# Development of Backend an Interactive Online Service for Conducting Numerical Experiments with Flat Multi-Pinhole Coded Apertures

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# Development of backend an interactive online service for conducting numerical experiments with flat multi-pinhole coded apertures

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***Abstract*— There are over 70,000 different coded apertures currently known. However, in the studies described in the modern literature, approximately the same coded apertures appear, which usually are far from optimal. The goal of our project is to develop a publicly available online service to allow any interested researcher conduct an unlimited number of experiments with any coded apertures. Each experiment can be accurately modeled using the Geant4 simulation software.**

***Keywords—geant4; coded apertures; tomography; python; flask; online-service***

## I. Introduction

Integral-code or multiplexed measuring systems (MSS) are a set of systems consisting of coded apertures (CA) and a position-sensitive detector (PSD), which form a general image , with integral character. General image is a superposition of images from each point of the collimator, which has no resemblance to the object under study, i.e. the collimator encodes the radiation which comes down on the PSD. Various numerical computational methods are used for decoding [1].

## II. Coded Apertures

### A. Characteristics

A coded aperture is a device that allows you to obtain images without focusing beams emanating from point or flat sources of radiation. The simplest is a single-pinhole collimator (SPC). A pinhole is a small hole on an opaque screen. Various CA are known: in the form of a Fresnel zone plate or two gratings perpendicular to each other, slotted collimators and multi-pinhole collimators, in which pinholes can be located in a random or pseudo-random way, and each pinhole is considered as OK [2]. The best type is the multi-pinhole CA (MPCA), which is built, for example, in a pseudo-random way.

CA is similar to a lens, since it has the property of focusing radiation, it is also insensitive to the radiation wavelength. The initial motivation of using MSS was their noise-suppressing properties, they sharply reduced the contribution of statistical error, but these advantages are insignificant in radiation instroscopy [3]. MSS is widely used in radiation introscopy due to its tomographic properties. The Point-Spread function (PSF) can serve as a criterion for the tomographic qualities of MSS. If the HF is close to the three-dimensional delta function, then the better the tomographic qualities of the CA will be.

### B. Applications

CA used in various fields of science and technology, for example, in spectrometry, radio astronomy , radiation introscopy, radiation safety, and in many other areas [4].

For example, there is a certain difficulty in observing such massive cosmic bodies such as black holes, quasars, neutron stars, pulsars, etc. Moreover, they are all located at great distances from the Earth, and the further they are, the more background noise will be during registration radiation of bodies. Space objects can be considered as point sources with radiation, which are in a wide energy range. X-ray and gamma-ray astronomy are engaged in their study. In this case, it becomes relevant to use MPCA with good noise suppression properties.

## III. Pseudo-Random Sequences

As already mentioned, the best is MPCA with pinholes arranged in a pseudo-random way. Such collimators are built on the basis of two-dimensional tables, called pseudo-random tables (PRT), which are built on the basis of one-dimensional pseudo-random sequences (PRS) of zeros and ones, which have some special properties.

A pseudo-random sequence is any row or column of the circulant matrix with parameters v, k, λ. The cyclicity of the matrix is achieved by using collimators with a large number of pinholes and with a cyclic continuation of the main part of the collimator.

A circulant matrix is a square matrix with dimension v if the following condition is satisfied (1),

$$\hat{A}\hat{A}^T = (k - \lambda)\hat{I} + \lambda\hat{J} \quad (1)$$

where $\hat{I}$ is the identity diagonal matrix, $\hat{J}$ is a square matrix of order v from ones, $\hat{A}^T$ is the transposed matrix. Accordingly, the length of the PRS will also be v, k is the number of ones, and λ is some integer that satisfies the condition (2).

$$\lambda = k(k-1) / (v - 1) \quad (2)$$

*A. Methods of Construction*

There are three ways to construct two-dimensional PRT based on one-dimensional PRS: line-by-line, diagonal, and self-sustaining. The line-by-line method allows one to obtain a two-dimensional table of (3) dimensions from one PRS, and a mosaic from the PRS is obtained with a shift. The table obtained by using the diagonal method has the same dimensions, but the numbers must be relatively simple, the mosaic will be without shift. The self-sustaining method gives a table of two PRS with dimensions (3), the mosaic will also be without a shift. The dimension of a sequence constructed in a self-sustaining method is,

$$v = m*n \quad (3)$$

where m - dimension of the first pseudo-random sequence, n - dimension of the second pseudo-random sequence.

