Processing of data from innovative parabolic strip telescope.

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Abstract. This paper presents an innovative telescope design based on the usage of a parabolic strip fulfilling the function of an objective. Isaac Newton was the first to solve the problem of chromatic aberration, which is caused by a difference in the refractive index of lenses. This problem was solved by a new kind of telescope with a mirror used as an objective. There are many different kinds of telescopes. The most basic one is the lens telescope. This type of a telescope uses a set of lenses. Another type is the mirror telescope, which employs the concave mirror, spherical parabolic mirror or hyperbolically shaped mirror as its objective. The lens speed depends directly on the surface of a mirror. Both types can be combined to form a telescope composed of at least two mirrors and a set of lenses. The light is reflected from the primary mirror to the secondary one and then to the lens system. This type is smaller-sized, with a respectively reduced lens speed. The telescope design presented in this paper uses a parabolic strip fulfilling the function of an objective. Observed objects are projected as lines in a picture plane. Each of the lines of a size equal to the size of the strip corresponds to the sum of intensities of the light coming perpendicular to the objective from an observed object. A series of pictures taken with a different rotation and processed by a special reconstruction algorithm is needed to get 2D pictures. The telescope can also be used for fast detection of objects. In this mode, the rotation and multiple pictures are not needed, just one picture in the focus of a mirror is required to be taken.

1. INTRODUCTION

The greatest advantage of the parabolic strip telescope is its simpler and cheaper construction. It only requires two holders with a cut-out for a parabolic strip and a strip of a reflective flexible material to create its objective. Tension in the strip material guarantees stability and precision of the reflective surface. The main idea of the reconstruction is based on the same principle as CT (Computer Tomography): the reconstruction of a 2D image from 1D samples by applying the Radon transformation principle. Four algorithms were implemented and tested.
2. DATA PROCESSING
Four various algorithms of data processing have been designed to reconstruct images from the parabolic strip telescope. The image reconstructing software has been developed in MATLAB. The software uses some of its libraries, for example the iradon library, to filter and reconstruct images. This library is employed for example for the filtered back projection algorithm. Individual algorithms are programmed using parallel data processing on CPU. Increases in the processing speed differ depending on an employed algorithm and its specific setting. The filtered back projection algorithm requires $0.7371 \text{sec}$ to process 10 images while only $0.2205 \text{sec}$ is needed when data are processed in a parallel manner. The parallel processing speeds up data processing by about 30%. When the iterative algorithm was used (on the same data set, the reconstruction process was speeded up by about 15%.

2.1. Summation algorithm
The basic reconstruction algorithm is the summation algorithm. This procedure is based on the principle of the reciprocal adding up of resulting projections. Intensities of the points that are covered by segment lines of individual images are accentuated by the summation of multiple images. The other points in lines can be removed by subtracting the matrix with constants in all the places. This technique is very simple and fast. This algorithm is mainly used for quick image reconstruction.

\[
\begin{align*}
X_k & \in \mathbb{R}^{m \times m} \\
\theta_1, \theta_2, \ldots, \theta_N & \in < 0, 2\pi > \\
\vec{x}_k & = \vec{e}X_k, \vec{e} = (0, \ldots, 0, 1, \ldots, 1, 0, \ldots, 0) \in \mathbb{R}^m \\
Y_k & = f\vec{x}_k, f = (1, \ldots, 1)^T \in \mathbb{R}^m \\
Z_k & = \text{rot}(Y_k, \theta_k) \\
Q & = \sum_{k=1}^{N} Z_k
\end{align*}
\]
2.2. Back filtered projection

The filtered back projection algorithm was originally designed for the reconstruction of an image obtained by means of computed tomography. Because the basic principle of the telescope is based on the Radon transformation, it is possible to use filtered back projection for image reconstruction from the parabolic strip telescope. The filtered back projection is a very useful algorithm as the resulting reconstructed images are fine.

\[
X_k \in \mathbb{R}^{m \times m} \quad (7)
\]

\[
\theta_1 , \theta_2 , \ldots , \theta_N \in <0, 2\pi> \quad (8)
\]

\[
\bar{x}_k = \bar{e}X_k, \bar{e} = (0, \ldots , 0, 1, \ldots , 1, 0, \ldots , 0) \in \mathbb{R}^m \quad (9)
\]

\[
Y_k = f\bar{x}_k, f = (1, \ldots , 1)^T \in \mathbb{R}^m \quad (10)
\]

\[
S_k = \text{Ramplfilter}Y_k \quad (11)
\]

\[
Z_k = \text{rot}(S_k, \theta_k) \quad (12)
\]

\[
Q = \sum_{k=1}^{N} Z_k \quad (13)
\]

2.3. Multiplication algorithm

The multiplication algorithm is an enhanced analogy to the summation algorithm. It is based on reciprocal multiplication of individual pre-processed matrices. The main advantage of this algorithm is that if we have a zero (i.e. a dark point) in one matrix, the zero will remain in the resulting matrix when we execute the multiplication. This attribute works as an image filter because dark points partially eliminate the noise from the reconstructed image.

