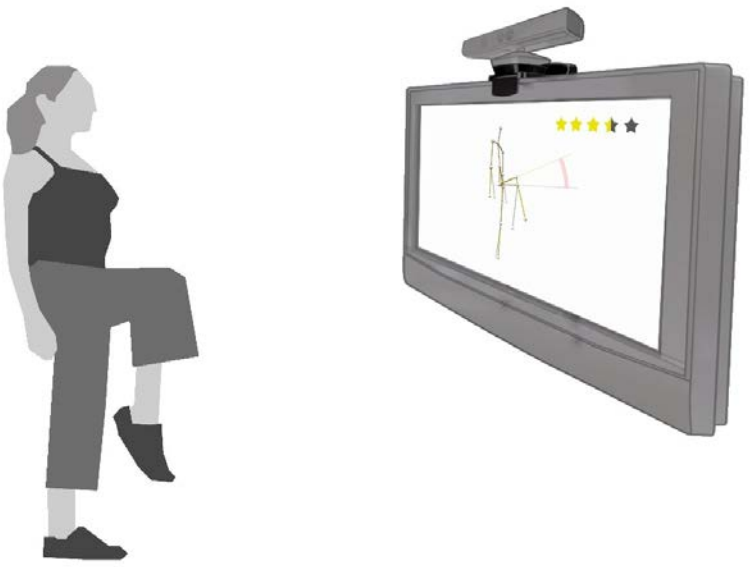

Figure 3: KINOPTIM GUI showing a posture reached by the person and the score translated in stars. The more the stars, the better the achieved posture.

KINOPTIM integrates wireless optical (depth) and accelerometers sensors to analyze body postures in time and manner during the motion. The depth/optical sensor captures depth/distance data at video frame rates by measuring the round trip time of infrared light emitted into and reflected from the scene [18].Results are shown in Figure 4.

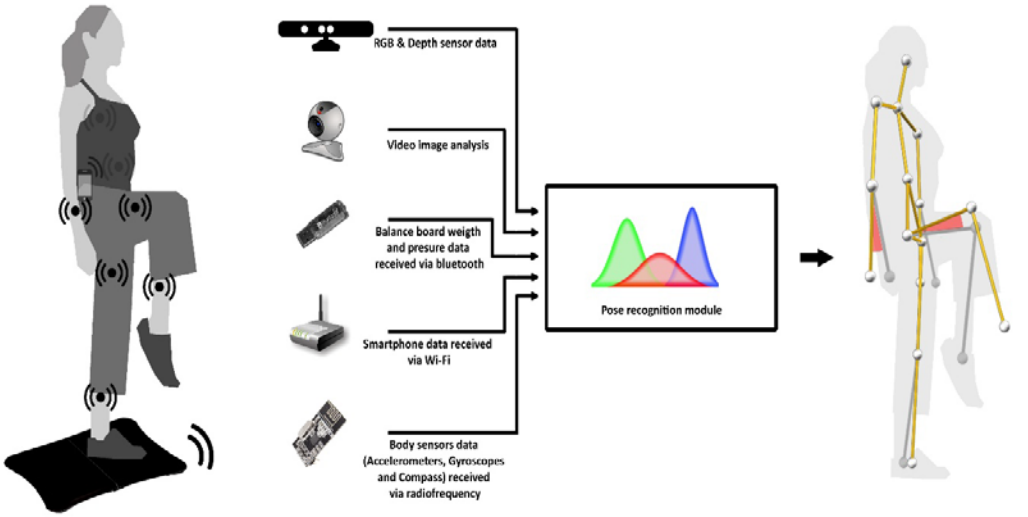

Figure 4: A snapshot of expected result for a posture of the “walking in place raising the knee” exercise. Camera data overlaid with reconstructed skeleton and KINOPTIM avatar.

A library of postures will be created within a design and game generation tool, enabling new exercises creation combining positions in an easy way.

3.2 Set of Poses and Fuzzy Logic Module

The following step is to break down the exercises selected, into static postures where the user targets his/her efforts. Each exercise is represented by a series of postures to be reached in a specific time period (Figure 5).

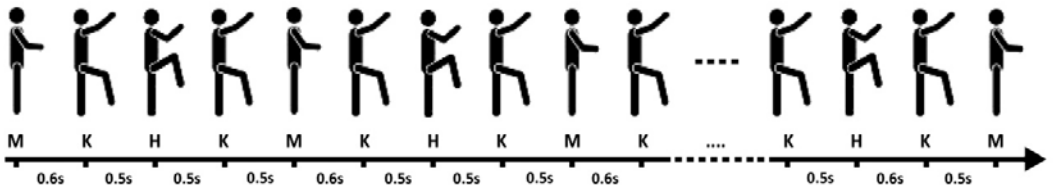

Figure 5: Succession of static postures the user has to reach within specific time for the “walking in place raising the knee” exercise.