Figure 1 shows coded aperture constructed by the line-by-line method with dimension 71*73. Figure 2 shows coded aperture constructed by the diagonal method with dimension 71*73. Figure 3 shows coded aperture constructed by the self-sustaining method with dimension 71*73.

*Fig.1 Line-by-line coded aperture*

Also, pseudo-random tables can be built not only on the basis of zeros and ones, but also on the basis of ones and negative ones, also on ones, zeros and negative ones. Implementation of minus ones using two measurements with two multi-pinhole CA and the subsequent difference between the two measurements.

*B. Extended Pseudo-Random Sequences*

There is one significant drawback when using coded apertures - the existence of a small number of PRS with dimensions suitable for constructing a PRT, therefore, the problem of finding new types of coded apertures hasn't been losing its relevance until now.

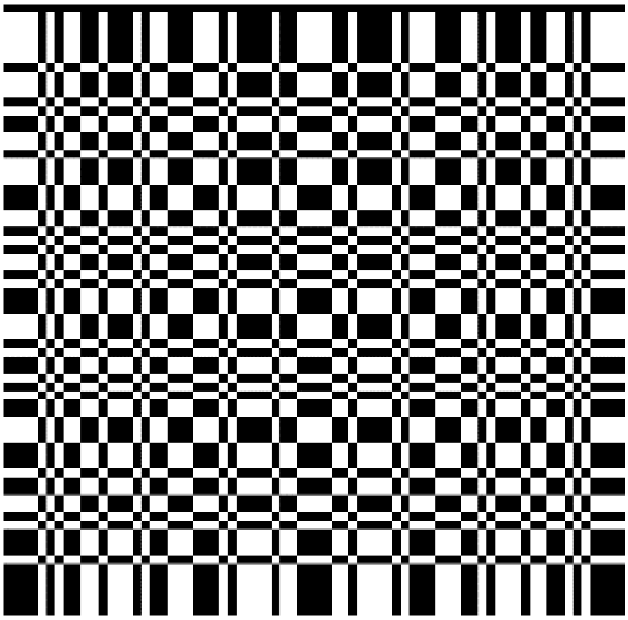

*Fig.2 Diagonal coded aperture*

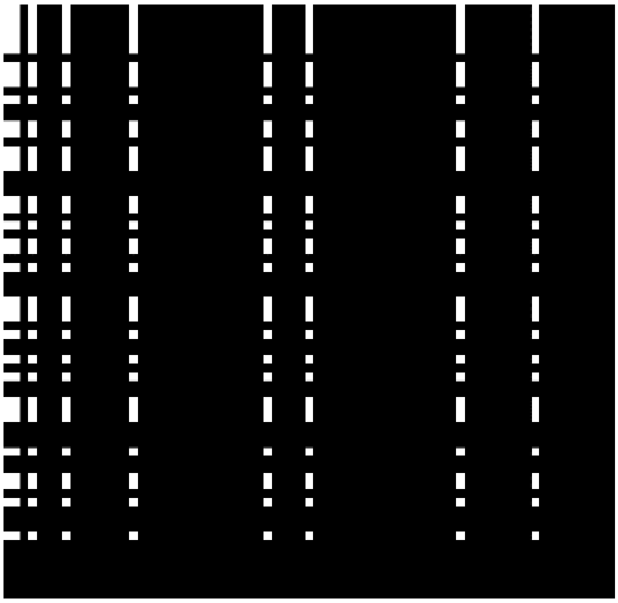

*Fig.3 Self-sustaining coded aperture*

For example, there is a class of generalized pseudo-random sequences (GPRS), as well as extended PRS (EPRS). The algorithm for constructing the EPRS consists in adding to each element of the PRS any equal number of zeros [5].

At the same time, the number of possible two-dimensional PRT and the corresponding CA, built on the basis of the EPRS with the sequence dimension from 7 to 99, increases from 57 for the line-by-line, 46 for the diagonal, and 276 for the self-supporting methods of constructing sequences, respectively, to 75234 for the first, 37764 for the second, and 51681 for the third way. The dimension of the sequence can be calculated by the (4).

$$v = v(b+1),\ b=1, 2, 3\ldots \quad (4)$$

That is, it can be seen that the number of extended PRS existing on their basis exceeds many times the same number of conventional PSP, and the number of suitable sequences for research also increases. This solves the problem of finding new types of sequences.

