

Deliverable 5.2

RASim Prototype

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1.X = 1st version circulating between the members / 2.X = 2nd version following comments of members
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Acronyms:

RA: Regional Anesthesia.

Courseware: An application to maintain/track the user training scenarios and profiles and serves as primary user interface.

H3D: H3D API is an open source haptics software development platform that uses the open standards OpenGL and X3D with haptics in one unified scene graph to handle both graphics and haptics. H3D API is cross platform and haptic device independent. It enables audio integration as well as stereography on supported displays. (<http://www.h3dapi.org>)

RASim: Simulator part of the RASimAs project.

RASim As: Regional Anesthesia Simulator and Assistant.

SOFA: Simulation open framework architecture, SOFA is an Open Source framework primarily targeted at real-time simulation, with an emphasis on medical simulation. (<http://www.sofa-framework.org>)

US Images: Ultrasound images.

US Module: Ultrasound guided needle insertion simulation module providing virtual ultrasound images for needle insertion assistance.

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1 Abstract

This deliverable is focused on the development of a working prototype to be used in clinical trials (WP6). The project will require the development of 2 portable system and a development system, which will be transferred or directly integrated within the facilities of the testing institutions, and additional units to be used by the developers, the combination of hard- and software will lead to the prototype of the simulator.

This will be a four-stage process consisting of the following steps:

- (i) Hardware acquisition and modification
- (ii) Hardware and software integration
- (iii) System tests and evaluation
- (iv) Final system design.

This document (Deliverable 5.2) aims at presenting the RASim simulator Prototype document based on the reference architecture plan defined in Deliverable 2.2 (WP2) and specification Deliverable 5.1. Furthermore, the technical features / specification of software and hardware platform of the prototype for the developed in the RASimAs project are listed accordingly.

2 Introduction

2.1 Context

This report outlines the training simulator prototype for Regional Anaesthesia (RA) procedures (RASim), that will allow trainees to develop their skills and confidence in patient specific needle and ultrasonic handling for safe performance. RASim will let an increase in the effectiveness and the success rates of RA and spread the broader clinical use. As depicted in Figure 1, the work environment for the (RASim) simulator is designed to be a workbench. The mannequin (Leg model) is proposed to be placed on the work bench for user interaction. The hardware devices are connected with the RASim running on a Windows based machine (PC), and multiple views are used to display the user interaction with virtual environment.

The system consists of three components, namely the input peripheral devices interface, the output (views) interface, and the core simulation software. The input interface primarily connects the input devices, such as the haptic devices, the 3d magnetic tracker (used for ultrasound probe), the keyboard / mouse etc. The output interface is responsible for showing updated views to its users.

The output views are mainly divided in three views to be displayed on two monitors, the first is patient view that shows the virtual scene being rendered by the RASim, which includes the virtual patient and the needle. Second and third view are bundled in one package (courseware view), which shows the virtual ultrasound view produced by the ultrasound module. The courseware view further shows the trainee data and metrics being recorded such as available scenarios, profile records, and server updates (manage curriculum/training lessons, replay lessons, scoring).

