www.fit4work-aal.eu

Fit4WORK

SELF-MANAGEMENT OF PHYSICAL AND MENTAL FITNESS OF OLDER WORKERS

CO-FUNDED BY

AAL PROGRAMME

The National Centre for Research and Development

GOBIERNO DE ESPAÑA · MINISTERIO DE INDUSTRIA, ENERGÍA Y TURISMO

ZonMw

UEFISCDI · EXECUTIVE AGENCY FOR HIGHER EDUCATION, RESEARCH, DEVELOPMENT AND INNOVATION FUNDING

REPUBLIC OF SLOVENIA · MINISTRY OF HIGHER EDUCATION, SCIENCE AND TECHNOLOGY

PARTNERS

PSNC

AWF · Poznan University of Physical Education

"Jožef Stefan" Institute

UNIE KBO

SGS

Teamnet · transforming technology

OSM

Physical fitness exercises

Ambient Assisted Living Joint Programme project no. AAL-2013-6-060

Deliverable 4.5.1 version 1.0

Deliverable 4.5.2 version 1.0

Lead author: Przemysław Lutomski, Poznań University of Physical Education

Co-authors: Robert Szeklicki, Poznań University of Physical Education
Tomasz Zaporowski, Poznań University of Physical Education
Aleksander Stroiński, Poznań Supercomputing and Networking Center
Jacek Walczak, Poznań Supercomputing and Networking Center
Leszek Nowak, Poznań Supercomputing and Networking Center

Published on 28th of April, 2016 (D4.5.1), 30th of October, 2017 (D4.5.2)

- European Commission
- National Centre for Research and Development, Poland
- Ministry of Industry, Energy and Tourism, Spain
- Executive Agency for Higher Education, Research Development and Innovation Funding, Romania
- Ministry of Higher Education, Science and Technology, Slovenia
- The Netherlands Organisation for Health Research and Development (ZonMW), The Netherlands

Table of contents

1. Introduction

Fit4Work aims at monitoring and improving the lifestyle of elderly workers. To do that the developed system monitors the users' physical activity, mental stress and the ambient conditions at the workplace.

Fit4Work can be summarized as follows:

- it helps to improve occupational lifestyles through providing recommendations aimed at preserving health and increasing quality of work experience,
- it supports behavioral changes through focusing attention on the particular areas causing workplace strain and through helping tackle these strain situations,
- it keeps older adults motivated and active thanks to increasing their overall quality of life,
- such solutions are not yet available on the market and present huge market opportunity.

This document aims to depict the purpose of physical fitness module in Fit4Work developments. This physical fitness module provides a set of exercises to maintain or enhance human physical capabilities according to his/her daily activities at work. Above 30 minutes, three to five days a week of aerobic activities, as a combination of series of functional exercises, provides a balance for improving strength, mobility and stability for everyday life.

It should be noted that the component described herewith was not included into the full prototype of the Fit4Work system (i.e. the minimum viable product) at the time of project implementation within the AAL Programme. It is treated as a potential extension of the system functionality in the future exploitation.

The current document contains contents related to the initial phase of the prototype development and to the final version of the component as developed within the project. The former relates to deliverable 4.5.1 and is concerned with designing the program of functional fitness training that could be monitored using the motion capture technology (this is presented in Section 2-5). This, together with the final implementation of the component as presented in Section 6, stands for the contents of deliverable 4.5.2.

2. Physical activity recommendations

The aim of using physical activity (PA) as a factor of prophylaxis, and as therapy for diseases affecting the elderly, is based mainly on effectively slowing progressive involutional changes, maintaining functional independence and ensuring optimal quality of life [Chodzko-Zajko et al. 2009].

The World Health Organization [2010], American College of Sports Medicine [2011] and European Commission [2008] recommends above 30 minutes of moderate intensity physical activity most days of the week for improvement of physical conditions in adults (cardiorespiratory, muscle, bones and functional capabilities) and reduction of depression risks and cognitive impairment.

The most effective methods of promoting PA are sought after almost all over the world. It is assumed that contemporary humans should be on average more active than just doing activities of daily living, with a value equivalent to losing at least 1000 kcal (4200 kJ) per week [MacAuley, 2000]. PA can be very moderate but should be done for at least 30–40 minutes a day, 5–7 days a week. It was shown too that health benefits might also result from the effects of occasional but intense physical activities. Thus, exercise need not be done in a continuous and organized way. A year-long study on the effects of PA showed that maintaining good levels of physical fitness in men and women could be achieved in subjects who walked 7-8 thousand steps a day and spent at least 15-20 minutes of every day performing an activity of an intensity higher than 3 MET [Aoyagi et al. 2009].

Our base criterion will be the WHO [2010] recommendations for 18-64 years old people, which are described as follow:

“For adults of this age group, physical activity includes recreational or leisure-time physical activity, transportation (e.g walking or cycling), occupational (i.e. work), household chores, play, games, sports or planned exercise, in the context of daily, family, and community activities. In order to improve cardiorespiratory and muscular fitness, bone health and reduce the risk of NCDs and depression the following are recommended:

1. Adults aged 18–64 years should do at least 150 minutes of moderate-intensity aerobic physical activity throughout the week or do at least 75 minutes of vigorous-intensity aerobic physical activity throughout the week, or an equivalent combination of moderate- and vigorous-intensity activity.
2. Aerobic activity should be performed in bouts of at least 10 minutes duration.
3. For additional health benefits, adults should increase their moderate-intensity aerobic physical activity to 300 minutes per week or engage in 150 minutes of vigorous-intensity aerobic physical activity per week, or an equivalent combination of moderate- and vigorous-intensity activity.
4. Muscle-strengthening activities should be done involving major muscle groups on 2 or more days a week.”

