Transfer of knowledge and skills in STEM: Exploring and promoting digital analysis skills - Testing optimal conditions of X-ray irradiation

Prenos znanja in veščin na področju STEM: Raziskovanje in promocija digitalnih veščin: Testiranje optimalnih pogojev rentgenskega obsevanja

Svit Pestotnik Stres
Gimnazija Bežigrad
Peričeva 4, 1000 Ljubljana
svit.pestotnik@gimb.org

ABSTRACT

In this paper, we describe the transfer of knowledge and skills between the High school and University system in establishing of a digital environment for analytics in physics experiments. ICT skills are essential in establishing the potential for automated or digital analysis in the observation of physics experiments. We have proven that this claim is valid in the case of X-ray detection on a imaging phantom. We photographed an irradiated imaging phantom under different initial conditions and tried to compare results with each other in terms of different output parameters as optimal voltage used and signal to noise ratio. With the help of independently created automated Python software for the RGB analysis of the images and using analytical tools as Root and Logger Pro programmes, we showed that collaboration between the two educational systems is crucial for the transfer of knowledge and skills.

Keywords

Digital technologies, digital skills, data analysis, STEM, X-ray detection, imaging, observation

POVZETEK

V tem prispevku opisujemo prenos znanja in veščin med gimnazijo in univerzitetnim sistemom pri vzpostavitvi digitalnega okolja za analitiko v fizikalnih eksperimentih. IKT spretnosti so bistvenega pomena pri ugotavljanju možnosti avtomatizirane ali digitalne analize pri opazovanju fizikalnih eksperimentov. Dokazali smo, da ta trditev velja v primeru rentgenskega zaznavanja na slikovnem fantomu. Fotografirali smo obsevan fantom za slikanje v različnih začetnih pogojih in poskušali med seboj primerjati rezultate glede na različne izhodne parametre kot sta optimalna uporabljena napetost in razmerje signal / šum. S pomočjo neodvisno ustvarjene avtomatizirane programske opreme Pyton za RGB analizo slik in z uporabo analitičnih orodij kot sta programa Root in Logger Pro smo pokazali ključno soodvisnost med obema sistemoma izobraževanja za namen prenosa znanja in spretnosti.

Ključne besede

Digitalna technologija, digitalne veščine, analiza podatkov, STEM, rentgensko zaznavanje, slikanje, opazovanje

1. INTRODUCTION

In today's world, knowing digital approaches is increasingly crucial. On the other hand, the relationship between the various branches of science - chemistry, physics, computer science - even in the education system itself is still in its infancy. Interdisciplinarity and cross-curricular integration depend on individual initiatives. Particularly noteworthy is the link between information technology and science education to motivate young people to STEM content. In this context, digital skills are crucial for establishing closer links between science and education. We presented one of the options in our paper.

In this paper, we describe an experiment done in collaboration between the International Baccalaureate at the Gimnazija Bežigrad and the Faculty of Physics and Mathematics of the University of Ljubljana. The aim of this experiment was twofold: firstly, to explore how changing the voltage affects different image quality properties in X-ray Imaging phantom detection; secondly, to explore how and to explore digital tools necessary to execute the experiment as a regular study and collaboration tool. The experiment and its data analysis allows for an exploration of digital tools in STEM experiments and can represent a good basis for further collaboration between the institutions.

The crucial element of this work was to establish a collaboration that would enable the realization of the goal. The goal of this research was to prove the correlation between the voltage applied to the X-ray apparatus and the image quality of the recorded picture. We were also exploring the impact of the distance between the fluorescent screen and the phantom irradiated by the x-ray apparatus on the intensity of the light measured.

The experiment conducted is based on the theory of X-rays. The rays are produced by an apparatus, where a certain voltage is applied to a X-ray tube that accelerates the electrons towards the molybdenum's anode. The x-ray beams are the result of the interaction of electrons with matter. They are shielded by a collimator so that can only exit the sources at a certain spatial angle.

The detection of X-rays was achieved by taking a picture of a fluorescent screen [1], which emitted fluorescent green light when hit by x-rays, with a camera. The acquisitions had to be taken in complete darkness with a long exposure time to enable enough light to accumulate on the sensor.

After the data was converted to numerical form, a double error function was fitted on the 2D response image. The parameters, which I received as an output, were then used in the analysis.

2. METHODS

The experiment was performed at the University of Ljubljana, Faculty of Mathematics and Physics. I used the experimental equipment for the X-ray exercise of the subject Laboratory experiments V [2].

