IARIA

Sensors-Based Virtual Reality Environment for Volumetric CT Analyses of Agricultural Soils Samples

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Embrapa

ufscar

Summary

- Introduction
- Materials and Methods
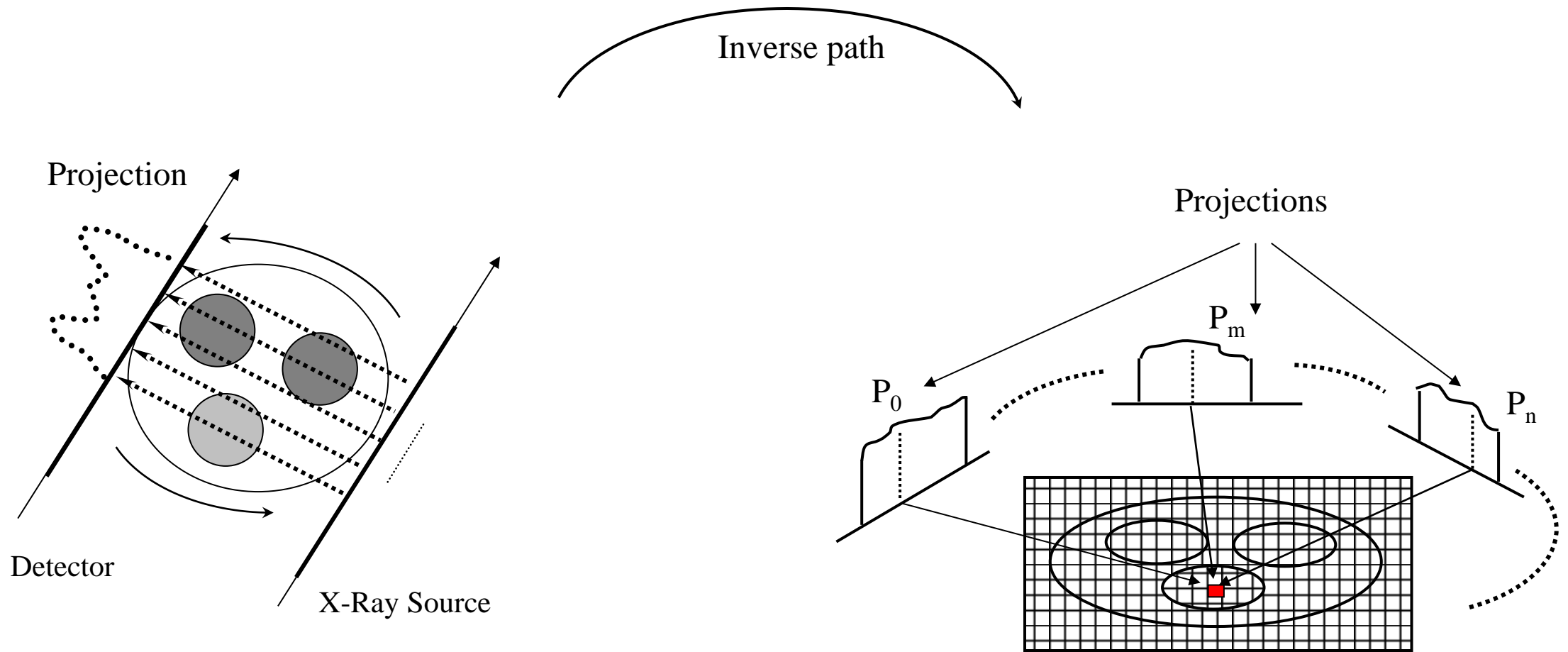- Results and Discussions
- Conclusions
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- ## Introduction

Agricultural Soil Analysis:

a) Non-invasive technique - CT

- There is an increasing interest in the scientific community in the development and application of non-invasive techniques for the study of physical characteristics of agricultural soils.

- One of the noninvasive methods used for the evaluation of water movement into soil due to morphology as well as aggregates distribution has been the application of sensors and Computed Tomography (CT) for agricultural soil imaging

CT Image Reconstruction from Projections

CT process

Attenuated photons intensity

Initial photons intensity

Linear attenuation coefficient (in cm^{-1})

$$N = N_0 e^{\oint_p (-\mu(\rho, Z_N, E)x)dp}$$

Material density (g/cm^3)

Atomic number

If the study body is a chemical component or a mixture, its mass attenuation coefficient can be roughly evaluated from the coefficients of the elements.

CT physical concepts

$$\frac{\mu}{\rho} = \sum_i w_i \left(\frac{\mu_i}{\rho_i} \right)$$

where w_i is proportional to the weight of the i_{th} constituent of the material. The mass attenuation coefficient of a component or mixture can be calculated from the mass attenuation coefficient of the components.