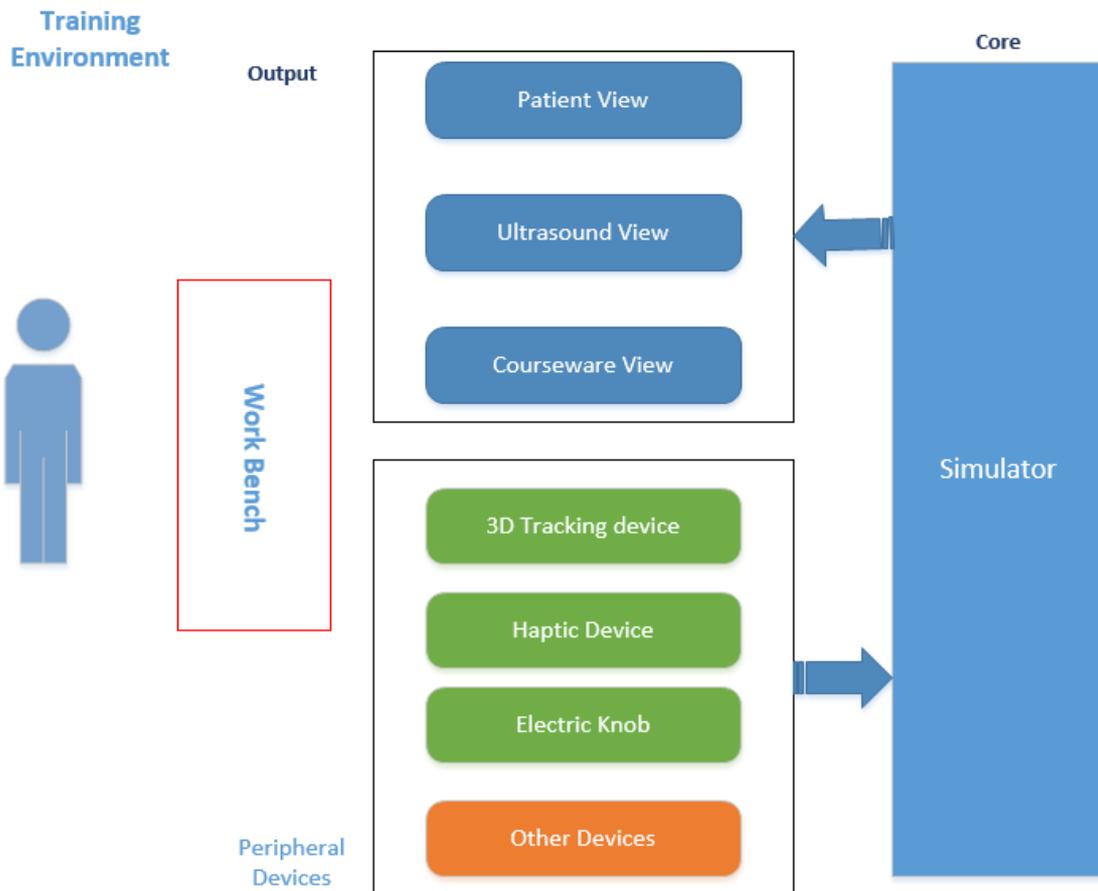


Figure 1. Simulator training workbench environment.

In the following sections, hardware specifications and integration of hardware with software is discussed in detail.

2.2 Objectives

2.2.1 Deliverable description

As stated in the Description of Work, the deliverable that constitutes this plan is described as follows:

D5.2 RASim Prototype

This deliverable is a successor of the prototype of D5.1 with extended functionality and results in three portable test systems that will be used for evaluation. Furthermore, a public report will describe those prototypes functionality in text and photos for press release and documentation.

3 Hardware Specification & Modification

This prototype will be evaluated within the project in controlled clinical studies targeting both experts and anaesthesia trainees. Before reaching the clinical trial milestone, every module of the simulator will be beta tested upon its integration with core simulator to ensure evaluation process and allowing an iterative development approach securing delivery of a validated and reliable final prototype. To fulfil the above defined task the following hardware specification are proposed for the simulator workbench:

a) Computer

The machine to host the RASim prototype is opted to be a Windows (PC) client machine (figure 2). Following are the minimum hardware and operating system requirements for the training environment:

- Windows-7 / Linux platform.
- Visual Studio x86 redistributable dependencies supported.
- Tested with GTX980 graphics card (minimum CUDA capability 3.0 required).
- Minimum Intel i5 core processor.
- 500GB, hard disk space.
- 8GB Ram.



Figure 2. Computer used in workbench for RASim simulator

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b) Base platform

A “T” shape base platform is proposed for the RASim workbench (Fig 3). The sketch has been designed with support of member clinics in RASimAs project. The positioning of the haptic device and the mannequin are relative to each other and can be moved accordingly for left and right handed operators. The platform further includes a basin in the center that can be filled with needle insertion material. A 3D magnetic tracking system (Transmitter/sensor) is placed in middle as well to track the ultrasound probe. A plain wooden plate is be used as base for placing the devices. The platform also assists as hand/arm rest support if required in future prototypes.