The detection of the x-ray particles was double-phased. The apparatus used to produce x-rays was "Didaktiksysteme 554811" [3]. The first part of the experiment was acquiring data in the form of captured photos, whereas the processes and techniques employed further on my research are analytical and systematical.

However, there is a second segment of activities embedded in this paper. It presents a proposal for technology transfer between different parts/sectors of the educational system. In particular, the paper proposes to enhance the capabilities of high schools by giving them access to digital tools that can only be found on the university level, but which could potentially be utilized by high school students.

2.1 Transfer of knowledge from one to the other educational environment

It has soon become clear that without digital tools the observation of the processes taking place in the imaging phantom and the setup as a whole would be impossible on the level of accuracy requested to draw reliable conclusions.

Thus the second aim of the study was to use existing and to develop missing digital tools to enable RGB analysis of the images taken.

These tools were developed with the assistance of the experts from the University of Ljubljana, Faculty of Mathematics and Physics and Jožef Stefan Institute.

The main purpose of the collaboration was to enable quick, accurate and reliable analysis.

On the other hand, the process at hand demanded that a knowledge transfer in terms of technologies used and skills that enable analysis, to be transferred from one educational environment to the other, to enable analysis of the data themselves.

2.1.1 Transfer of knowledge and skills in STEM

During the measurements it soon became obvious that the scope of analysis is too broad and too extensive to allow for a usual approach of analysing single data sets with simple analytics tools as Excel or Logger Pro analysis, which are usually used in the high school environment.

Thus in a constructive dialogue with my IB Physics teacher it was decided to seek for further assistance with the experts at the Faculty of Matematics and Physics and Jožef Stefan Institute.

They proposed to collaborate on creating suitable analytics tools that would be useful for the concrete analysis, but would also be further used in the IB process, if necessary. The digital skills in question included in particular:

- Python script-image color processing,
- Root script-intensity analysis and
- image splitting.

The relevant digital skills to be transferred from a University to a High School environment proved to be crucial for the execution of the research at hand.

To understand how the process of knowledge transfer happens from a University to a High School environment, we need to start with more background information on how collaboration between high school and faculty commenced and where in the process the knowledge transfer occurred.

2.1.2 Process of transfer

Since 2017 in Slovenia there is a systematic approach, the project SKOZ [4], trying to connect students from high schools to mentors at the Public research organizations. Although this particular connection has been established via personal means, it is significant, that the researchers involved take part in the initiative SKOZ.

The project itself will end at the end of 2020, during which time, together with schools from the Western Cohesion Region, research partners and business partners, established a solid and functioning network of organizations that encourage the most talented students with projects. Jožef Stefan Institute took part in the initiative, supporting more than 40 students so far.

The purpose of SKOZ was to connect students with mentors and experts for the transfer of knowledge, in order to allow specific subjects from a supportive environment to deal with the field of work in specific research of the students.

Gimnazija Bežigrad was not the recipients of the funds of the tender announced in August 2017 by the Ministry of Education, Science and Sport. Even though it was not actively involved, it still aimed at supporting and encouraging collaboration of the experts with talented students.

In line with the idea of the project, in which the experts of the Jožef Stefan Institute actively collaborated and understood its purpose, also other more personal initiatives as this one were absorbed.

Thus on the point where digital skills transfer of knowledge was established as a break through element, which will enable this study to be carried out, although via personal contacts, the collaboration has been established between the IB Gimnazija Bežigrad student and the experts from Jožef Stefan Institute and Faculty of Mathematics and Physics.

The transfer of knowledge resulted in the setup of the processes required for the data analysis, as described below.

2.2 Analysis of data

2.2.1 Python script- image color processing

The photos taken by the camera were then transferred to a computer, where further analysis was carried out. The captures were analyzed using a Python script that determines a specific RGB light composure of a certain pixel on a straight line, whose direction and extremes are provided by the user. The result of the image color processing is a graph of light intensity in the correlation with coordinate of the pixel explored. The base code was found on the internet [5] and was then changed so that it suited my experiment's needs.