Noise in the tomographic process – Poisson noise (most significant)

- The probability of detecting N photons in an exposure time interval t can be estimated by the Poisson probability distribution function, given by:

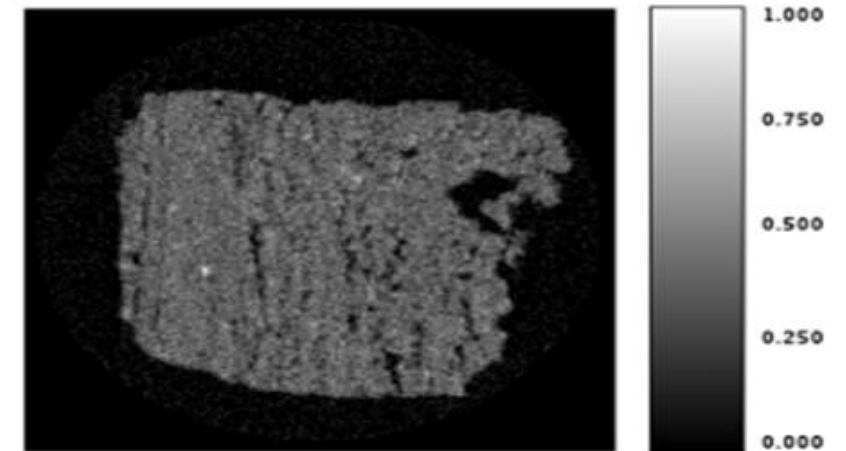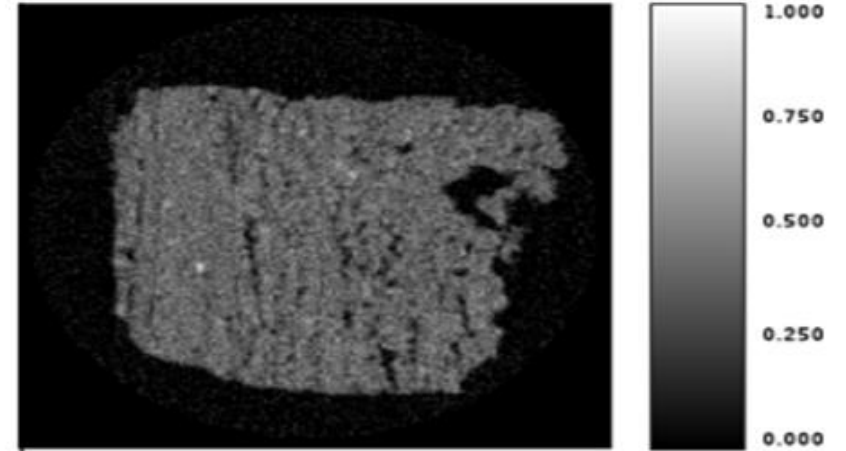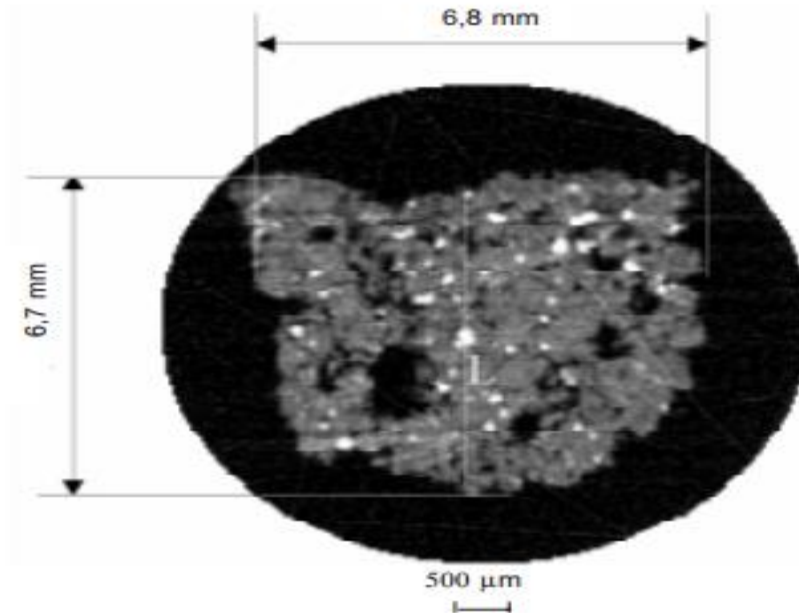Quantum efficiency of the X-Ray detector

Mean ratio of photons (photons/second)

$$\overline{N}_0 = \xi R t$$

The uncertainty or noise is given by the standard deviation, given by:

$$\sigma = \sqrt{\overline{N}_0}$$

Agricultural soils, examples of CT Images

- # **Introduction**

Agricultural Soil Analysis:

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b)Non-invasive technique – Virtual Reality (VR)

actuators algorithm cameras cognitive collision detection dataglove depth developed distance example eyes mechanical mechanoreceptors menu monoscopic movement necessary observer optical orientation parallax parameters perception physical pixels planeprojection projectors proprioceptiverealworld receptors representation requires resolution robot rotation schema screen selection sensitivity sensorimotor sensory vision surface techniques teleoperation environment virtual reality

Virtual Reality (VR) is the use of computer technology to create a simulated environment. Unlike traditional user interfaces, VR places the user inside an experience. Instead of viewing a screen in front of them, users are immersed and able to interact with 3D worlds.

Virtual glasses with sensors
(GSD 300 from Innovatek™)

Compatible with smartphones and other mobile phone devices with a CCD sensor screen to bring a totally immersive visual 360 degrees experience. Used in the method for allowing the virtual reality including headsets sensors for eyes properly align with the screen of the computational environment area, in order to reduce distortions.

Virtual Reality Glove with sensors for 3-D Virtual Controller System (from Mindflux™)

As one of the first widely available 3D controllers, this virtual tool works well with the developed method. It's extremely lightweight which makes it great for intuitive analysis of soil samples into a VR environment. It is ergonomically adequate designed to allow for comfort during use. The glove features an infrared control receptor with an anti-reflective and scratch resistant lens.