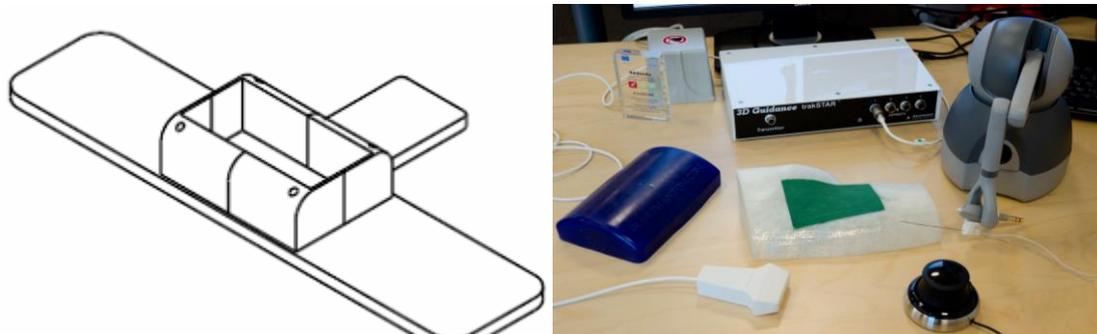


Figure 3. Base platform for RASim.

c) Mannequin/ ROI Basin

To construct the region of interest (ROI) for needle insertion which possesses the capabilities to look and feel closely as human tissue and can hold the needle in position while it's inserted, a soft basin shaped mannequin (Fig 4), is designed with a silicon layer on top surface to get more number of needle insertions in the foam. The basin is a 3D printed surface/volume/hollow representing the ROI of the anatomical model used in the simulator platform and present in the middle of T shape base.



Figure 4. Mannequin (ROI) designed for needle insertion

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d) Views (Monitor display)

To display H3D simulation/patient view and courseware/US view standard display monitors are proposed as hardware solution. These monitors hold both views showing the current rendered virtual scene and ultrasound images. Fig 5 shows the both display monitors while the simulation is running, the patient view can be seen on the left display and Ultrasound & courseware on right.

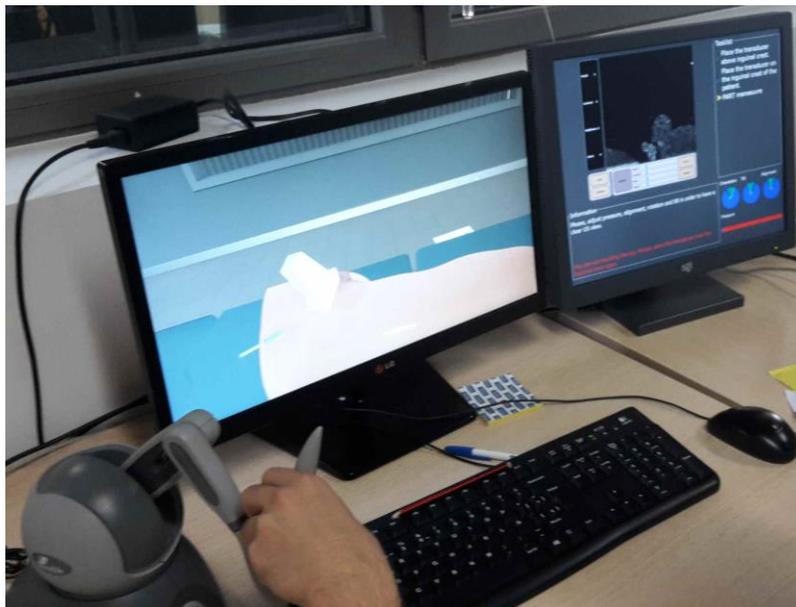


Figure 5. Dual monitors for displaying patient view (left) and courseware + ultrasound view (right).

e) Haptic Device

Real needle insertion is most commonly performed in 5 degrees of freedom (dof), whereas the haptic device only delivers force feedback in 3 degrees of Freedom (x, y, z). In RASim to simulate the needle insertions during RA procedure, a phantom haptic device together with a mannequin is designed to deliver a realistic feeling by imitating both a physical “hands-on” object and a simulated “haptics feeling”.

Initial tests for the first prototype the needle is mounted to the standard “pen/probe” of the haptics device, whereas it’s also being considered that final RASim simulator most likely is a modification of the haptics device with real needle integrated with the haptics “pen”.