2.2.2 Root script- intensity analysis and image splitting

ROOT [6] was in this experiment used in two parts of analysis. Firstly, the picture of the phantom had to be split up in several smaller pictures, which were only showing one hole in the phantom at a time. This step was required to enable easier management with the original data. Other processes in the analysis were then run on large amount of very similarly structured photos, which enabled the code to be less complicated.
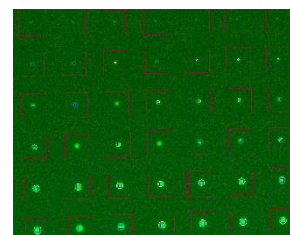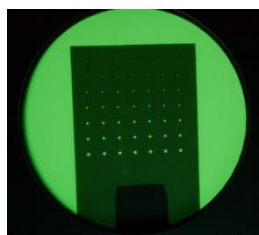

Figure 1. Irradiated phantom   **Figure 2. Image splitting**

Secondly, the color analysis done in ROOT analysis framework is similar to the one in Python. However, in this case the options for the analysis are much wider. A light composition analysis investigation can be done over the x-, y- axis and over the whole

picture. To achieve the highest accuracy of the outputting values the analysis over the whole picture was done. The program tried to fit an error function [7] on the 2D response. Borders of such a signal is usually treated as a Gaussian function [8], so when a number of signals are treated together as one signal, convolution of the point response with the image shape makes the borders take form of an error function. The fitting of an error function was in my case used all around the given circular 2D signal (Fig.6).
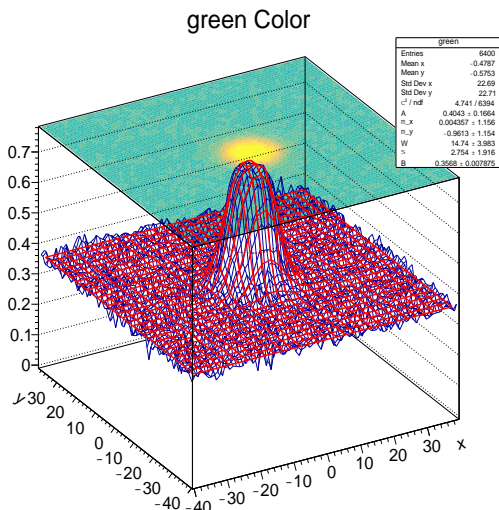

Figure 3. 2D histogram of a captured photo

The outputs that determined the double error function were:

-A, the height of the signal,
-W, the width of the signal,
-B, the height of the background,
-∂, the width on the half of the height of the graph od derivative of the error function

2.2.3 LoggerPro analysis

The data acquired from the analysis by the code in Python and ROOT can be transferred to LoggerPro by importing the data as a text file with different columns. After the data is appropriately represented, we can identify the average height of the signal and the average width of the border by using cursor coordinates displayed by LoggerPro. The data gathered was then presented in the table to show the correlation. Graphs were drawn to explore different dependences.

3. RESULTS

The images captured using the phantom with holes and the above described setup (Fig.3), were analyzed using the described digital tools.

Our goal was to determine the sharpness of the holes' images. The results acquired from the exploration were firstly in the form of pictures (see example in Fig.7). After the analysis using the developed Python programming tools the results had a numerical form, since they represented an average width of the signal and the average height. Both obtained values are an important test of the sharpness of the picture border and the quality of the photo.

After the ROOT script was run on a set of little pictures, as presented above, the code tried to find the best fit for the mentioned double error function. The parameters that root used to find the best correlation, were then exported to a .txt file, where they could be used for further analysis.

On the pictures captured with the lower input voltage the smallest holes of the size of 0.5mm were really hard to see and the analysis of light intensity on those was not returning consistent results.

That is why I decided to perform the research only on the remaining 6 different sizes of gaps (0.8mm, 1mm, 1.4mm, 1.6mm and 2mm).
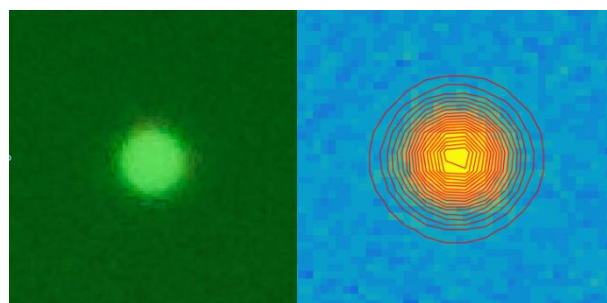

Figure 4. Example of analyzed material   (left)

Figure 5. Python color intensity test   (right)

The voltages used in this experiment are displayed in the table below:

Table 1. Accelerating voltages used on the X-ray apparatus

Trial no.	1	2	3	4	5	6
Voltage [kV]	35	32	29	26	23	20

The aim of this experiment was to explore how changing the voltage affects different image quality properties.