### *C. Hexagonal Configuration*

An one-dimensional PRS can be used to obtain another type of PRS - two-dimensional pseudo-random hexagonal configurations (PRHC), obtained from PRS by folding into a hexagonal structure [6]. But not every PRS will be suitable for building PRHC on its basis. The dimension of the hexagonal configuration can be calculated by the (5),

$$v = 3R(R+1)+1 \quad (5)$$

where R - integer, configuration rank.

Extended PRHC can also be built from EPRS, the number of possible configurations will also increase many times. The PSGK mosaic structure can be built by adding to the main hexagon on all sides of the halves of the same hexagons, except for those elements that are located on the diagonal.

To further increase the number of existing configurations, there is a way to build pseudo-hexagonal coding configurations (PHCC). A number of cells are added or removed to the main part of the hexagon, but the periodicity of the resulting configuration must be preserved, and the mosaic must remain feasible. For configurations with rank R, there are an infinite number of possible positive configurations, and the quantity of negative configurations exists is one less than R. The dimension of the extended configuration is determined by (6),

$$v = 3R(R+1)+1+Q(2R+1) \quad (6)$$

where Q- coefficient of modification, equal to: -R, -R+1, …, 0, 1…

## IV. Online-Service

More than 70,000 different coded apertures are currently known. However, in the studies described in the modern literature, approximately the same coded apertures appear, which always are not optimal. The numerically calculated instrumental functions of the coded apertures are a useful tool for analyzing the tomographic properties of the spacecraft. Point-Spread functions and their characteristics, brought together in a single database, allow not only choosing the best of the whole set of possible ones, but also carrying out a statistical analysis of CA characteristics.

### *A. Purpose of the Project*

The development team of which I am a member, creates a project, the goal of which is to develop a public online service which allows any interested researcher to make an unlimited number of experiments with any coded apertures. All parameters of the experiments will be flexibly configurable, and the results are saved in the database for further analysis. Also, the results can be saved as a report at any convenient time.

An especially important task is to expand the class of possible coded apertures, as well as to study and optimize their focusing properties, which are essential for tomography.

Also, there are no complete or incomplete analogs currently. Only my team and I, for the first time in history will collect and systematize knowledge about coded apertures, about classical unextended and extended pseudo-random sequences. On the platform, you will not need to repeat experiments with collimators every time and wait for the construction of Point-Spread functions, but you can look at the experiments already carried out in your profile and upload their results in any form.

This is a huge array of systematized data that has not been collected in one place previously, which is a huge advantage.

### *B. Opportunities and Areas of Interest*

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

The user will be able to conduct an unlimited number of flexibly customizable experiments of several types:

- The behavior of the CA when encoding / decoding a noisy flat image. It will be interesting to researchers using CA in gamma astronomy.
- Construction of the point spread function of the CA for various geometric parameters. It will be interesting to researchers using CA in gamma visors.
- Carrying out longitudinal tomography using the focal plane method. It will be interesting to researchers using CA in tomography.

Each experiment can be modeled accurately and statistically using the Geant4 physics simulation program. It should be noted that the Geant4 physical simulation system has not been used for numerical experiments with coded apertures before. There is no single systematized database that contains all known coded apertures.

Before making the experiment, the user will have the opportunity to choose the coded apertures of interest from a huge list of CA.

After the experiment, the user will be able to save a report on the experiment, compare the results with previous experiments of the same type. Conduct a statistical analysis of the results.

The developing service will find application in research centers and laboratories actively engaged in developments related to coded apertures.

## V. Development Tools

### *A. Python Programming Language*

Python is a versatile high-level programming language widely used for various development projects. Its interpreters exist for many platforms, so it shouldn't be a problem to run it on any OS. With Python, a huge number of services, development environments, and frameworks are available. Having a variety of sources of information about Python. It will not be difficult to find an answer to any question that may arise. There are lots of free literature, video tutorials, and online courses.