P5 Clove
Main Characteristics

- Lightweight, ergonomic design for easy use in the developed method;
- Virtual 3D controller;
- Mouse-mode compatible;
- 6 degrees of tracking (X, Y, Z, Yaw, Pitch and Roll) to ensure realistic movement;
- Bend-sensor and optical-tracking technology to provide true-to-life mobility
- Easy, plug-and-play setup - plugs right into the USB port;
- Infrared control receptor with scratch-resistant, anti-reflective lens.

Agricultural Soil Analysis:

Combining Non-invasive techniques
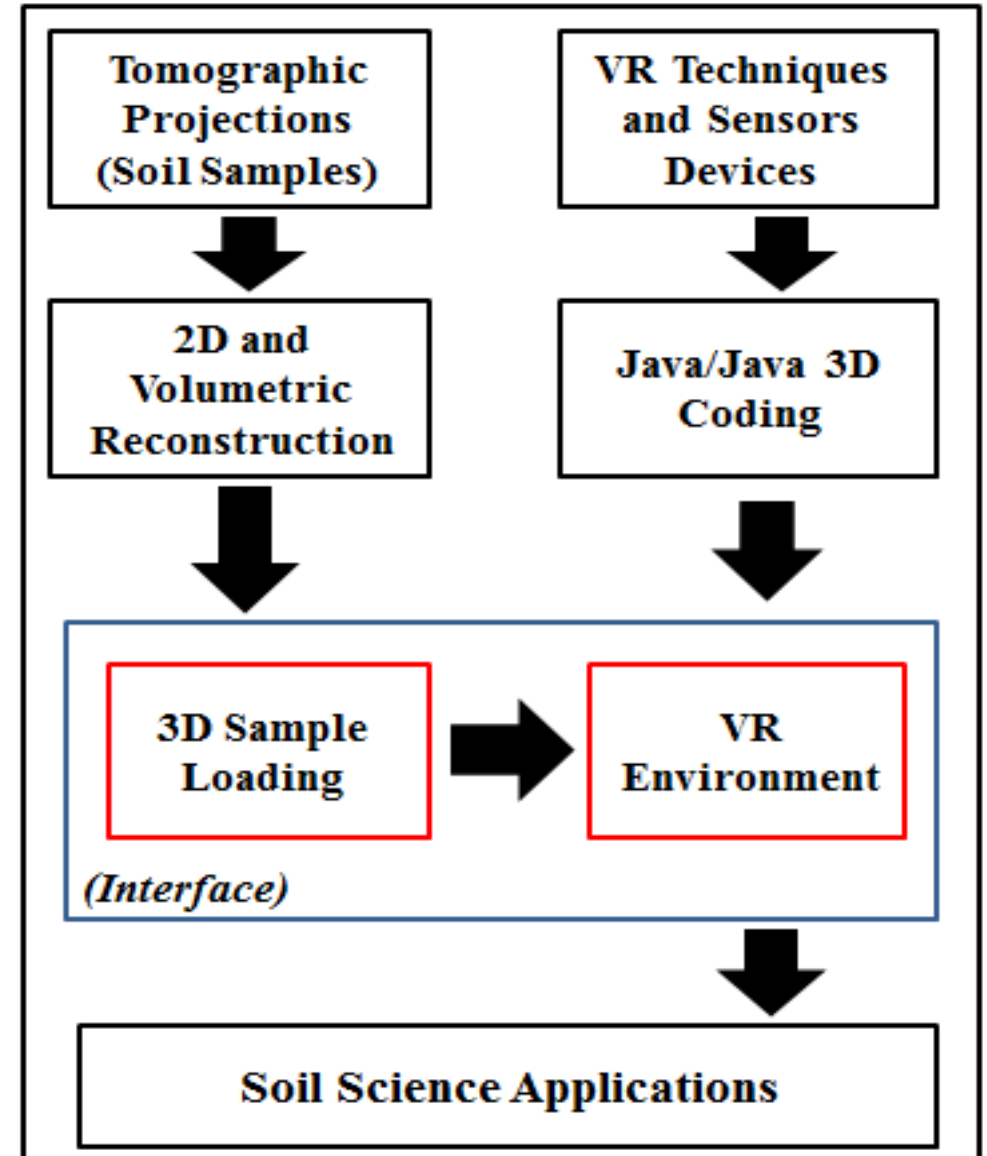

- Combined with the development of CT, new methods of three-dimensional (3-D) reconstruction have been developed, mainly motivated by the lack of information from two-dimensional models for a precise diagnosis in studies that require volumetric information, and their visualization.

Materials and Methods

General View

General view of the sensors-based VR system dedicated to the tomographic inspection of agricultural soil samples, as well as the dataflow. From this tomographic image data, soil samples can be reconstructed, imported, and treated by several VR processes, focusing on the analysis related to the soil science area.

Main Classes

- The software system was organized based on the concept of classes. In object-oriented programming, a class is an extensible program-code-template for creating objects, providing initial values for state (member variables) and implementations of behavior (member functions or methods).