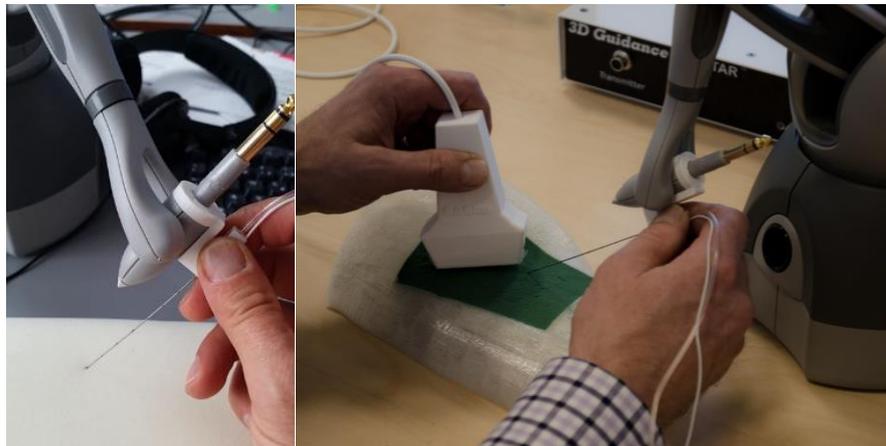


Figure 6. The needle (Braun 50 mm) is attached to the haptics pen allowing for movement in x, y, z, direction, pitch, yaw and limited rotation.

f) Ultrasound Probe

To simulate the ultrasound probe and interactions during RA procedure. A 3D printed probe with cord based position sensor integrated in the first RASim prototype design. The tracking solution from Ascension 3D-Guidance trakSTAR magnetic tracker (model 800 <http://www.ascension-tech.com/medical/trakSTAR.php>) is implemented for the ultrasound probe simulation. A positioning sensor is integrated in the probe to keep track of position and orientation.

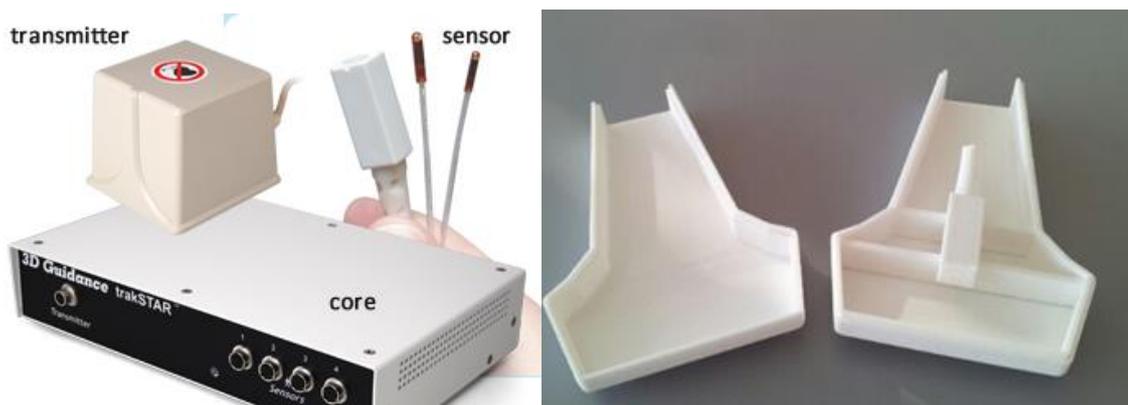


Figure 7. 3D printed US probe (right), with sensor embedding position for the Ascension tracker solution (left).

4 Hardware & Software Integration

H3D serves as core API to communicate with all software modules and hardware interface. H3D being a simulator core module in the software part is responsible for metadata exchange between all of the RASim modules. It simulates information such as scene being rendered, the tool positions, the US probe position, force feedback, and anatomical

geometries. H3D mainly collaborates with the SOFA module for soft muscular deformations, the US module for simulation of ultrasound-guided images, the courseware module for keeping track for the user metrics (profile and scenarios), and the electrical nerve stimulator module to stimulate electrical impulse-guided needle insertions. On hardware part all device interface/drivers both, input and output devices connect with H3D API to support user interactions. H3D provides haptics, 3D tracker interface, and software threads to read the device info and provide this information to desired modules.