Physical activity can be expressed in qualitative way as an amount of energy expenditure related to physical activity (EE-PA). In experts’ recommendations 200-400 kcal of daily EE-PA (or 4 kcal per kg of weight) is enough for maintaining good health [Haskell, Montoye & Orenstein, 1985]. 200 kcal of EE-PA is the minimum level in other opinions [Pate et al., 1995].

Including above recommendations, two kind of physical activity parameters were implemented into Fit4Work:

- time - 150 minutes of moderate-intensity aerobic physical activity throughout the week, or at least 75 minutes of vigorous-intensity aerobic physical activity throughout the week,
- amount of energy expenditure related with physical activity – 200 kcal per day.

3. Health-related fitness (H-RF) and functional fitness

The aim of exercises (systematic physical activity) is improvement or maintenance of suitable level of health-related fitness (H-RF), which is related with positive health. HRF is defined as a state characterized by [Pate, 1988]:

1. An ability to perform daily activities with vigor.
2. Demonstration of traits and capacities (abilities) that are associated with low risk of premature development of hypokinetic diseases and conditions.

The typical components of H-RF are [Howley& Franks, 1997]:

- cardiorespiratory function,
- relative leanness,
- muscular strength,
- muscular endurance,
- flexibility.

Functional fitness performance is having the physiologic capacity to perform normal everyday activities safely and independently without undue fatigue [Rikli & Jones, 2001]. The typical components of functional fitness are:

- aerobic endurance,
- body composition,
- flexibility.
- motor ability (power, speed/agility, balance),
- muscular strength/endurance.

According to ACSM [2011], for most adults, an exercise program including aerobic, resistance, flexibility, and neuromotor exercise training is indispensable to improve and maintain physical fitness and health. Some individuals will want to, or need to, include only some of the health-related components of physical fitness in their training regimen or exercise less than suggested by the guidelines presented in this chapter. Performing some exercise is beneficial, especially in inactive or deconditioned individuals, and, for that reason, should be encouraged except where there are safety concerns.

Beyond the daily life activities, a regular exercise program of structured and repetitive physical activities is essential for most adults. Exercise recommendations can be satisfied by 30-45 minutes of moderate intensity exercise (five days a week). An elemental unit of a workout program may refer to a session. Sessions have three fundamental parts: (I) 10 min Warm-up, (II) 30 min of main activity and (III) 5 min of stretching. Different types of physical activities work on different health-related components of physical fitness, as summarized in Table 3.1.

Table 3.1 Types of physical activities and their effects on physical fitness

Type of Physical Activities	Effect on Physical Fitness
Aerobic Activity	Improves body composition and cardiorespiratory fitness
Muscle-strengthening Activity	Improves muscular fitness such as muscular strength and endurance
Stretching Activity	Improves flexibility such as range of motion
Neuromuscular Activity	Improves neuromuscular fitness such as balance, agility and proprioception

Aerobic endurance (cardiorespiratory fitness)

Cardiorespiratory fitness is an important aspect of quality of life for healthy individuals, as well as a risk factor for coronary heart disease. The ability to utilize oxygen during exercise is the basis for this fitness component [Howley & Franks, 1997].

Cardiorespiratory exercises at moderate intensity, which maintains the heart rate between 65–85% of the maximum heart rate, also known as aerobic exercises, refer to the use of oxygen to adequately meet energy demands during exercise via aerobic metabolism [McArdle, Katch & Katch, 2006]. Most common cardio exercises are jogging, cycling, swimming, etc.

Muscle strength and endurance

Muscle function can be classified in terms of strength or endurance. Muscle strength is the capacity of the muscle to generate force. Muscle endurance is the ability of the muscle to sustain continuous work [Howley & Franks, 1997].

Strength exercises build muscle, and even very small changes in muscle strength can make a real difference in your ability to perform everyday activities like carrying groceries, lifting a grandchild, or getting up from a chair. Some of the typical muscle strengthening exercises that target the upper and lower body are shown in Table 3.2.

Table 3.2 Typical strengthening exercises

Upper Body Exercises	Lower Body Exercises
wrist and arm curls	back leg raises
side arm raises	knee curls
elbow extensions	leg straightening exercises
chair dips	toe stands
seated rows with resistance band	

Flexibility (stretching, range of movement - ROM)

Flexibility is the ability to move a joint through the full range of motion (ROM) without discomfort or pain. Having good ROM can decrease chances of having a low-back problem [Howley& Franks, 1997]. Range of motion (ROM) exercises help to preserve flexibility and mobility of the joints involved. These exercises reduce stiffness and will prevent, or at least slow down, the freezing of joints, usual at older ages. Range of motion is the term that is used to describe the amount of movement you have at each joint. There are active and passive ROM exercises. In this project, only active exercises will be recommended since they are addressed to be performed on your own at home. Passive exercises are usually applied by a caregiver, physiotherapist or similar.