Reconstruction,

Loader,

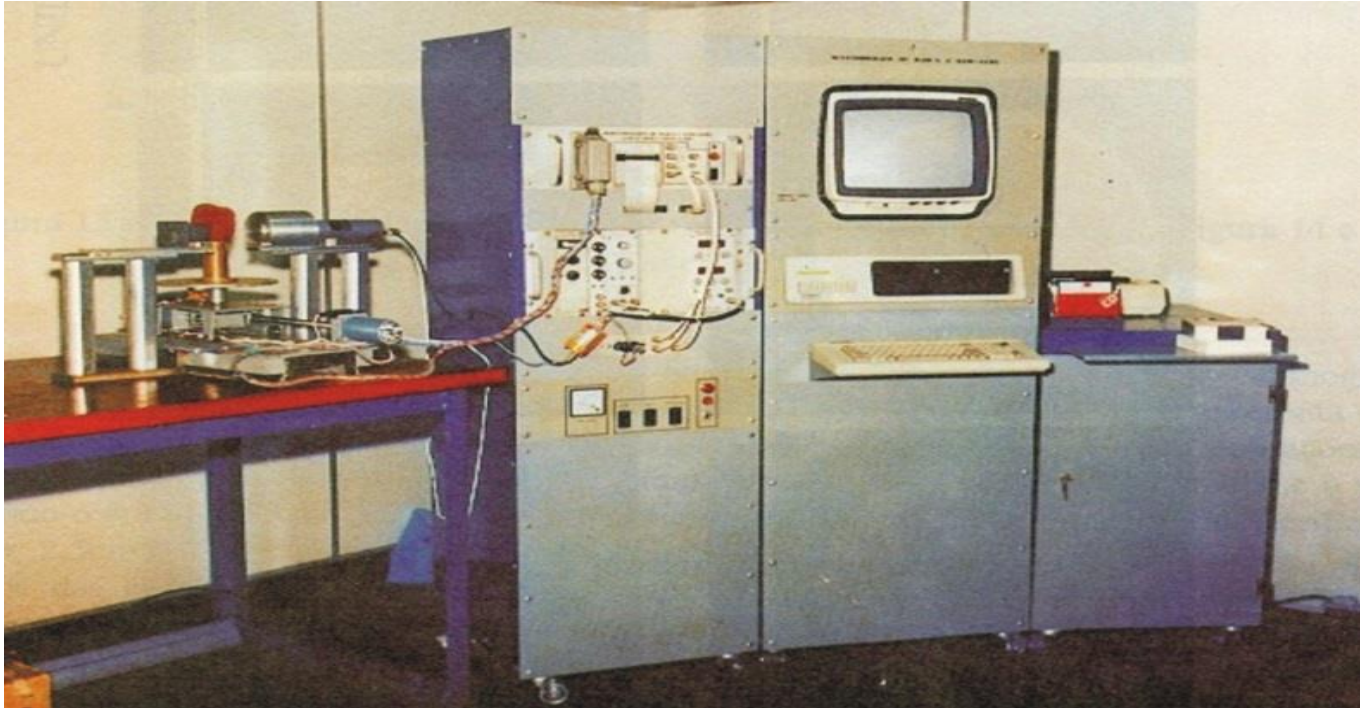*Polygonal Attributes Extraction,*

Non-conventional Collision,

Non-conventional Model Manipulation,

Non-conventional Scene Manipulation,

Quaternion,

Visualization and VR Environment.

Embrapa CT Scanner

- The CT scanner from Embrapa Instrumentation has been used to obtain the tomographic image data. All of the tomographic projections allowed image reconstruction, i.e., turning possible generation of mass attenuation coefficient maps given in cm^2/g with spatial resolution equal to or larger than 1 mm.

- All of the soil samples were submitted to the acquisition process using an amount of energy of 59.6 keV and a time window equal to 10 seconds for sampling of the points for the tomographic projection.

Main Classes - Reconstruction

- An interpolation-based overlapping algorithm of reconstructed two-dimensional slices was adopted for volumetric reconstruction. Such a technique consists of setting up the plans generated by the function f(x, y, z$_i$) for i = 0... (n-1), where n is the number of reconstructed plans. Consequently, specific two-dimensional slices were interpolated to reconstitute the spaces left among these overlapped plans.

- An overlapping method was used to reduce the computational costs and the radiation time, with the use of interpolation in between the spaces of the reconstructed slices based on the use of *B-splines*. Thus, with only a few slices, the algorithm was prepared to estimate and complete the entire information.

Voxel

Interpolated Planes

Pixel   Reconstructed Planes

- Tomographic data are acquired without displacement of the sample under analysis. The position during the scanning process remains the same;

- Completion of the intervals between acquisition plans (A) and virtual plans (V);

- This feature allows to use interpolation and to increase resolution of 3D objects, i.e., called as Volumetric Reconstruction

B-Spline Interpolation Algorithm

- Function for interpolation

$$f(u) = \sum_{i=0}^{N} a_i B(Nu - i)$$

Where u represents the step in interpolation and N is the number of known points

Blending Function

$$B(x) = \begin{cases} \dfrac{1}{6}(2+x)^3 & -2 < x \le -1 \\[2mm] \dfrac{1}{6}(4-6x^2-2x^3) & -1 < x \le 0 \\[2mm] \dfrac{1}{6}(4-6x^2+2x^3) & 0 < x \le 1 \\[2mm] \dfrac{1}{6}(2-x)^3 & 1 < x < 2 \\[2mm] 0 & 2 \le |x| \end{cases}$$

Main Classes - Loader and Attributes Extraction

- In the **Loader** class, the volumetric model is converted into the *Wavefront File Format* (.obj) using the *vtkOBJExporter* class from the *vtkOBJExporter.h* package of the visualization toolkit, and brought into the sensor-based VR system

- The **Attributes Extraction** class obtains the voxels data from a volumetric image, using those above-mentioned input non-conventional devices, i.e., supplying the users' information on a specific point of the volumetric representation.