Figure 8 sketches the hardware and software architecture integrated in simulator environment. H3D API renders the patient view courseware and US views which are updated by the relevant modules. The modules issue requests to H3D and get response with desired information.

Primarily the user interacts with the courseware module user interface to select user desired scenarios and proceeds with loading process. The H3D module loads the selected scenario (x3d scene file depicted in figure 9) in 3D simulation environment and proceeds with the initialization of the haptics force feedback and 3d magnetic tracker controls for US probe. Furthermore, It is also responsible at this stage for the data transfer to SOFA module for soft body simulations/deformations. H3D renderer (H3D Viewer) serves the main window called patient view. Whereas, SOFA works on hidden layer/thread (invisible) to perform the tool tissue interactions and soft body deformations that occur due to collision of tools with tissues.

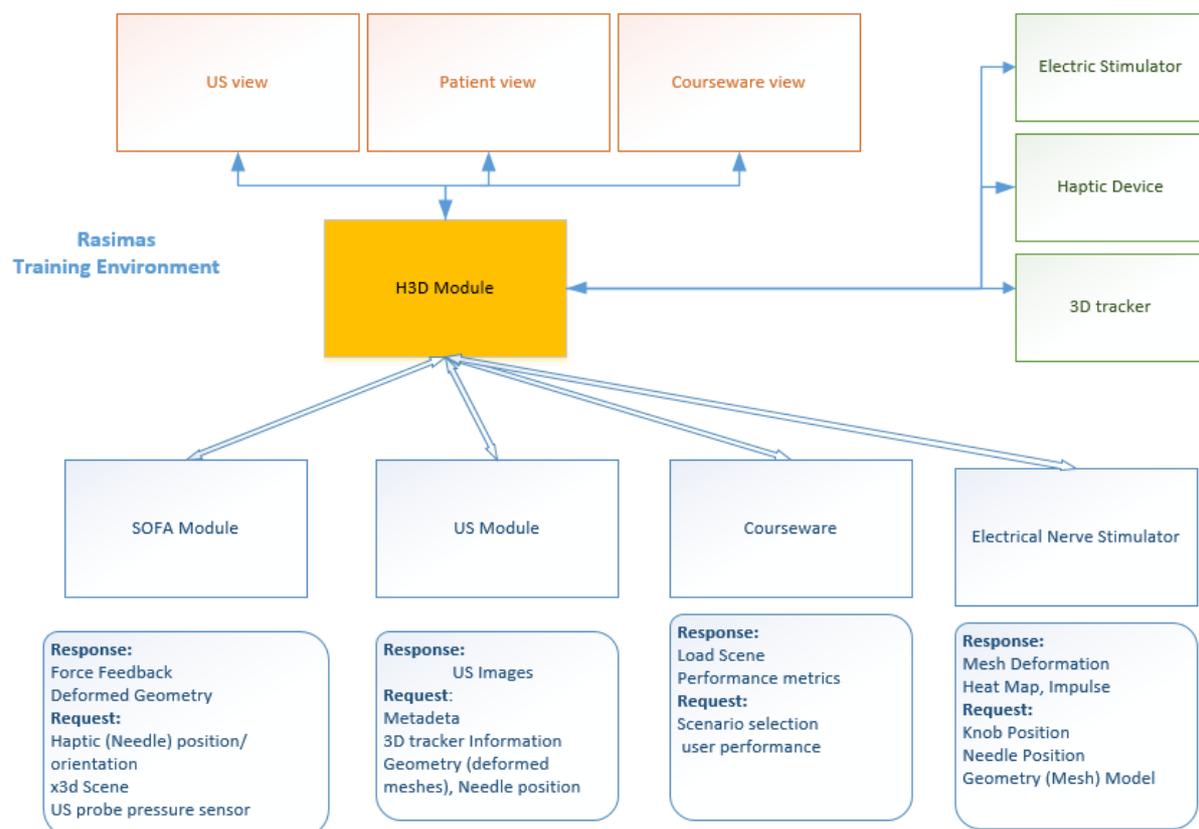


Figure 8. Hardware and software integration of RASim.

```

<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE X3D PUBLIC "ISO//Web3D//DTD X3D 3.0//EN" "http://www.web3d.org/specifications/x3d-3.0.dtd">
<X3D version="3.0" profile="Immersive" xmlns:xsd="http://www.w3.org/2001/XMLSchema-instance" xsd:noNamespaceSchemaLocation="http://www.web3d.org/specifications/
<head>
  <meta name="filename" content="RASimDemoScene.x3d" />
</head>
<Scene>
  <Viewpoint position="0.31 -0.6 2" set_bind="true">
  </Viewpoint>

  <Background DEF='gXR' groundColor='1 1 1' skyAngle='' skyColor='1 1 1' />
  <IMPORT inlineDEF='H3D_EXPORTS' exportedDEF='HDEV' AS='HDEV' />
  <Inline importMode='AUTO' traverseOn='false' DEF='LEGCOMPONENT' url='../components/r_leg.x3d' />
  <Inline importMode='AUTO' traverseOn='false' DEF='NEEDLE_TOOL' url='../tools/stimulplex_a_needle.x3d' />
  <Inline importMode='AUTO' traverseOn='false' DEF='PROBE_TOOL' url='../tools/probe.x3d' />
  <Inline importMode='AUTO' traverseOn='false' DEF='US_pointsData' url='../sofa/2-needle_insertion/data/mesh/USDeformPoints.x3d' />
  <!-- for ultrasound module -->
  <!-- <Transform translation=' -0.08 0.25 -0.01'>