\[
X_k \in \mathbb{R}^{m \times m} \quad (14)
\]

\[
\theta_1 , \theta_2 , \ldots , \theta_N \in <0, 2\pi> \quad (15)
\]

\[
\bar{x}_k = \bar{e}X_k, \bar{e} = (0, \ldots , 0, 1, \ldots , 1, 0, \ldots , 0) \in \mathbb{R}^m \quad (16)
\]

\[
Y_k = f\bar{x}_k, f = (1, \ldots , 1)^T \in \mathbb{R}^m \quad (17)
\]

\[
Z_k = \text{rot}(Y_k, \theta_k) \quad (18)
\]

\[
Q = \prod_{k=1}^{N} Z_k \quad (19)
\]

2.4. Iteration algorithm

The successful variation of the multiplication algorithm is the iteration algorithm based on mutual multiplication of the final projections that proceeds in multiple steps. Images are decomposed to subsets. The subsets are multiplied and extracted until one image remains.

\[
X_k \in \mathbb{R}^{m \times m} \quad (20)
\]

\[
\theta_1 , \theta_2 , \ldots , \theta_N \in <0, 2\pi> \quad (21)
\]

\[
\bar{x}_k = \bar{e}X_k, \bar{e} = (0, \ldots , 0, 1, \ldots , 1, 0, \ldots , 0) \in \mathbb{R}^m \quad (22)
\]

\[
Y_k = f\bar{x}_k, f = (1, \ldots , 1)^T \in \mathbb{R}^m \quad (23)
\]

\[
Z_k = \text{rot}(Y_k, \theta_k) \quad (24)
\]

\[
Q = \prod_{k=1}^{N} Z_k \quad (25)
\]
3. THE PROOF OF PRINCIPLE EXPERIMENT

A simple experiment has been prepared to prove functionality of the device and the software. The experiment was carried out in the form of laboratory measuring. To simplify the whole process, the telescope was in a stationary position. Rotation was performed on a diode board representing a simulated constellation. The simulated constellation was rotated in steps by five degrees. An image was taken during each rotation. Individual images were subsequently processed. It is apparent from the outcome of the reconstruction that the taken image corresponds to its model.

During the next test of the telescope, the night sky was scanned, specifically Venus, the second planet of our solar system, which was selected in particular because of its sufficient brightness. One of the images in the focal point of the mirror taken during the rotation of 0° can be seen in the image (of Venus). Ten images were taken which the resulting image was subsequently reconstructed from. The filtered back projection algorithm and the iteration algorithm were used for the reconstruction. Its outcomes are considerably loaded with noise caused in particular by a low number of individual images. It is apparent that the outcomes achieved by means of the iteration algorithm are better than those achieved by the filtered back projection algorithm.

![Figure 2. Principle of parabolic strip telescope](image)

![Figure 3. Snap](image)
4. EXPERIMENTAL OBSERVATION METHOD
The experimental observation method is another way to make use of characteristic features of the optical system of the parabolic strip telescope. The algorithm of image processing is as follows: Every observed object is recorded by a camera as a line segment of a constant length and constant intensity which is directly proportional to the height of the parabolic strip (the primary optic element). In this manner, the signal on $K$ pixels is obtained. When there are two superimposed objects aligned in one axis, the line segments overlap one another. Let $x_n$ assign a number to each of the pixels in one column of the image matrix which is being analysed. If the intensity of objects observed by means of standard telescopes in individual superimposed points is marked as a set of numbers $F(x_n)$, then it is possible to record intensities of individual pixels for the parabolic strip as the $F(x_i) = \sum_{i}^{i+K} f(x_n)$ function. The relation of $F(x_{i+1}) - F(x_i) = f(x_{i+K}) - f(x_i)$ will be used for reconstruction of an image. The reconstruction algorithm begins in front of the point where the image line segment begins, where $f(x_i) = 0$ for all $i$ smaller than the first pixel of the image line section. The zero value has to be assigned to all the points from $F(x_i - K)$ to $F(x_i 0))$. This algorithm can be used to reconstruct an image from one snap without any need to rotate the telescope. The reconstructed image will not be in full resolution in both directions.
Figure 6. Snap of Venus

Figure 7. Reconstructed image of Venus – Back filtered projection

Figure 8. Reconstructed image of Venus – Iteration algorithm
5. CONCLUSIONS
The construction of the whole telescope is relatively simple. It is composed of four parts. The base is a multi-axis astronomical tripod with automatic Earth movement corrections. The second part is a firm holder for a servomotor. This servomotor is responsible for rotating the objective of a telescope. Furthermore, a CDD camera is attached to the telescope in the focal point. An image from the objective is projected directly on the CCD chip without any other optical elements. The support elements are made of aluminium and duraluminium. The whole surface is anodized to black colour to minimize light reflection. The mirror holders are made of hardened plastic. This low-cost design makes building of many observatories all around the world possible. It would be possible to observe a large part of the sky when such a system of telescopes with a big objective and an angular freedom of about 15 degrees were employed. Thanks to its low weight, this system is also fit for usage in satellite constructions. The best place for such a telescope is an orbit of the Earth, where all adverse effects of the atmosphere are absent and so it is possible to construct an objective that is large hundreds of meters. A telescope of this magnitude can make observation of distant stars and searching for exoplanets more precise and easier. The resolution of a 120cm large parabolic strip telescope based on preliminary calculation equals those of a parabolic telescope with a 150cm diameter. This design has one more very unique usage. The telescope can be used for observations made outside of the visible spectrum, more precisely within the X-ray and gamma-ray wavelength, by exchanging the parabolic strip material.

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