

STEM TEACHER AWARD FESTIVAL 2017

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Tomography in school - Optical CT Scanner with Lego or Arduino

Students develop a low-cost optical CT scanner and use tomography to investigate transparent objects of their interest, such as gummy bears, candies, fruits and plants. They are familiarized with the basic principles of tomography and simulate the scientific method during their research activities.

Keywords: CT scanner, computed tomography, tomography, optical projection tomography, Lego Mindstorms, Arduino

Disciplines: Physics, biology, ICT, chemistry

Age level of students: 15+

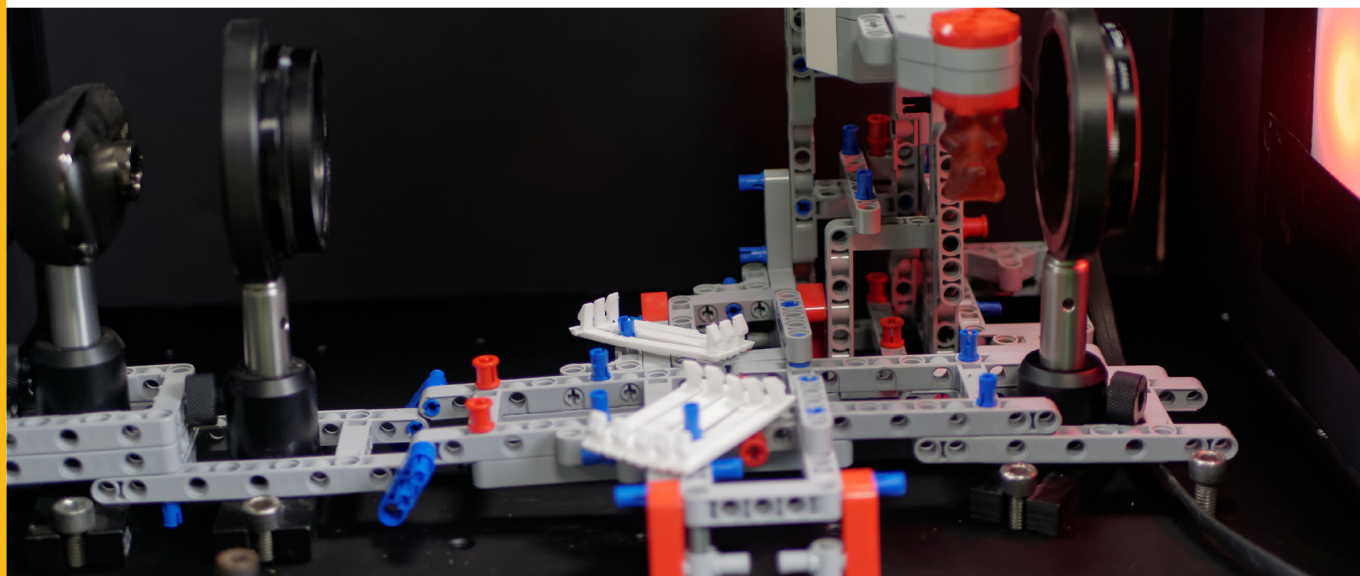


Fig. 1.1 CT scanner based on Lego Mindstorms



Fig. 1.2 CT scanner based on Lego Mindstorms



Conceptual introduction

The development of X-ray computed tomography (CT) has been a real innovation in medical and industrial imaging. Have you ever wondered how a CT scanner actually works? Wouldn't it be great if you had the chance to build a CT scanner and use it for your own science projects in school? Optical projection tomography (OPT) implements the same principles like X-ray tomography, but utilises visible light instead, which is harmless for living organisms. Thus, building an optical CT scanner is the most appropriate way to introduce tomography in school.