Main Classes – Non-conventional Scene Manipulation

- The **Non-conventional Scene Manipulation** class is one of the most important for user interactivity and immersion in the *VR environment*, since it allows user browsing in all directions through the synthetic scene, approximating and going into the reconstructed structures using data gloves *P5Glove*

- The **Non-conventional Scene Manipulation** class is also used with the ViewingPlatform class. In such a way, two other specific parameters are included, each of them related to the translation and rotation steps respectively. Such an arrangement is responsible for defining when the virtual models will be moved or leans in each movement of the device in the real world and recognized by the *FPSGlove* class

Main Classes - Quaternion

- The ***Quaternion*** class implements a conversion algorithm so that the system stops using just rotations on the x, y and z axes, and starts to accomplish orientations on some intermediate axis, defined by a vector that goes through the origin and reaches a point in space. Such a type of an axis can be represented by a specific coordinate of the real device, e.g., the Cartesian coordinates (x, y, z) of one of the eight LEDs present in the controller tower which is used with the glove.
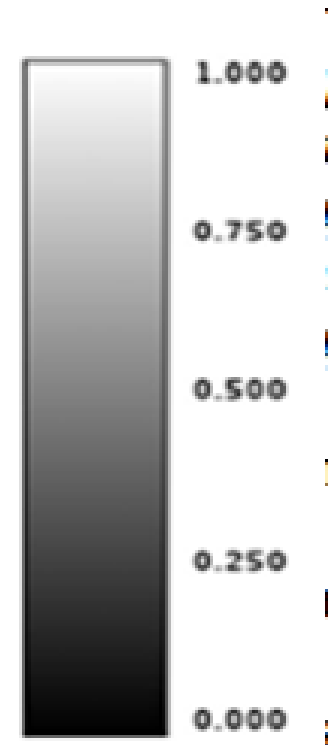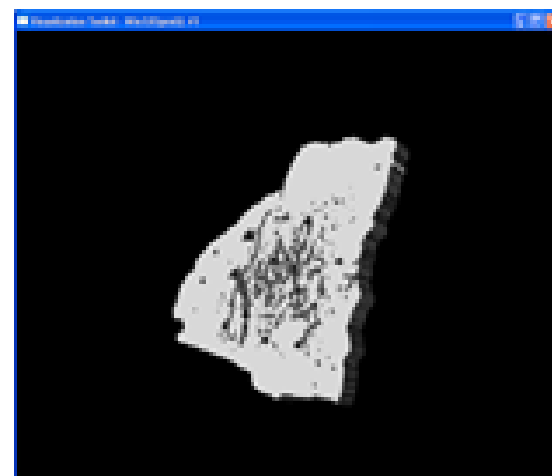
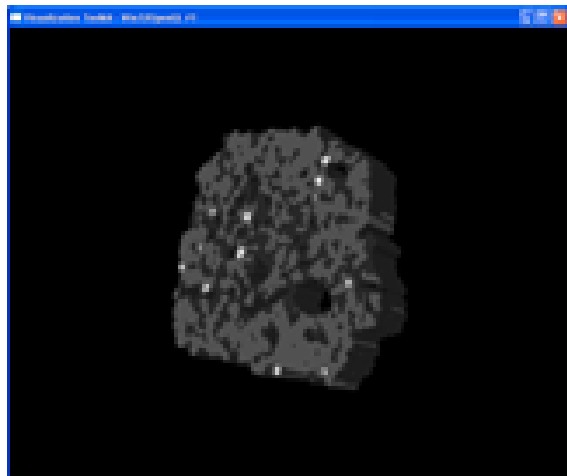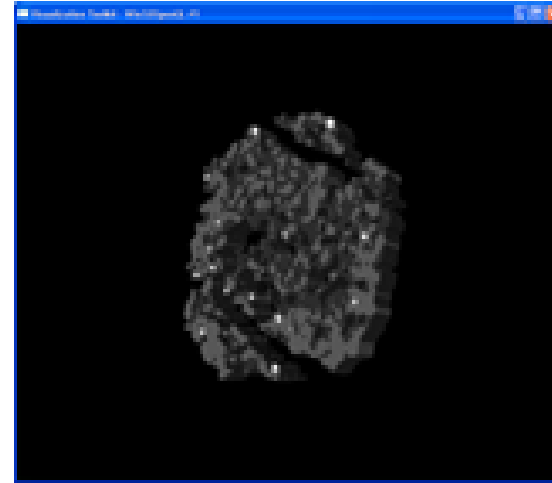# Main Classes - Visualization

- For the implementation of the **Visualization** class, the system interface prepares a volumetric tomographic image to be visualized. This way, the volumetric tomographic image is prepared to be adjusted to the 3-D model, i.e., to occupy the whole extension of the *Canvas3D* object, so that all of the spaces are taken advantage of, contributing to the visualization quality.

• Results and Discussions

- Based on the use of the tomographic projections and the two-dimensional reconstruction FPB algorithm, it was possible to get volumetric images by means of use of the *B-spline* algorithm.

- Follows examples of the volumetric tomographic images obtained for stratified agricultural soil, degraded soil, and a clay soil sample, respectively. Based on the **Attributes Extraction** class, intrinsic characteristics of the scene and of agricultural samples could be obtained through the use of either the mouse or the *P5Glove*, with a data origin in the three-dimensional representations in the VR environment.

- The data set was divided into two categories: one concerning the scene, and the other concerning the CT measurements.

Volumetric latosoil images reconstructed by FBP and the B-Spline algorithm

Volumetric latosoil images reconstructed by FBP and the B-Spline algorithm

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- In relation to the first category, the synthetic scene data are related to: borders, which have represented the geometry limits or the geometry limits that involved it; the scene graph, that has represented the node hierarchy in the tree; the current geometry in the model and its composition, the distance of a certain voxel in relation to the coordinates chosen in the scene, the closest vertex to the chosen point in the scene, the three-dimensional coordinates, and the normal straight line in the closest face, which involved the chosen coordinates.