  <Inline importMode='AUTO' traverseOn='true' DEF='Skin_TOOL' url='../tools/skin.x3d' />
  </Transform> -->

  <!-- Decoration Disabled for development purpose in H3D view -->

  <Transform DEF='DECORATION' translation="-0.5 -0.42 -1.14" rotation="0 0 1 -89.62" scale="0.1 0.1 0.1">
    <Inline importMode='AUTO' traverseOn='true' DEF='BED' url='../tools/or_patient_cart.x3d' />
    <Inline importMode='AUTO' traverseOn='true' DEF='ROOM' url='../tools/or_room.x3d' />
    <Transform DEF='Tray_Trans' translation="20 -3 0">
      <Inline importMode='AUTO' traverseOn='true' DEF='TRAY' url='../tools/or_tray.x3d' />
    </Transform>
    <Transform DEF='Lamp_Trans' translation="0 -3 0">
      <Inline importMode='AUTO' traverseOn='true' DEF='LAMP' url='../tools/or_lamp.x3d' />
    </Transform>
    <!-- Routes are set in the RASimAs.py SetStreamingRoutes function -->
    <USStreaming DEF='Us_streaming' offsetOrientation="1 0 0 3.1" offsetPosition="0 1.2 0.3" isActive='true' />
  </Transform>

  <SofaSimulation DEF='SIMULATION' filename='sofa/2-needle_insertion/femoralBlock2.ggg'
  enabled='false'
  sofaGUI='true'
  sofaGUIFrameRate='1'
  useThreadedAttributeGenerator='false'
  threadedAttributeUpdateInterval='0.05'
  geometryTogglesNames=''>
    <IndexedTriangleSet USE='LegModel' />
    <IndexedTriangleSet USE='NeedleModel' />
    <IndexedTriangleSet USE='ProbModel' />
    <PointSet USE='USPoints' />

    <ContactReport DEF='Needle_Contact' containerField="contactReports" modelName="ROI_contact" />

    <SofaNode DEF='LCD' name="/Needle/LCDFF" fieldNames="activate" forceConf="">

```

Figure 9. H3d scene file an xml structure defines the device info as well as simulated geometries and sofa simulation node.

SOFA (Simulation Open Framework Architecture) is an open source framework (LGPL License) in RASim running on a child thread of H3D. It is responsible for soft tissue deformations and tools interaction with geometries, and interacts with sofa simulation node defined in the H3D scene file. The SOFA library, coded in C++, contains all the main components and algorithms needed for a surgical simulation: solvers, specific physics-based models using the finite element method, collision detection, collision response, rigid and flexible instruments models.