Neuromotor fitness

Neuromotor exercises, usually known as functional fitness, incorporates motor skills such as balance, coordination, gait, and agility, and proprioceptive training. Neuromotor exercise training is beneficial as part of a comprehensive exercise program for older persons, especially to improve balance, agility, muscle strength, and reduce the risk of falls [Bird et al., 2011; Martinsen, 2008].

Agility is the ability to start, stop, and move the body quickly in different directions. Balance is the ability to maintain a certain posture, or to move without falling. Coordination is the ability to do tasks integrating movements of the body and different parts of the body [Howley & Franks, 1997].

4. Functional fitness exercises

4.1. Justification for the selection of exercises

The exercises used in Fit4Work are based, among others, on those used in the Functional Mobility Screen (FMS) exercise system. FMS is a proven and tested measuring system for quickly finding the weakest link in the range of motion. Weak points will affect the body leading to disorders and limitations in the functioning of the musculoskeletal system [Perry & Koehle, 2013]. This system, due to its simplicity, versatility and possibilities, is widely used in many sports such as taekwondo [Razi, 2016], football [Schroeder et al., 2016], hockey [Parenteau-Ga, Gaudreault & Chambers, 2014] and many others. Not only athletes utilize it, but gradually, even people working in professions requiring fitness, such as policemen [Bock & Hinton, 2016]. Research does not focus only on young and training people, but also on adults who do not have much in common with physical activity [Koehle & Michael, 2016], thanks to which old injuries can also be detected. Exercises included in FMS are able to uncover, as quickly as possible, a large percentage of dysfunctions and places where they limit the body the most. E.g: deep squat explains 17% of the variance in the composite score, shoulder mobility explains 21% of the variance in the composite score [Kazman, Galecki & Lisman, 2014].

4.2. Functional fitness exercises

Functional fitness exercises are based on FMS exercises which were divided into four levels, each level further divided into four or five steps. Some steps are additionally divided for more detailed exercises. The participant should do each exercise for 10 moves, then take a break for 30 sec. They should be taken to the next step on a given level (or next level), if she/he can with ease perform exercises of the current level/step.

The proposed exercises are described below.

4.2.1. Level 1

Step 1.

1. Side step
2. Forward-backward step
3. Cat back
4. Lifting and lowering of hands
5. Head forward-backward

Step 2.

1. Side shuffle step
2. "Monster" Step
3. Cat back with stop
4. Raise your hands sideways

5. Bending head to the side

Step 3.

1. Side shuffle step with tilted knee
2. Monster step wheels turning your feet
3. Lying on your stomach and lift your hands
4. Retract and protract your shoulders (pull your shoulders back and forth)
5. Raise your shoulders up and down

Step 4.

1. Side shuffle step. Lift the knee/high knees. The pelvis parallel to the ground.
2. Step "Monster" with big wheels and a smooth transition from foot to foot
3. Lying on stomach. Lifting both arm and leg diagonally
4. Turning the wheels barge
5. Bending to the side with hands on the body

4.2.2. Level 2

Step 1.

1. Side shuffle step with high tilted knees. Upturned toes
2. "Monster" step with an entrance on one leg
3. Lying on stomach. Raise both hands / feet to up
4. Alternate lifting hands up front in standing
5. Side bends. Hands on your head. Elbows wide

Step 2.

1. Step with a high knee maintaining balance
2. Legs wide squat. Transfer weight from foot to foot
3. Lying on stomach. Raise both hands / feet up with holding down.
4. The alternate side of the elevating hands drawn back blades
5. Side bends with straight sideways hands

Step 3.

1. Step with a high knee and straightening the legs at the knee.
2. Props on his knees. Lifting alternately hands / feet
3. Pump on knees
4. Rotation of holding down

Step 4.

1. Inputs on the front step
2. Entry to the degree of sideways
3. Props on his knees. Lifting an arm and leg at the same time on a slant.
4. Bending with rotation

4.2.3. Level 3

Step 1.

1. Inputs on the front of the high degree of elevation knee
2. Descent to the side on stage
3. Supports front - plank
4. M - Pump / F pump on her knees sagging with alternate hands
5. World Greatest Stretch

Step 2.

1. Leg all the time in the desert. The second goes knee top and back
2. Leg all the time in the desert. The second goes knee to the side and back
3. Supports side - side plank
4. M - pump in a small holder / F - on her knees
5. Squat grip your ankles and torso rotation

Step 3.

1. Passage by the degree to raid forward and back to back the same route
2. Passage by the degree to raid the side and return to the same route
3. Plank on the stomach. The change we raise per second. 1 leg and change
4. M - pump with the transition from hand to hand / F - on her knees
5. Triangle of yoga on his hands farther than the legs on the front of

Step 4.

1. Foray back -> climb up knee tight up, straighten the legs at the knee
2. Side steps-> climb up knee tight up, straighten the legs at the knee
3. Plank on her belly 1 foot in the air
4. M - pump with narrow legs. Transitions from hand to hand / F - on lap 1 leg straight
5. Stretching sciatic-tibial method

6. Dynamic stretching

4.2.4. Level 4

Step 1.

1. Squats to 90 degrees.
2. Low position. Legs wide. Moving weight from foot to foot.
3. Plank sideways
4. M - Pump on 1 leg, the other in the air. / F - on lap one leg straight and raises at the time the deflection of the arms
5. Circulatory whole legs of storing legs

Step 2.