The main disadvantage of Python is that programs written in it run slower than programs written in compiled languages.

### B. Microframework Flask

Flask is a microframework for building small web applications with simple requirements in a short time with Python. This framework implements only the basic functionality, providing developers with flexible tools to add functions as needed during the implementation of the program's functionality.

The advantage of Flask is that simple tasks do not take up a lot of code, and for a not too big application like ours, this is an advantage. This is also its main drawback - it is poorly suited for the development of large projects.

Flask is implemented with minimal add-ons, provides simplicity and accuracy in work, allowing the user to choose how to implement certain things, and also shows flexibility in working with databases, automatically configures Jinja2, which makes it easier to render HTML templates. It protects against the most common and well-known methods of hacking, such as XSS (cross-site scripting). You can easily use file uploading with it . Downloaded files are saved to server memory or to temporary storage in the file system.

### C. Database Management System MS SQL Server

Databases are repositories that store large amounts of information. In our case, these are PSP and their characteristics, user logins and passwords. You can send requests, receive information from them using control systems. Such a system is Microsoft SQL Server.

The advantages of this system are the ability to work on weak computers. Database search and easy editing are implemented. Data is retrieved quickly, and large volumes of requests are also processed quickly. Their disadvantages are that it only works together with the Windows operating system.

### D. PyCharm Development Environment

PyCharm is a cross-platform development environment that is used to compile and debug projects. It can automatically format or complete lines of code, indent for easier reading of the code, highlight possible places in the code where there may be an error, and convenient navigation allows you to instantly navigate in the project.

PyCharm provides full support for various web frameworks and platforms for Python development, and supports the template languages of these frameworks.

Live Editing Preview lets you open an editor and a browser at the same time and track the results of your code changes on a web page. PyCharm saves your changes automatically and they are instantly displayed in the browser without reloading the page.

### E. Model-View-Controller Pattern

Model-View-Controller (MVC) is a technique for building an online service by dividing it into three parts: model layer, controller layer, and view layer. This is necessary for the simplicity and convenience of developing a future application.

Model is a part that operates with any functions related to the application data. This includes, for example, the validation process, the user authorization status, and retrieving information from databases. This part also reduces the complexity and load of the code that is located in the front-end of the application.

View is the part responsible for managing the application's GUI. Graphic elements include all forms, buttons, and other HTML elements inside the application. Separating the design of an application from its logic significantly reduces the risk of errors.

The Controller is responsible for handling events that can be triggered either by the user interacting with the application or by a system process. It accepts requests and prepares data for the response, and is also responsible for setting the response format and interacts with the Model to get the necessary data and generate the View. Figure 4 shows this pattern scheme.

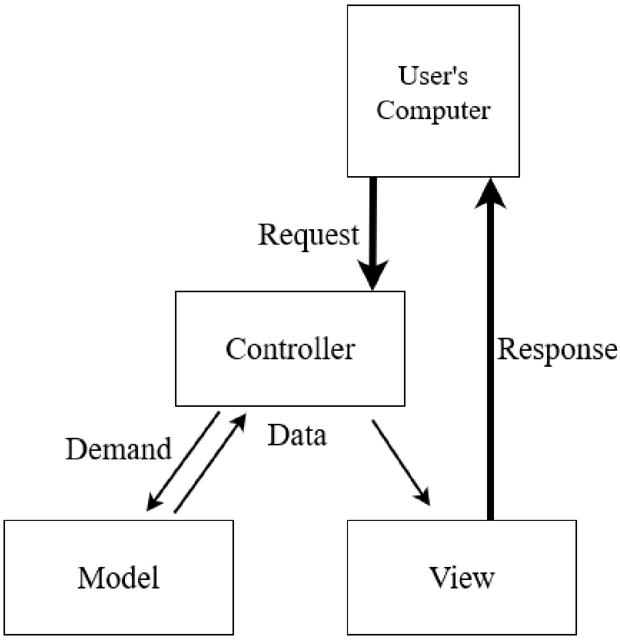


*Fig.4 Model-View-Controller scheme*

## VI. CONCLUSION

In the paper, we presented an online service for conducting numerical experiments with coded apertures. Justified the need to create a service. Told about different types of apertures, as well as about the existence of a huge number of them. Then, we showed the tools used in development and their advantages.

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