The quality of "matching" between the positions to perform and the ones carried out by the user will be scored, and become a key aspect in the game mechanics. There are margins to allow evaluating the posture’s quality, letting the user know how well the performance has been, obtaining stars depending on the difference between the target posture and their own performance. The fuzzy logic approach and the setting of specific margins are explained here: a)the motion of a person under evaluation is subject to small variations from one session to another without decrease or increase in performance, b)a sensor’s incorrect placement or minor system errors might generate deviationsfrom the objective set, despite the user’s accurate performance. These margins will be defined basedon literature and a recognition posture module (Figure 6).

Figure 6: Specific margin (in red) for thigh elevation when raising the knee. The hip angle for the H posture should vary within this margin (120° ± 8,3°) [19] for the objective set to be validated.

The therapist may include new postures to the predefined exercises or create new exercises with their respective postures (Figure 7).

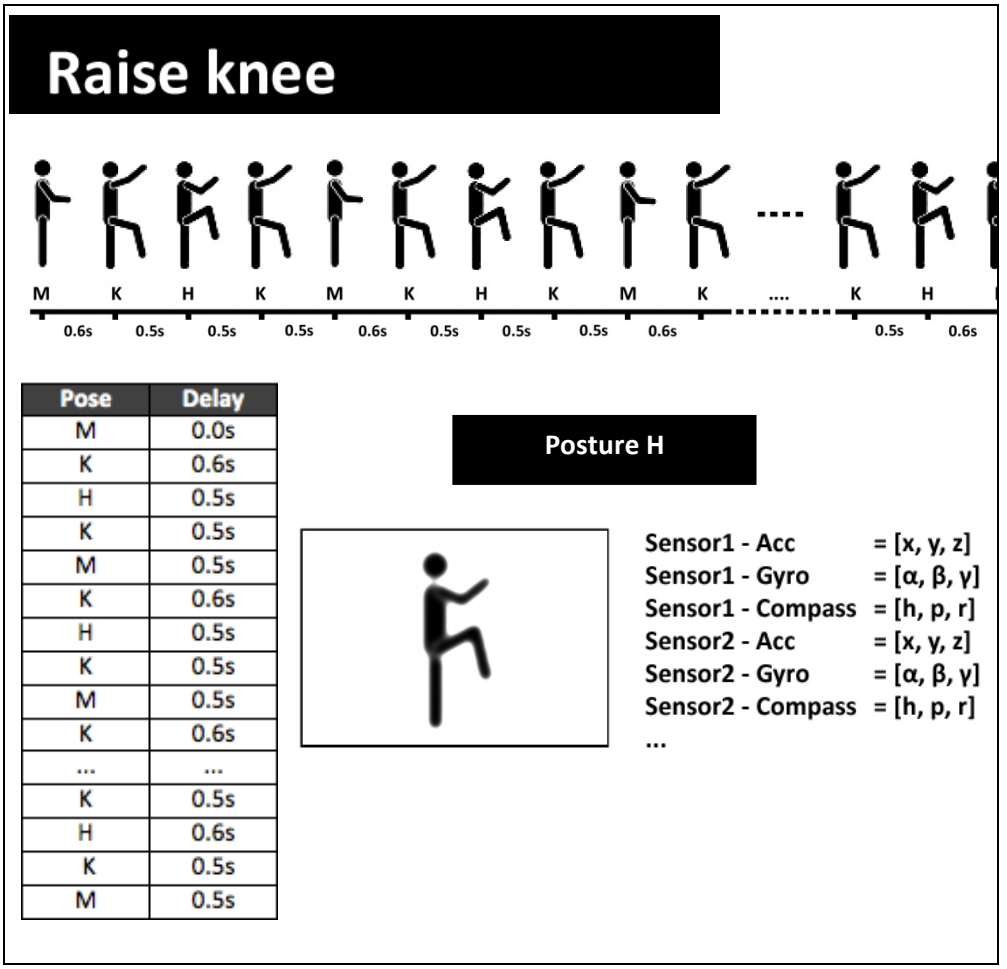

Figure 7: Posture definition

4 Future Work and Conclusions

KINOPTIM is an integrated tele-rehabilitation system delivering innovative prevention and rehabilitation management service for the elderly. It consists of an adaptive game platform enhanced by a Tele-monitoring and a Medical Intelligence System. KINOPTIM, by its elderly centric holistic approach, aims to provide more efficient rehabilitation options, not available with traditional methods.
When writing this article, KINOPTIM has completed the users' requirements and specification phase. KINOPTIM platform is designed in a way to ensure seniors' adherence to the rehabilitation program. It takes into account the elderly specificities e.g. reduced agility, vision and mental problems and it translates them into an adaptive game able to act as a relaxing and entertaining interface of a tedious rehabilitation session.
The RG module comes actually in the form of stand-alone components. The video and image processing algorithm for motion features extraction and the gaming content and mechanics are currently implemented and will be tested and further developed. Integration of the global communication platform and service based on these stand-alone components is currently ongoing.

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