In the RASimAs project, SOFA is responsible for tool tissue interaction and force feedback. Mainly it performs the following tasks:

- The deformation of the skin and other tissue layers, using co-rotational tetrahedral Finite Element Methods,
- The needle manipulation on the different tissue types, with skin penetration and tissue friction,
- The muscles contraction, depending on the physiological response and soft tissue properties,
- The user interactions and haptic force feedback.

Similar to the x3d scene file a SOFA scene is rendered using the H3D scene using an XML high-level code rather than C++. The entire simulation of tool tissue interaction/deformation is described in the SOFA scene file (Figure 10).

```

<?xml version="1.0" ?>
<Node name="root" gravity="0 0 0" dt="0.01">
  <RequiredPlugin name="BeamAdapter" pluginName="BeamAdapter" />
  <RequiredPlugin name="NeedlePlugin" pluginName="NeedlePlugin"/>
  <RequiredPlugin name="RASimAsPlugin" pluginName="RASimAsPlugin" />
  <RequiredPlugin name="SofaH3DBaseNodes" pluginName="SofaH3DBaseNodes.dll" />

  <VisualStyle displayFlags="hideVisual hideBehaviorModels showForceFields showInteractionForceFields showCollisionModels showWireframe" />

  <FreeMotionAnimationLoop />
  <GenericConstraintSolver tolerance="1e-5" maxIterations="5000" printLog="0"/>
  <CollisionPipelineMonitored depth="5" verbose="0" draw="0"/>
  <BruteForceDetection name="N2" />
  <LocalMinDistance name="Proximity" alarmDistance="0.001" contactDistance="0.0005" angleCone="0.0"/>
  <RuleBasedContactManager name="Response" response="disabled" rules="10 11 NewNeedleContact 1 11 FrictionContact" />
  <LCPConstraintSolver name="LCPSolver"/>

  <!-- Probe Controller Node here -->
  <Node name="ProbeControl" >
    <MechanicalObject template="Rigid" name="PDOFs" position="0 0 0 0 0 1" />
    <SofaH3DHapticsDevice deviceInfoFilename="../../../x3d/devices/HapHydra.x3d" name="Hydra" deviceIndex="1" scale="1.0" drawDevice="0" permanent="1" printLog="true"
      positionBase="0.35 -0.24 0.05" orientationBase="0.5 -0.5 -0.5 0.5"
      positionTool="0 0 0" orientationTool="0 0 1"
    />

    <Node name="PRefModel">
      <!-- <MeshObjLoader filename="../../Zigote_Models/Obj/Right_leg_scaled=0.023/probe.obj" name="ploader" /> -->
      <MeshX3DLoader filename="../../../x3d/tools/probe.x3d" loadNamedGeometries="ITS_right" name="ProbeMeshLoad" />
      <!-- <MeshTopology name="pmeshTopology" position="@ProbeMeshLoad.position" edges="@ProbeMeshLoad.edges" triangles="@ProbeMeshLoad.triangles" quads="@ProbeMeshLoad.quads" /> -->

      <Mesh src="@ProbeMeshLoad" />
      <MechanicalObject src="@ProbeMeshLoad" name="PCollisionState" />
      <RigidMapping />
    </Node>
  </Node>

  <Node name="UProbe" activated="true">
    <EulerImplicit />
    <CGLinearSolver />
    <MeshX3DLoader filename="../../../x3d/tools/probe.x3d" loadNamedGeometries="ITS_right" name="ProbeMeshLoad" />
    <MeshTopology name="pmeshTopology" position="@ProbeMeshLoad.position" edges="@ProbeMeshLoad.edges" triangles="@ProbeMeshLoad.triangles" quads="@ProbeMeshLoad.quads" />
    <MechanicalObject name="probeState" template="Rigid" />

    <Node name="RigidPoint">
      <MechanicalObject name="rigidPointProbe" template="Rigid" />
      <RigidRigidMapping name="MM->VM mapping" object1="probeState" object2="rigidPointProbe" />
    </Node>

    <UniformMass totalmass="0.5" />
    <UncoupledConstraintCorrection />
  </Node>
  <Node name="ProbeVisualModel">

```

Figure 10. SOFA scene file in the XML structure defines the soft body physics and deformation properties for every geometry.

