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1. Introduction
The remote sensing is a general information source of objects on the ground without any physical contact. Moreover, in this study area the radar images have a wide application. The main difficulty at object recognition using remote sensing data is in the variability of patterns at different view angles. Therefore, the task of new recognition technology creation is an urgent. The idea technology is based on training of recognition algorithm using different images, which were obtained by modelling. In this paper, ideas and methods are continuing developed [1], where the radar images modelling method using synthetic aperture technique was considered.

One of this study task is to decrease the computational complexity with increasing of radar images modelling speed. To solve this problem we using the CUDA. The most cost-based part of modelling is computing of raw backscattered signal through the whole trajectory of vehicle with radar movement. In this study, an algorithm was implemented to obtain radar characteristics from all faces of scene using CUDA.
2. Modelling technology

2.1 Modelling stages
Information technology of modelling includes the stages of scene editing and modelling of radar signals and images. The scene editing consists in creation of 3D model of ground with labeled area types and location of object 3D models. The Figure 1 shows the example of some simulated ground scene. Modelling of signals and images includes calculation of the electromagnetic field scattering and the SAR images formation of the objects located on the ground.

The possibility of independent editing of ground, the integration of anthropogenic objects in the scene and “labelling” of the radar characteristics on the relief surface and objects provides the possibility to model a huge number of SAR images variations for different ground and objects parameters and angles of view. For real-time modelling, it is necessary to create a database of typical ground features, 3D models, radar antenna characteristics, the object materials and underlying surface parameters. In addition, the radar movement parameters in the coordinate system associated with the 3D scene of the ground with the objects need to be specified.

![Figure 1. Example of simulated scene.](image_url)

2.2 SAR images modelling method
The image of a synthetic-aperture radar (SAR) antenna is the most informative and useful form of radar data at solving of object recognition problems. We model a process of aperture synthesis, based on the principles of the SAR imaging [2-4]. The trajectory signal is formed in a result of the radar movement along a specified trajectory with recording of the phases and amplitudes history. During the movement, the radar sequentially transmits and receives radar pulses.

The backscattering signal of one point can be presented as:

\[ U(r,t) = U_{\text{max}} \frac{1}{r^2} F(\theta, \phi) a(t - \frac{2r}{c}) e^{j\omega t - \frac{2r}{c}}, \]

where \( r = r(x, y, z) \) is a slant range to point, \( F(\theta, \phi) \) is an antenna pattern function and \( a(t - \frac{2r}{c}) \) is a radar signal function, for example rectangle or chirp pulse.

Therefore, we can write the expression to calculate the signal from some surface \( S(x, y, z) \):

\[ U(t) = \iiint_S v(r) h(r, t) dS, \]

where \( h(r, t) = \frac{1}{r^2} F(\theta, \phi) a(t - \frac{2r}{c}) e^{j\omega t - \frac{2r}{c}} \)

is a the spatial unit-impulse response and \( v(r) \) is the reflection function.
To find the image it is necessary to compute the deconvolution of the received signal and the complex conjugate of the spatial unit-impulse:

\[ I(r') = \int_0^{T_s} U(t) h^*(r', t) dt, \]

where \( T_s \) is a time of synthesis and \( r' \) is a range to some point on the imaging surface.

The described model allows solving the problem of SAR modeling based on spatial and time domain description of the signal processes generation, propagation and processing. The ground range and cross-range are the coordinates of obtained SAR image.

2.3. Modelling examples

As an example, the results of modeling experiments of the SAR images formation for T-72, BMP, and BTR models are presented below. In accordance with the described above technology stages, firstly, a three-dimensional model of ground was created. Secondly, the 3D model of an object was joined in the formed 3D scene. To obtain the image, in the 3D scene with the object model was simulated and the radiation of radar signal. Finally, the raw signal was processed in accordance with the antenna model and it motion parameters in coordinates of the 3D scene.

In the modelling, we set the parameters given in Table 1, which correspond parameters that were used in the experiments of SAR images obtaining for MSTAR dataset (Moving and Stationary Target Acquisition and Recognition).