1. Like in Step 1 + On the front of the steppe
2. Like in Step 1 + On the step on the side of + entry at the step
3. Like in Step 1 + 1 hand straight up
4. M – Like in Step1 / F – Like in Step 1 + pump to 90 degrees, elbows
5. Like in Step 1 + Non-away legs

Step 3.

1. Squats above 90 degrees.
2. Squats in a wide position from foot to foot
3. Plank on his stomach, side by side
4. M - Pump Hindu. / F pump on one knee
5. Extensive kicks his legs. circular

Step 4.

1. Like in Step 3 + 1 leg on the steppe
2. Like in Step 3 + Weight on the leg on the steppe
3. Like in Step 3 + On the side of their hand up
4. M - Pump Hindu elevation hand before himself / F - Indian Pump
5. Like in Step 3 + Non-away legs

4.2.5. Level 5

Step 1.

1. Slow squats above 90 degrees.
2. Transitions from one foot to raid "skier"
3. Plank with due knees to the elbow (for a change)
4. M - Pump with due knees to the elbow. / F - the supports of the hands straight
5. Step without taking your fingers off the ground (slow)

Step 2.

1. Like in Step 1 + 1 leg on the steppe
2. Like in Step 1 + Skier on the distance

Project coordinator: Poznań Supercomputing and Networking Center, ul. Jana Pawła II 10, 61-139 Poznań, Poland, email: fit4work@fit4work-aal.eu

3. Like in Step 1 + Plank of rotation on the sides
4. Like in Step 1 + M - leg all the time up / F - supports the adding of the knee to the elbow
5. Like in Step 1 + Make their hands work

Step 3.

1. Squats with pulses
2. Skier with jump
3. Plank with moving legs to the side (rotation)
4. M - Dragon Walk with hips high / F - "pump" pulses high
5. Step out of your fingers on the ground (fast)

Step 4.

1. Like in Step 3 + 1 leg on the steppe
2. Like in Step 3 + Skier with a low jump over a distance
3. Like in Step 3 + Crossing legs sideways backwards
4. Like in Step 3 + Transfer legs sideways on hands
5. Like in Step 3 + Hands

4.2.6. Level 6

Step 1

1. Squat with bounce
2. Skier high jump
3. Plank with moving the hand back
4. M - Dragon Walk Low / K pump
5. Trot

Step 2

1. Like in Step 1 + 1 leg on the steppe
2. Like in Step 1 + Over a distance
3. Like in Step 1 + 1 leg up
4. M – Like in Step 1+ with pump / K pump with the transition from hand to hand
5. Like in Step 1 + Legs straight in front

Step 3

1. Squat with reproach hands up
2. Skier widely. The leg does not touch the ground
3. M - Dragon Walk with pump K - Pump with straightening hand in front
4. Transfer the leg side for a distance
5. Run with knees high

Step 4

1. Like in Step 3 + Over a distance
2. Like in Step 3 + Over a distance

3. M Like in Step 3 backwards / F – Like in Step 3
4. M – Like in Step 3 / F - Dragon fighting high
5. Like in Step 3 + Works only 1, second leg is straight

4.2.7. Level 7

Step 1

1. Jumping from a high elevation legs
2. Lunges - > Go to the front-> tuck jump
3. M - Dragon Walk backwards / K - Pump on 1 leg
4. Pump with rotation
5. Puppet

Step 2

1. Like in Step 2 + Over a distance
2. Lunges -> descent to plank-> back and jump
3. M – Like in Step 2 + with pump / F - Dragon Walk Low
4. Like in Step 2 + Once again with a rotation of reach-out in front
5. Like in Step 2 + Over a distance

Step 3

1. Jumping on one leg
2. Excursions. Jump with a change legs.
3. Low position. Walk into the squat
4. Pump with elevation and holding hands
5. Steppe

Step 4

1. Like in Step 3 + Over a distance
2. Like in Step 3 + Over a distance
3. Like in Step 3 + work your hands
4. Like in Step 3 + Detachment of arm and leg or jump
5. Like in Step 3 + 1 leg on the steppe

5. Physical Fitness Exercises component

From a technological point of view, the final implementation of the Physical Fitness Exercises component can be summarized by the following statements:

- Exercises were recorded using a motion capture system (Xsens) and with help of professional fitness trainer.
- Exercises are archived in the FBX open data format for 3D animation, ready to use in various frameworks, platforms and systems.
- Application uses a Unity3d engine as main technology to perform physical training for the users

Implementation details, technical issues, programming nuances, explanations and motivation about technologies and standards behind Physical Fitness Exercises module are described in the following sections.

5.1. Assumptions and requirements

The Fit4Work system was created to help improve and maintain physical fitness and keep older adults motivated and active thanks to increasing their overall physical activity. In order to meet these requirements, the Fit4Work system should recommend to the user the performance of sets of physical fitness exercises. Therefore, the Physical Fitness Exercise module should:

- contain a set of functional exercises with instructions on how to correctly perform them
- contain a mechanism to check how well the user performs the training
- provide the user with a possibility to choose type of training to adjust it to their current level of physical activity

From the user perspective the Physical Fitness Exercise module should be organized as a virtual trainer which helps them perform given exercises by showcasing how to correctly perform the training. The virtual trainer should play the role of a guide for the user to - recommending best sets of exercises and adjusting training intensity to their actual level of physical fitness.