Within the framework of this project, students develop a low-cost optical CT scanner using either Lego Mindstorms or the Arduino platform. The goal is to present the basic principles of computed tomography in upper

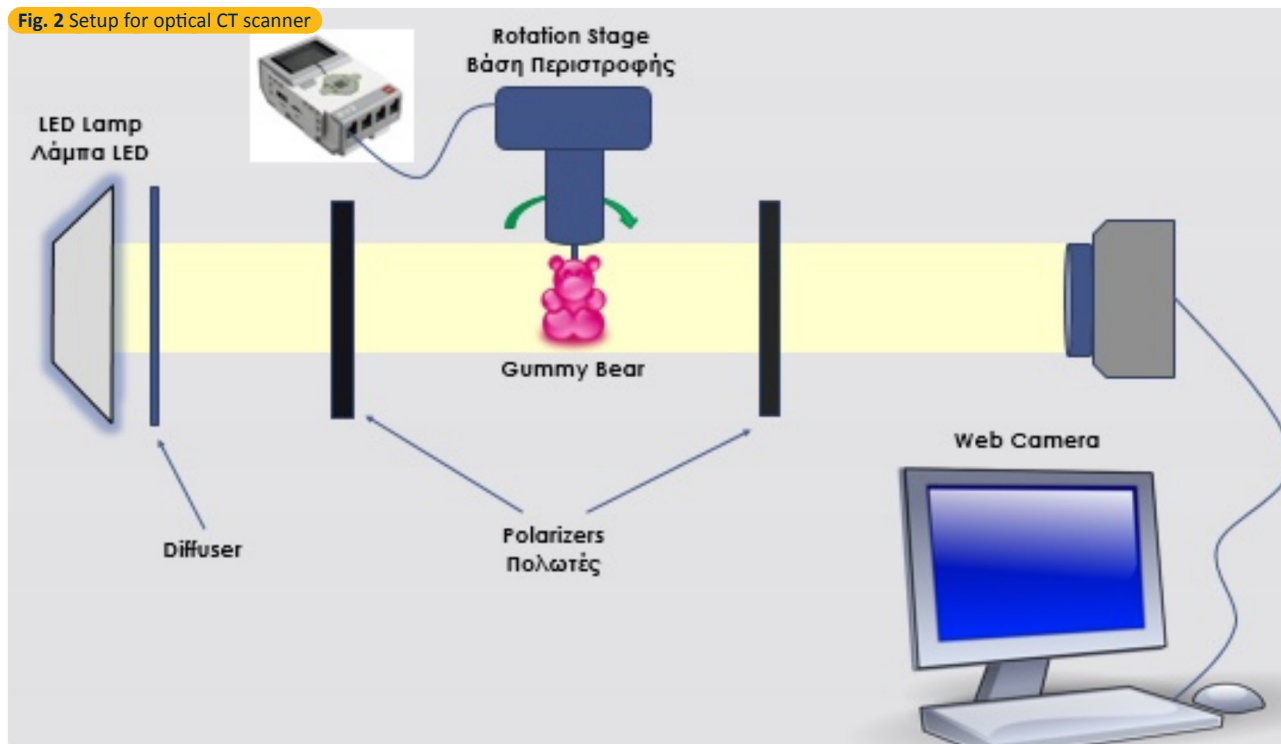
secondary school by CT scanning gummy bear candies or other transparent objects. The project represents the simplified transformation for secondary education of a real scientific research project. Students have the chance to work the same way as scientists by utilising the same techniques, methodology and software.

What the students do

1. BUILD A CT SCANNER

The main goal of the project is to construct a simple, low-cost but fully functional optical CT scanner. This alone is a challenging engineering project for students and the basic idea is to construct a setup similar to the one depicted in Figure 2. Actually, two CT scanner models were constructed, one based on Lego Mindstorms (cover image, top; Figure 1.1 and 1.2) and a second one based on the Arduino platform (cover image, bottom).

Fig. 2 Setup for optical CT scanner



In the following, the Lego setup is described briefly but the same principles stand for the Arduino setup as well.

A thin semitransparent piece of paper is placed in front of an LED Lamp to act as a diffuser in order for the light beam to be more homogeneous. Using parts of the Lego Mindstorms we construct a platform to hold the object that is going to be CT scanned.

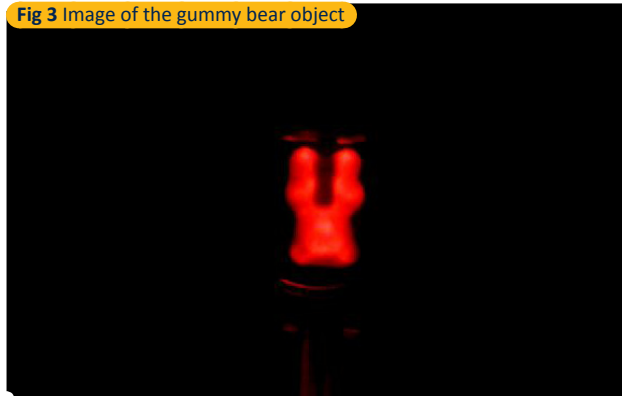
The objects that were chosen to demonstrate the operation capabilities of the CT scanner were gummy bear candies of different colors. Obviously, for an optical projection tomography CT scanner to operate, the object has to be transparent. The use of gummy bears proved to be an excellent choice for this purpose since they possess all the necessary optical characteristics for good tomography results.