5 Views (Ultrasound/Courseware and Patient View)

The courseware module is the main component that connects the simulator with the server side database and resources. Initially, the user is required to log into the course-ware module and receive the statistics/profile data from the server. The data will include the user training hours and metrics. Based on the user level and metrics, courseware module provides training scenarios for users to load and practice defined number of hours on a given protocol. The courseware module is proposed to connect with the H3D as core module and loads metadata for selected scenario through server storage. This module performs the user authentication process by contacting the User Management Subsystem of the RASimAs platform (Deliverable 2.2).

As illustrated above (figure 8), the US module and courseware module communicates with the H3D module using predefined H3D interface. The US simulation module is supposed to be the primary component to generate the artificial US images required for the training of ultrasound-guided needle insertion. During the configuration step, the US module receives metadata from the H3D module and loads simulation parameters, tissue properties, and the anatomy models from disk. These are then processed to setup and fill according tissue textures and data structures needed during the simulation process.

Fig 11 depicts the US and courseware views rendered as one display. As seen in the right display multiple user controls are provided to guide the user as well as tune the parameters to achieve specific tasks in the RA simulation.

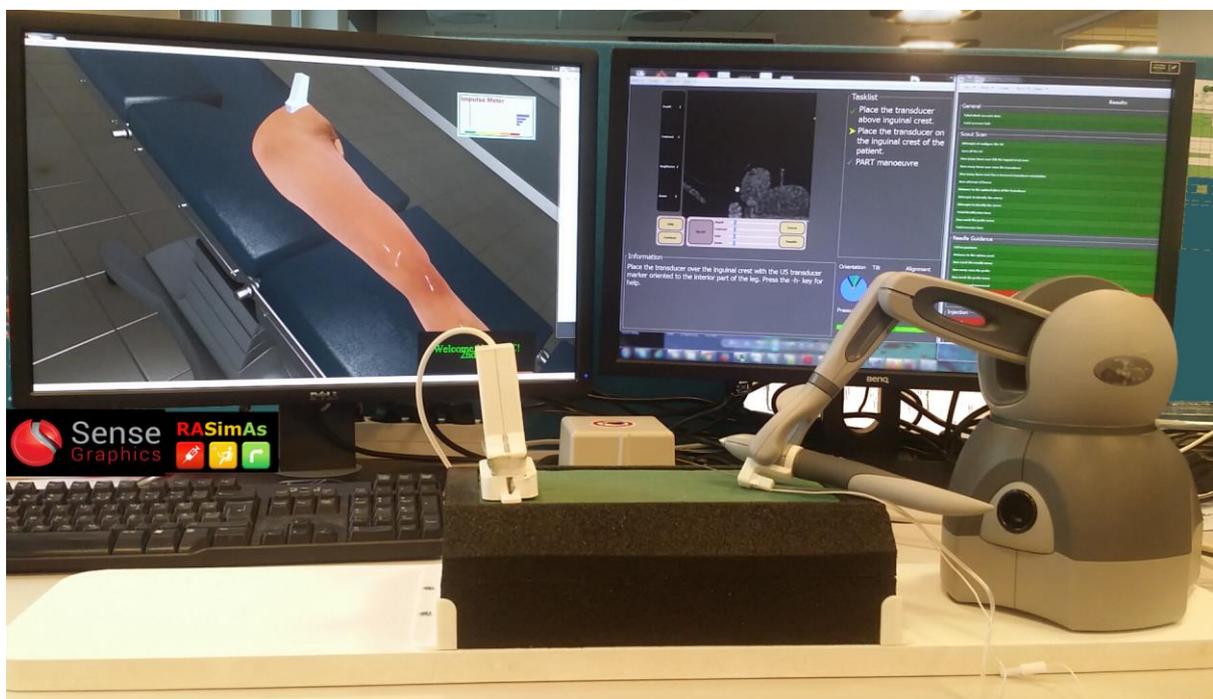


Figure 11. Courseware + Patient view rendered in RASim simulation environment.

6 Deviations and Problems

The integration done so far is functional and stable. At this stage of the project, there is one minor deviation from the proposed plan. The Simulator prototype was supposed to be delivered in month 24, where as now its planned to be delivered in month 27. Some of the modules from WP3 and WP4 are still in development phase which are core parts of the RASim prototype.