5.2. Motion capturing of exercises

The first basic step in creating Physical Fitness Exercises module was gathering data for the exercises. It was assumed that the module will be showing instructions (in the form of a virtual trainer showing how to perform the exercise) in order for the user to achieve the best result in improving their fitness. For this purpose, it was decided to use the motion capture technique which yields the best results in mapping human movement to the virtual world, because of years of technological development resulting in many methods of motion capture (mocap) called: mechanical mocap, optical mocap, magnetic mocap, acoustic mocap and inertial trackers mocap [Xsens].

- In motion capture terminology, the human body is often considered as a system of rigid links connected by joints. Human body parts are not actually rigid structures, but they are customarily treated as such during studies of human motion. Therefore, in mechanical mocap, mechanical trackers utilize rigid or flexible goniometers which are worn by the user. In this technique, goniometers sensor can restrict movement, resulting in inadequate quality of the recording.

- Optical sensing encompasses a large and varying collection of image-based systems to determine position by using multiple cameras tracking predetermined points (markers) on the subject's body segments. The technique requires several cameras to record an exercise from each side to avoid situations where one limb is covered during complex movement.
- Magnetic motion capture systems utilize sensors placed on the body to measure the low-frequency magnetic fields generated by a transmitter source. Magnetic systems do not suffer from line of sight problems, because the human body is transparent to magnetic fields, but they are very sensitive to electromagnetic interference especially related to radio waves.
- Acoustic tracking systems use ultrasonic pulses. The time-of-flight of the pulses is used to determine where the parts of the body are. The physics of sound limit the accuracy, update rate and range of acoustic tracking systems. A clear line of sight and adequate level of silence must be maintained.
- Inertial sensors can sense angular motion as well as linear acceleration of each part of the body. Inertial tracking uses a small sensor equipped with accelerometers and gyroscope which provide the change in angle and velocity of the body part. This technique is very accurate when relatively short period of times (counting in minutes) are involved - because of noise and bias errors associated the sensors, this makes it a little bit impractical to track orientation and position for longer time periods if no compensation is applied.

During implementation of Physical Fitness Exercises module, a lot of relatively short movements (exercises like: bending, squats, or pushups) should be recorded with very high quality and accuracy. In order to achieve this, acoustic and magnetic methods were rejected due to fact that special dedicated environment free from disruptions was needed. Mechanical technique was also rejected due to the restrictions that could affect the quality of the recorded movements. Optical sensing seemed to be a good option, but it would require proper calibration and testing of the minimum number of cameras to record exercises in the appropriate quality.

Inertial systems are dedicated to record short movement and give the desired quality. The inertial technique is also easy to apply and record a large number of movements in a short period of time.

Considering the above analysis, the inertial technique for motion capture was selected. For this purpose, the Xsens system was selected. Xsens is a 3D motion tracking technology using the inertial technique of sensing. The system enables seamless interaction between the physical and the digital world related to the 3D character animation. The system consists of several small, easy to wear inertial sensors. Sensors are wireless, which is an important advantage when recording exercises, because there are no cables to limit movements and reduce the quality of the recording. The Xsens system probing frequency is lower than 10 µs which provides a very smooth recording.

The system configuration used to record the exercises was equipped with 17 Inertial sensors attached with special straps to the individual parts of the body. The location of the sensors and the tracked parts of the body are shown in Figure 5.1.

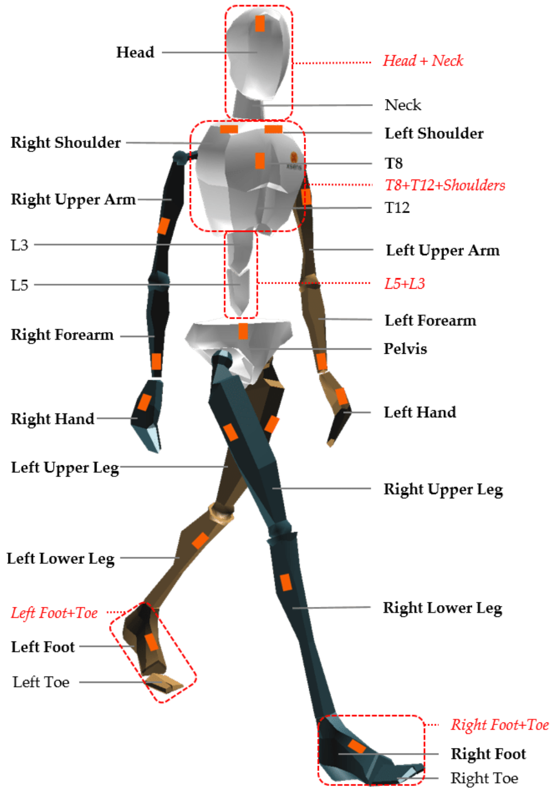

Figure 5.1 The location of the sensors and the tracked parts of the body [KinematicModel]

The Xsens system was coupled with the MotionBuilder tool to record actor's (trainer's) movements (i.e. sequences of exercises). MotionBuilder is a basic tool supporting 3D animation and process of cleaning recorded motion animation. With Motion Builder, is it possible to animate characters in an interactive 3D environment. MotionBuilder allows editing animations, modifying and adapting every aspect of the skeleton movement. It also allows automatic matching of motion animations to different skeletons, even with very different proportions which is a required feature in mapping human movements with high accuracy that is needed for Physical Fitness Exercise module.