- Secondly, concerning the tomographic data, the obtained data were: color attributes, which represented the individual color of each voxel, independent of illumination intensity; the mass attenuation coefficients values of the agricultural soils, which are represented by the colors of each analyzed voxel, and are related to the light intensity in each position; transparency attributes; and polygons attributes, and finally the saturation and matrix of the HSL coefficients.

Volumetric latosoil images reconstructed by FBP and the B-Spline algorithm

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- An experiment for validation of the result was prepared considering a digital and volumetric tomographic image obtained from a latosol soil. For such a volumetric image, the value of an arbitrary voxel was taken.

- Based on the developed method, the attributes can be obtained from the latosoil soil tomographic image at the sensors-based VR environment, i.e., under the two mentioned aspects, through the choice of any voxel coordinates, assuring the reliable recovery of the sample data.

Data obtained from soil sample where an arbitrary point is chosen using a non-conventional

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Colors:
Color=(0.03, 0.07, 0.04) | ShadeModel=SHADE_GOURAUD
Materials:
AmbientColor=(0.4, 0.4, 0.4)
EmissiveColor=(0.0, 0.0, 0.0)
DiffuseColor=(0.71, 0.70, 0.65)
SpecularColor=(0.3, 0.3, 0.3)
Shininess=128.0
LightingEnable=true
ColorTarget=2
Transparency Level: 0.3
Polygons: Planes
Gray Level: 156.82
Saturation: 22.86
Mass Attenuation Coefficient (cm²/g): 0.6521
Virtual borders:
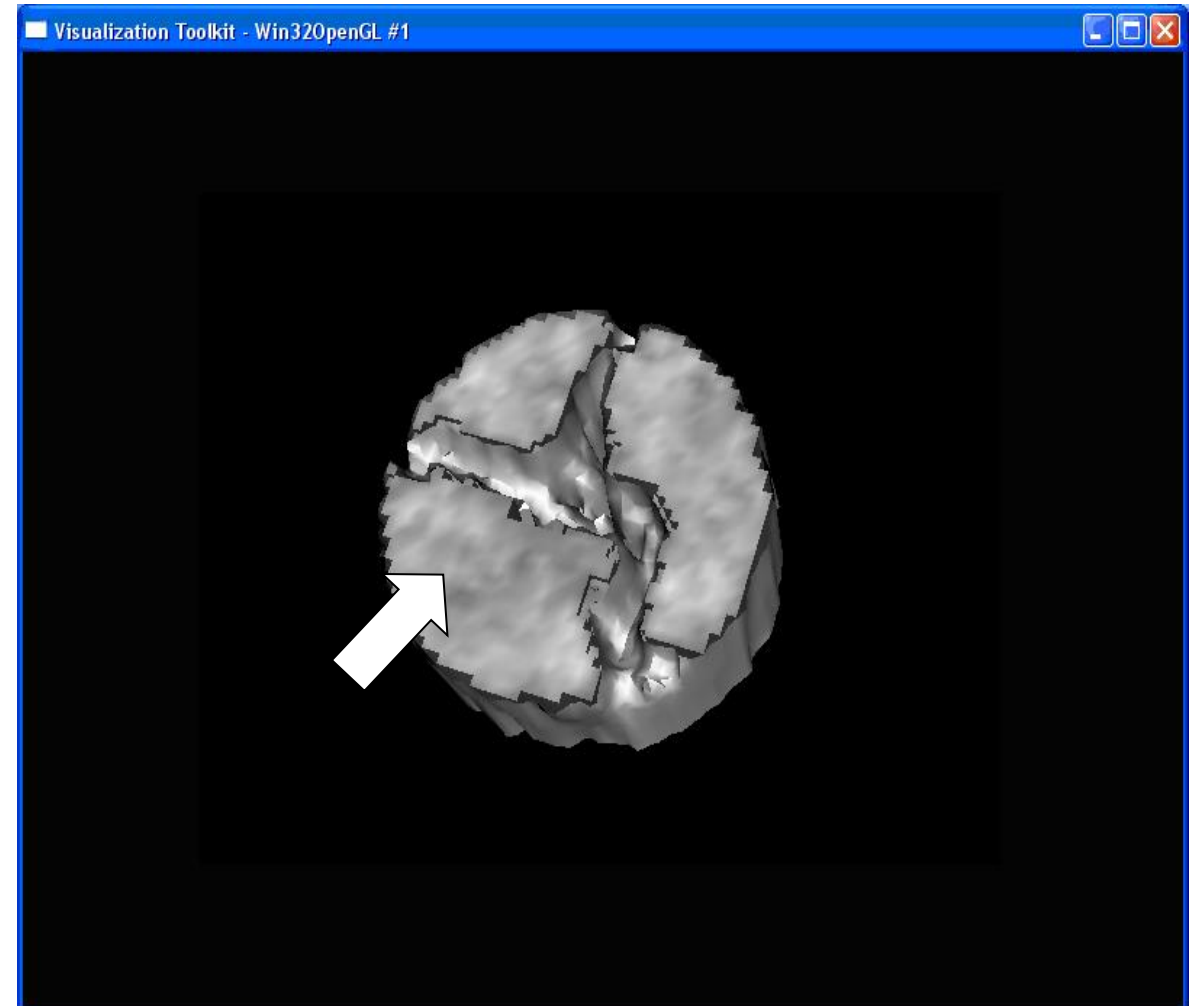Lower=-0.87 -1.0 -0.15
Upper=0.875 1.0 0.15
BranchGraphs: 3
Geometry: Triangles
Point Distance: 10.28
Closest Vertex: (0.92, -0.25, -10.24)
Point Coordinates: (0.75, -0.25, -10.26)
Point Normal Axis: (1.0, 0.0, 0.0)
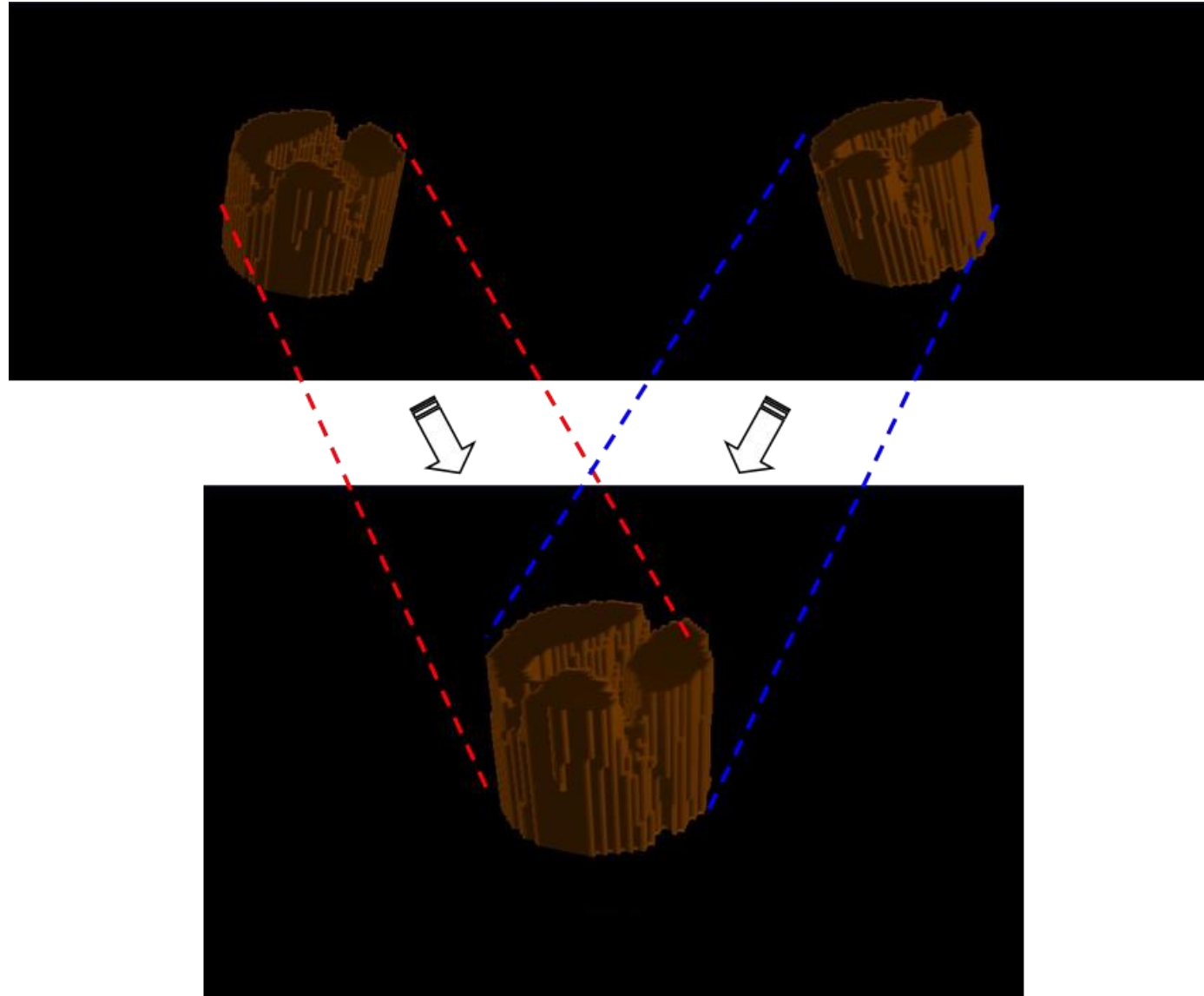
Scene Manipulation