The LED lamp, the object and the USB webcam need to be aligned together as well as possible. The source (LED lamp) and the detector (USB webcam) remain still, while a Lego motor, controlled by the Lego EV3 Brick, is used to rotate the object during the CT scanning procedure.

The light beam needs to be parallel and only the light from the object has to be captured by the webcam. In order to achieve this, we use two camera linear polarizers. The first is placed in front of the LED lamp and the diffuser and polarizes light linearly in one direction. The second polarizer is placed directly in front of the USB webcam with its polarizing axis vertical to the respective axis of the first polarizer. This way, the initially polarized light cannot pass through the second polarizer at all and the images captured by the webcam should appear completely black. This is generally true apart from the light coming from the gummy bear. As light passes through the object, it is scattered, loses its initial polarization and thus is not hindered by the second polarizer. The result is that only light from the gummy bear object (Figure 3) reaches the camera.

Having built and calibrated a robust CT scanner model, it is very easy to use it for CT scanning and your school science lab is equipped with a new device that can be used in various CT scanning research projects.

Fig 3 Image of the gummy bear object



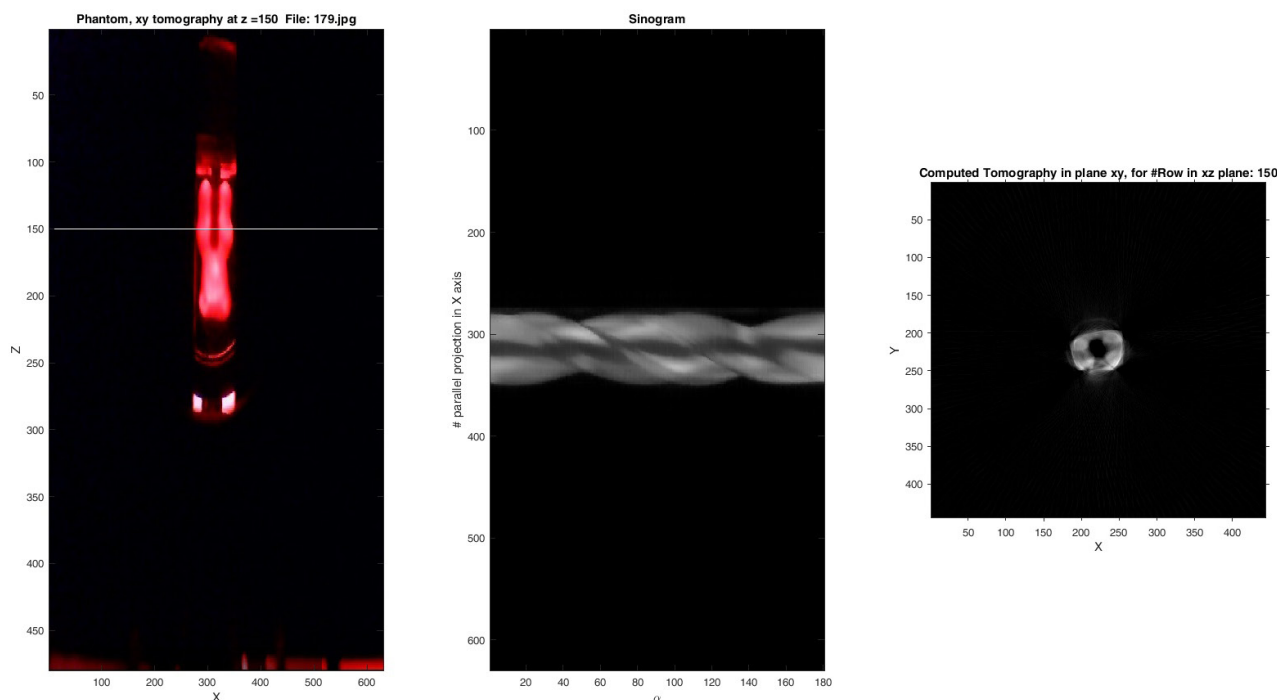
2. IMAGE ACQUISITION

The Lego Mindstorms motor is controlled by the LEGO Mindstorms EV3 Brick. The motor is programmed to rotate the platform, and consequently the gummy bear that has been mounted to it, by 2 degrees every 2 seconds, until a full rotation is reached. In the same time the webcam is automatically capturing images every 2 seconds respectively. This is achieved with the use of Matlab software. All the necessary code, project material and more specific instructions are available for download. ^[1]