During the retargeting process in MotionBuilder, sequences of movements of the recorded model were transferred to the digital skeleton of the actor model. The mesh of the actor, as a rigid structure, is deformed by the actor's skeleton imitating the natural deflection of the body. The imposition of movements on the model at this stage was intended to visually assess the correctness of movement modelling, to detect errors resulting in movements that are inconsistent with the anatomical model of human movements.

In the next step, each sequence has been cleared of noise and errors. The model's collisions (e. g. hand passing through thigh) and movements not needed to replicate the sequence (e. g. decomposition, downtime, etc.) were corrected manually. The final sequence of movements was exported into the FBX format to be embedded in the application.

Figures 5.2 – 5.5 present example screenshot from MotionBuilder during the recording of exercises.

Figure 5.2 The “T” pose - the starting position for every exercise

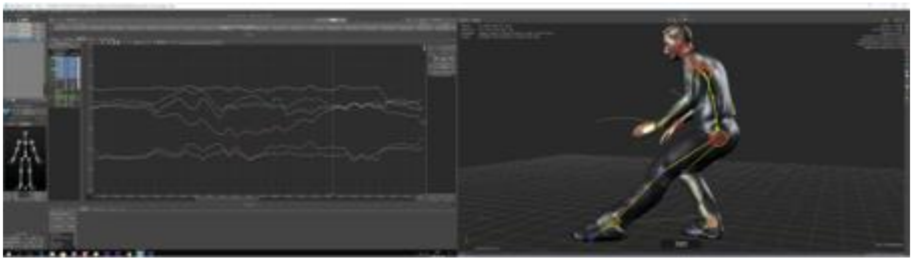

Figure 5.3 Example of recording exercise - Side shuffle step with tilted knee

Figure 5.4 Example of an advanced exercise recording - Lunges -> Go to the front-> tuck jump

Figure 5.5 Example of recording of exercise: > Lunges -> descent to plank -> back and jump

5.3. Component implementation

The final exercise movement was recorded in the FBX format, which is a format dedicated to exchanging digital 3D animation data between various systems. Originally, FBX was developed by Kaydara for MotionBuilder, later acquired by Autodesk, is now developed and documented in cooperation with Blender Foundation (independent non-profit public benefit corporation). The format supports storing all aspects of 3D animation and 3D modelling like: vertices, indices, normals, UV coords, geometry and animations transforming data. FBX has a text based (ASCII) and a binary version. Both versions have the same characteristics and are identical with each other feature-wise. Based on Blender Foundation documentation [FBXspec], the file consists of hierarchical building blocks (called nodes) as shown below:

```
NodeType: SomeProperty0a, SomeProperty0b, ... , {
 NestedNodeType1 : SomeProperty1a, ...
 NestedNodeType2 : SomeProperty2a, ... , {
 ... Sub-scope
 }
 ...
}
```

In other words, an FBX document is essentially a nested list of nodes. Each node has:

- a NodeType identifier (class name)
- properties associated with it; the properties are primitive data types: float, integer, string etc.
- a list which contains nodes in the same format (recursively).

Easy construction of the file format makes it one of the most popular formats for recording and exchanging data about 3D animation. This format was used within the mobile application responsible for managing the physical fitness exercises.

In order to develop this application, a mechanism for an animation system was needed to present recorded exercise animation in the form of a virtual trainer. The aim of this mechanism was to animate the virtual trainer using recorded animations to show to the user the best way of performing the exercises. Unity3D engine has a rich and extensive animation system, and a decision was made to use this system during development of the Physical Fitness Exercises module.

The implementation of the mobile application in question was done using Unity3D engine [Unity3D]. It is an integrated environment for creating three-dimensional application or interactive materials, based on visualizations or animations. It is a multiplatform framework supporting Microsoft Windows, OS X, and Linux operating systems and allowing to create applications for web browsers, personal computers, video game consoles and mobile devices (both Android and iOS).

The mechanism for an animation system within Unity3D is based on the concept of Animation Clips, which contain information about how certain objects should change their position, rotation, or other properties over time. Each clip can be thought of as a single linear recording. Animation Clips can be loaded into the engine using FBX. Animation Clips are then organized into a structured flowchart-like system called an Animator Controller. The Animator Controller acts as a "State Machine" which keeps track of which clip should currently be playing.

The Unity's Mecanim Animation System also has numerous special features for handling humanoid characters, which gives the ability to retarget humanoid animation from any source (e.g. apply animations recorded in external tools, like a mocap system and MotionBuilder, to a virtual trainer model). These special features are enabled by Unity's Avatar system, where humanoid characters are mapped to a common internal format.