- The feedback produced by the class implementation has indicated absolute control of user browsing on the scene using the *P5Glove*. In this context, according to device positioning, the users can browse through the scene where the displacement of their hand is faithfully translated in scene movements, including moving the environment cameras in real time.

- Practically, movement with a glove should commence with closed hands, where the sensors are activated by bending fingers, thus starting the action. The *Non-conventional Model Manipulation* class simulates the manual support of 3-D samples, as well as its total movement inside the scene, with 6 degrees of freedom.

The Quaternion contribution

• The **Quaternion** class, when evaluated, presented an adequate conversion from Euler`s coordinates to Quaternion`s coordinates. In addition, the results of application of the *Transform3D* class produced smooth orientation changes.

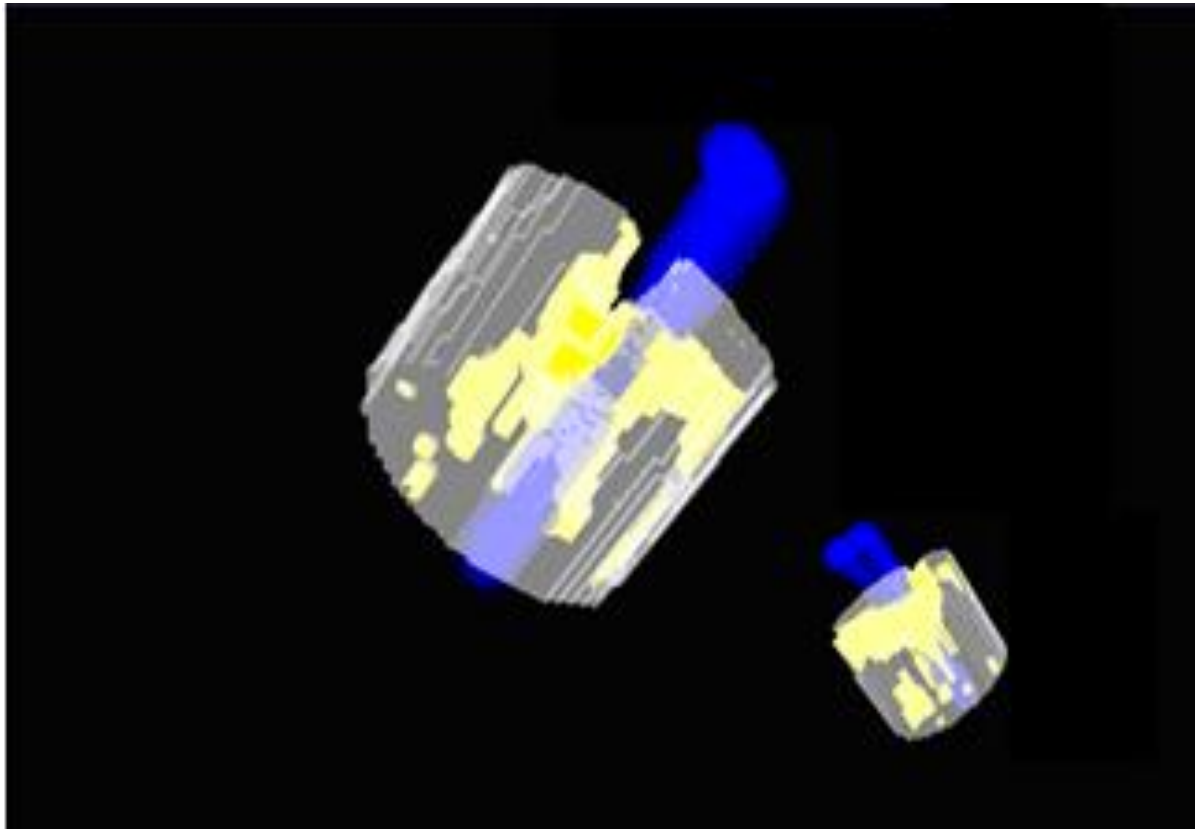| Initial Position (sample point)	Quaternion	Final Position (sample point)
(0.0,0.0,0.0)	vector: (0.0,0.0,0.0) scale:0.9238	(0.7071,0.7071,0.0)
(0.7071,0.7071,0.0)	vector: (0.2705,0.2705,0.0) scale: 0.9238	(0.9999,0.9999,0.0)
(0.9999, 0.9999,0.0)	vector: (0.3826,0.3826,0.0) scale: 0.9238	(1.2928,1.2928,0.0)
1.2928,1.2928,0.0)	vector: (0.4947,0.4947,0.0) scale: 0,9238	(1.6862,1.6862,0.0)

Visual results of the applied transform.

Visualization using HMD

- The three-dimensional samples were examined immersively by the Head Mounted Display through the ***Visualization*** class. First, *Canvas3D*, responsible for the rendering of three-dimensional images, was maximized to omit the parts related to the main interface in the device to focus only on the region where the sample was shown. Thus, each display of HMD forms an image which is shown and interpreted by the user's brain with a larger depth effect.

- Secondly, such an effect also has allowed performing the analyses of the preferential paths of the water flow into the agricultural soil samples, called fingering effects, as well as the verification of the percentage of pores in the samples.

Visualization using HMD

- Using the **_Non-conventional Scene Manipulation_** class, when the cameras are moving with the navigation processes, or if the keyboard interaction is being activated, or even the data glove _P5Glove_, the traveled paths can be demarcated i.e., leaving the itinerary registered under visual and mathematical form.

- Similar to the simple scene manipulation, such demarcation obeys the laws imposed by the **_Non-conventional Collision_** class, i.e., the traveled path is prevented from passing over the non-porous faces of the agricultural sample, leading the flow of fluids to pass through the related pores, which are the preferential paths.

Examples of the preferential paths for water movement

Result of the case study based on a tomographic image from degraded agricultural soil, where the sample is in gray tones and the water flow is represented with a blue color, demarcating the traveled paths.

• Conclusions

This work presented the development of a new method which considered the integration of a sensors-based VR environment with a CT for the dedicated inspection of agricultural soils. Results have shown both the possibility of accessing CT digital images of the agricultural soils and the opportunity of handling three-dimensional manipulation and graphic visualization processes through computational devices. Such a developed method allowed the addition of immersion and the user`s interaction with soil samples. These resources involved rendering control, illumination, coloring, attributes extraction, and physical transformation, as well as the integration of non-conventional data input and output devices, such as a Head-Mounted Display (video-helmet), and digital gloves.

- # **Future works**

Embedded systems based on the use of the *Field Programmable Gate Array* (FPGA), as well as use of the augmented reality concepts.

ACKNOWLEDGMENT

We thank you for the attention!