3.1 Resolution dependence on the voltage

σ is a parameter of the error function that essentially tells us how steep the border between the peak of the signal and background of the measurement is. It represents the width of a derivative function of the error function. The width of the derivative is a statistical value that tells us how well the border of the picture was captured, the quality of the image can be described.
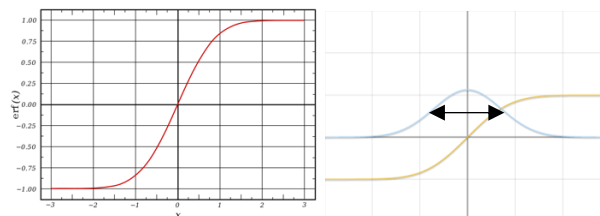

Figure 6. Error function   (left)

Figure 7. Average width of the derivative function of the error function   (right)

The data that was processed with the mentioned codes resulted in the graph, where the *sigma*-value does not increase or decrease with the variation of voltage. There was no found correlation since the changes in the values with different voltages are probably a result of a statistical error. The data gathered and averaged is collected in the table and the graph below.

Table 2. σ's average values for different gap diameters and voltages

Diameter of the hole [mm] / Voltage [kV]	2	1.6	1.4	1	0.8	0.5
35	3.07	3.43	3.47	3.38	3.63	3.72
32	3.03	3.45	3.46	3.46	3.60	6.04
29	3.00	3.44	3.47	3.41	3.11	3.54
26	3.21	3.66	3.70	3.49	3.68	2.97
23	2.92	3.33	3.48	3.17	3.28	3.55
20	3.93	4.39	4.46	8.93	10.17	4.01
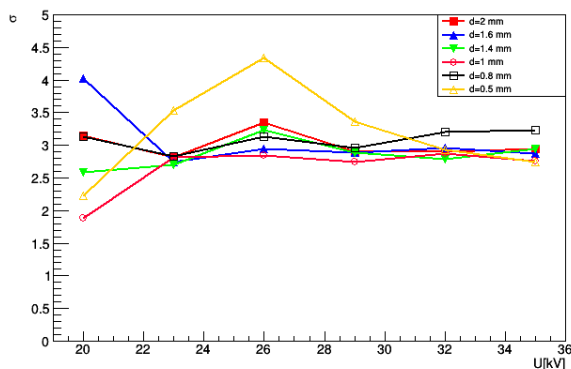
Graph 1. σ 's correlation with voltage

We can clearly see that the differences between the values are not the consequence of the variation of voltage.

4. DISCUSSION
4.1 Usefulness of the Transfer of knowledge

As the baseline, I need to reconfirm the thesis that none of this work would be possible without the collaboration between Gimnazija Bežigrad and Jožef Stefan Institute alongside with the Faculty of Mathematics and Physics. The knowledge transferred in the field of digital skills and analysis were of the utmost importance for the design and execution of the experiment.

The role of the project SKOZ was previously explained and can here be reconfirmed that it has created, at least for this particular setup of people, technologies and skills needed, an awareness of a need for collaboration and transfer of knowledge between the different educational systems.

The creation of digital skills in a different environment and a transfer of knowledge and promotion of digital analytics has been subject to personal experience and efforts, which I am thankful for. This, however, also sheds a ray of light onto the future possible transfer of knowledge and skills between the two educational systems.

4.2 Accuracy of the established digital tools

The ROOT and Python analysis scripts I ran on captured photos often did not give very accurate output, because the starting parameters were not set correctly. Even though I worked on improving the code to the point, where the efficiency and reliability was relatively high, there were still some cases where the code using the described models did not converge with the initial parameters provided. Especially the part of the experiment, where the Root script was finding optimum double error function to fit on the given data, was problematic, since a small difference in the way function was structured had major impact on the output parameters.

To conclude, the experiment could of course be performed more efficiently, professionally, accurately, the errors could be minimized. However, I believe that with given time, resources and my non-existing previous experience with such machinery, the experiment was performed optimally, and the results are quite relevant as they show how and to what degree digital skills are important in analysis of data obtained in physics experiments.

Moreover, not only is the transfer of knowledge important between the industry and public research organizations. It is pertinent that the transfer of knowledge is supported between the educational systems to allow for an optimal human resources development for the future industrial needs.

5. CONCLUSION

Ultimately, the results could not have been obtained without using digital skills. STEM collaboration between high school and experts with highly developed digital skills is of utmost importance in order to firstly promote digital skills at a relatively early age of students, and secondly, to enable the students to learn them and use them in real-experimental setups, measurements and analysis.

The conclusion is, that transfer of knowledge is very important in the STEM field and that young people can obtain many options and opportunities with such transfer of knowledge, which would otherwise would not be achievable for them – and is not time financially or consuming for the university system at all. Only through transfer of knowledge and skills between the two educational systems optimal solutions can be found.

6. ACKNOWLEDGMENTS

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