Mecanim Animation System [AnimationSystem] provides:

- easy workflow and setup of animations.
- support for imported animation clips in FBX format.
- support for humanoid animation
- convenient preview of animation clips, transitions and interactions between them.
- management of complex interactions between animations
- animating different body parts with different logic.
- layering and masking features

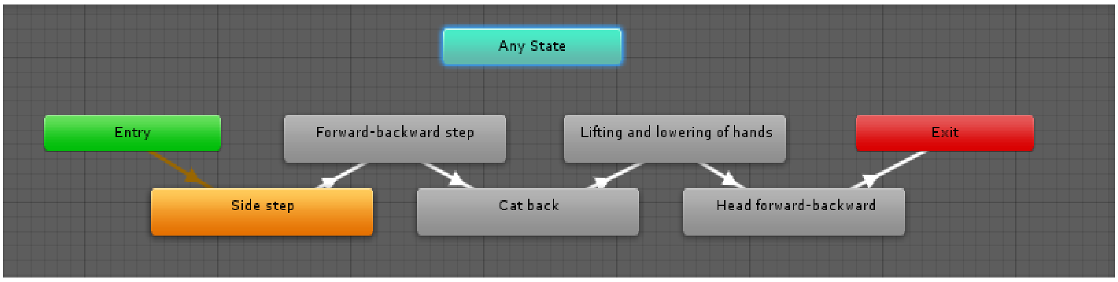

Figure 5.6 Animator Controller sequence of level 1 step 1 exercise

Adding an exercise to the application was performed as follows:

1. Animation clips are imported from an external source in FBX format.
2. Animation clips are placed and arranged in an Animator Controller. Figure 5.6 shows a view of an Animator Controller in the Animator window. The states (which may represent animations or nested sub-state machines) appear as nodes connected by lines.
3. The rigged character model (in this case, the virtual trainer) has a specific configuration of bones which are mapped to Unity's common Avatar format – see Figure 5.7.

The described workflow is used in the Physical Fitness Exercise module to animate the virtual trainer model to perform all recorded exercises. The Animator Controller state machine allows to create any set of exercises by composing it from basic FBX recordings and putting them together in a training sequence.

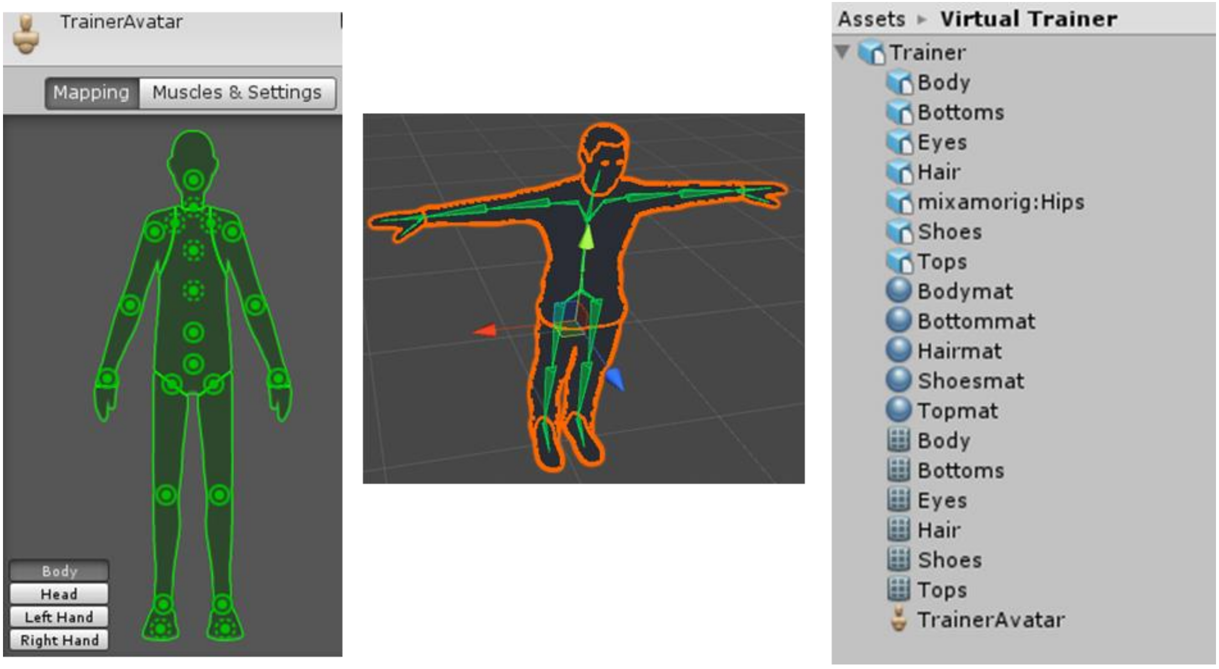

Figure 5.7 Virtual Trainer rigged with all bones mapped

Animations prepared this way are in result easily incorporated into the target end user application. In the case of the Fit4Work project this concerned an Android mobile application. This works in the form of a virtual trainer showing the given set of exercises on the screen of the smartphone (with a possibility of connecting to a larger tv screen) and leading the user through it. The application presents also a short description of currently performed exercise and allows the user to stop/pause at any time (see Figure 5.8).