In order to proceed to image acquisition of the object only the CT scanning code is needed. As a result of this procedure there are 180 successive rotation images of the object stored in a PC folder. The most important factor of the image acquisition process is to calibrate the axis of rotation of the object to be vertical and at the center of the captured images. Finally, we switch off the LED lamp and capture a last background image that will be subtracted afterwards from any other image.

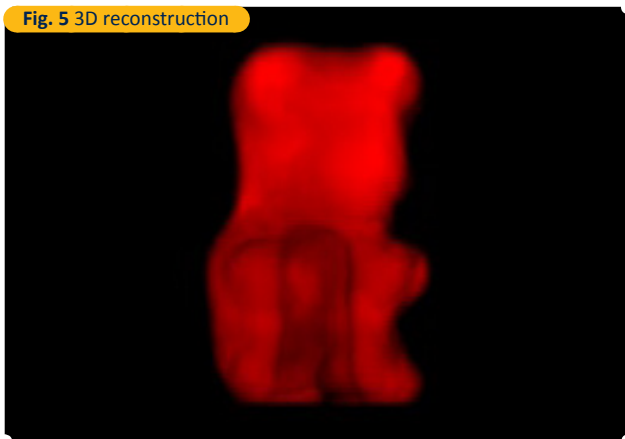
3. DERIVING CT SCANS

With the proper code the production of the CT scans is really a simple task. You just have to run the CT scanning code on the respective acquired object images. Matlab code^[1] is used to derive the CT scans but it can be done with other programming languages as well. However, Matlab is strongly suggested for this project because it offers libraries for tomography and support packages for controlling Lego, Arduino, USB webcams, etc. Moreover, it is usually the choice of scientists in the field of optical tomography. In Figure 4 a CT scan of a red gummy bear as derived with Matlab code is presented.

Fig. 4 CT scan derived with Matlab code

4. 3D OBJECT RECONSTRUCTION FROM CT SCANS

A good idea is to produce the full set of CT scans for the whole object. It is much more convenient to do this with a slightly modified Matlab code file that can derive and store the full set of the object CT scans in a three dimensional matrix. Consequently, this file is imported to Fiji – ImageJ^[2] as an image stack. ImageJ is a really powerful open source software and there are many options for filtering and manipulating your data. It offers plugins for 3D visualisation and with just a few clicks you can have a very impressive 3D reconstructed model of your CT scanned object (Figure 5). ImageJ has been developed by scientists and is used by researchers in biomedical imaging and optical tomography.

Fig. 5 3D reconstruction

Conclusion

The CT scanner project provides a great opportunity for students to get involved in pure STEM activities. It involves engineering while trying to setup the model in the most effective way. It involves mathematics while students get familiarised with the concepts of tomography. Technology and ICT are the core of the project and there is a lot of science involved. Students have the chance to implement the scientific method while working in the simulation of a real research experiment. They use the same techniques, software and similar tools that scientists use to conduct their own optical tomography research projects.

Several activities based on the CT scanner can be integrated into science lessons to teach concepts of physics like polarisation, light absorption, light scattering, colors. The CT scanner was used to CT scan candies, fruits, plants and other transparent objects and thus it is possible to design very interesting research projects in biology and chemistry classes. Changing the available tomography code to make it faster and more effective would be an interesting project for ICT classes in school.

In the reference section there is a link that provides detailed instructions with hints and tips on how you can proceed building either the Lego CT scanner or the Ardu-

ino CT scanner. It also provides all the necessary code files for both systems. Moreover, there are data sets available which you can use to produce CT scans and test the 3D reconstruction procedure without even having to build the CT scanner.

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References and sources

[1] Project data sets, implementation instructions, Matlab code, images, 3D reconstruction videos:

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[2] Image Processing Software Fiji –ImageJ:

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