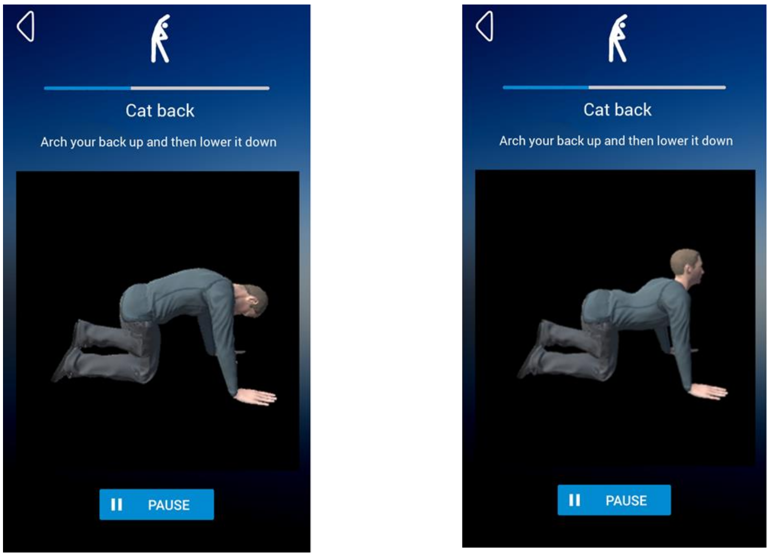

Figure 5.8 Mobile app for controling physical fitness exercise training programme

6. Bibliography

American College of Sports Medicine Recommendations (2011) Carol Ewing Garber et al., Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise, http://www.acsm.org/about-acsm/media-room/news-releases/2011/08/01/acsm-issues-new-recommendations-on-quantity-and-quality-of-exercise

Aoyagi Y., Park H., Watanabe E., Park S., Shephard R.J. (2009): Habitual physical activity and physical fitness in older Japanese adults: the Nakanojo Study. Gerontology, 55(5): 523–531

Bock C, Hinton B. (2016): Functional Movement Screen as a predictor of police recruit occupational task performance, Journal of Bodywork and Movement Therapies, 20(2): 310-315

Bird M., Hill K.D., Ball M., Hetherington S., Williams A.D. (2011). The long-term benefits of a multi-component exercise intervention to balance and mobility in healthy older adults. Arch Gerontol Geriatr, 52(2): 211-216

Chodzko-Zajko W.J., Proctor D.N., Fiatarone Singh M.A., Minson C.T., Nigg C.R., Salem G.J., Skinner J.S. (2009): *Exercise and physical activity for older adults.* Med Sci Sports Exerc, 41(7): 1510–1530.

EU Physical Activity Guidelines, Recommended Policy Actions in support of Health-Enhancing Physical Activity, October 2008, http://ec.europa.eu/sport/library/policy_documents/eu-physical-activity-guidelines-2008_en.pdf

FBX Specification – Blender Fundation, https://code.blender.org/2013/08/fbx-binary-file-format-specification/

Haskell W.I., Montoye H.J. & Orenstein D. (1985). *Physical activity and exercise to achieve health-related physical fitness components.* Public Health Reports 100 (2): 202-212

Howley E.T., Franks B.D. (1997): *Health fitness instructor's handbook.* Human Kinetics

Kazman J., Galecki J., Lisman P. (2014). Can one FMS test predict the final score?
https://www.functionalmovement.com/articles/Research/2014-05
29_can_one_fms_test_predict_the_final_score

Kinematic Model https://www.researchgate.net/figure/The-definition-of-the-23-segments-in-the-kinematic-model-of-Xsens-MVN-An-inertial_fig2_312036960

Koehle M.S., Michael S. (2016): Factor structure and internal validity of the functional movement screen in adults, Journal of Strength and Conditioning Research, 30(2): 540-546

MacAuley D. (2000): *The potential benefits of physical activity in older people*. Medicina Sportiva Polonica, 4(1): E7-E14

McArdle W.D., Katch F.I., Katch V.L. (2006). Essentials of exercise physiology. Lippincott Williams & Wilkins. p. 204. ISBN 978-0-7817-4991-6. Retrieved 13 October 2011.

Martinsen E. W. (2008). Physical activity in the prevention and treatment of anxiety and depression. Nord J Psych., 62(Suppl 47):25–29

Parenteau-Ga E., Gaudreault N., Chambers S., (2014): Functional movement screen test: A reliable screening test for young elite ice hockey players, Physical Therapy in Sports, 15: 169-175

Pate R.R. (1988) *The evolving definition of physical fitness.* Quest, 40: 174–179

PateR.R., Pratt M., Blair S.N., Haskell W.L., Macera C.A., Bouchard C., Buchner D., Ettinger W., Heath G.W., King A.C. (1995). *Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine.* Journal of the American Medical Association 273 (5): 402-407

Perry F.T., Koehle M.S., (2013): Normative Data for the Functional Movement Screen in Middle-Aged Adults, Journal of Strength and Conditioning Research, 458-62

Razi M. (2016): Normative data for the functional movement screen in healthy taekwondo athletes, Medicina Sportiva, 12(1): 2691-2697

RikliR.E., Jones C.J. (2001). Senior fitness test manual. Human Kinetics

Schroeder J. , Wellmann K. , Stein D. , Braumann KM. (2016): The Functional Movement Screen for Injury Prediction in Male Amateur Football, German Journal of Sports Medicine, 67:39-43

Unity3D engine, https://unity3d.com/

Unity3D Mecanim Animation System Documentation, https://docs.unity3d.com/Manual/AnimationOverview.html

World Health Organization (2010). Global recommendations for physical activity and health. http://www.who.int/dietphysicalactivity/factsheet_recommendations/en/

Xsens, Motion Capture System, https://www.xsens.com/fascination-motion-capture/