### Table 1. Modelling parameters.

| №  | Parameter                          | Measurement | Value             |
|----|------------------------------------|-------------|-------------------|
| 1  | Start radar point \((x,y,z)\)       | m           | (-4335.5;1325.5;-50) |
| 2  | Mode                               |             | spotlight         |
| 3  | Synthesis length                   | m           | 100               |
| 4  | Count of synthesis points          |             | 400               |
| 5  | Minimal wave length (chirp)        | m           | 0.02941           |
| 6  | Maximal wave length (chirp)        | m           | 0.03327           |
| 7  | Pulse duration                     | mcs         | 0.5               |
| 8  | Time discretization                | ns          | 0.5               |
| 9  | Minimal range                      | m           | 4510              |
| 10 | Maximal range                      | m           | 4630              |

In Figure 2 is shown the real SAR images of T-72 (a, b), BTR (c, d) and BMP (e, f) from MSTAR data set for depression angle of 17° and aspect angles of 3° (a, c, e) and 42° (b, d, f) accordingly. For convenience, Figure 3 presents SAR images of the same object with same angles were obtained using modelling approach described above.

The modeling software, which implements the information technology, includes the following components: map editor, 3D editor, terrain generator and common interface. In the program there was implemented two basic stages of modeling: the formation of a ground with specified parameters and the construction of a 3D model. The material properties of the models are assigned to all facets, which can reflect radar pulses at different angles. In the program, a radar response is simulated from all 3D scene faces, which is then processed for receiving SAR image.

3. HPC implementation

The main operations with high computational complexity is in solving the aperture synthesis task and calculation of the all elements of the three-dimensional scene backscattering with computing of the integral given in Section 2. In this study, the parallel program was implemented using CUDA.

For convenience, Figure 4 shows the time graph in log scale of CPU and CUDA programs execution, which depends on the radar image size. The result acceleration for models with different
faces counts is shown in Figure 5. The experiments were carried out on computers with AMD FX-6300 processor 4.2 Ghz frequency and Geforce GTX 750 graphic card 1 Ghz frequency.

The obtained results show the high potential using CUDA at SAR images modelling of complex scenes. Moreover, such program can be used for real time modelling of images that are used for training the recognition algorithms.

Figure 2. SAR images of T-72, BTR and BMP from MSTAR.

Figure 3. Modelled SAR images of T-72, BTR and BMP models.
4. Technology approval
To test the train possibility of the recognition algorithm on the images were obtained by modeling, we used the recognition technology described in study [5]. For example, in work [6] authors try to recognize ships on real images using modelled images and in the study [7] were presented the results of the recognition by pretraining the convolutional network on modelled images. There a lot of kinds of features that can be used in the recognition [8], [9]. In this work we used the pixel based features on account of better informativeness. To train the recognition algorithm for each models it was created 100 images (T-72, BMP and BTR).

![Figure 4. Comparison two algorithms time execution.](image)

![Figure 5. CUDA/CPU acceleration.](image)

Table 2 shows the results of recognition using training with modeled images. We reach the result of 62.78% correct recognition for three classes using relatively small training dataset of 300 images (besides the MSTAR dataset contains 587 images for train). The results of correct binary recognition of T-72 and BMP2 are shown in Table 3 and we notice that the result is rather high (80.24%).

|         | BMP2 | BTR70 | T72 |
|---------|------|-------|-----|
| BMP2    | 402  | 124   | 61  | 68.48% |
| BTR70   | 134  | 43    | 19  | 21.93% |
| T72     | 119  | 51    | 412 | 70.79% |

Table 2. The recognition experiment confusion matrix.

|         | BMP2 | T72 |
|---------|------|-----|
| BMP2    | 496  | 91  | 84.50% |
| T72     | 140  | 442 | 75.94% |

Table 3. Binary recognition confusion matrix.

It can be predicted that the quality of recognition using training step on modelled images is a little less than using MSTAR [5]. It is necessary to notice that the real images can be obtained for a limited set of registration parameters. The more accurate parameter values can be established when modeling the SAR images with using some specified parameters of vehicle movement, which are received from the onboard navigation devices.

5. Conclusion
We proposed the technology that allows sufficiently precisely model real processes of radar signals radiation and backscatter. An important advantage of the technology is the possibility of independent ground models formation, embedding 3D objects in the scene and implementation of radar antenna movement nearby the scene for modelling of radar signals radiation and backscatter. A software that implements the technology has been created where the most resource-intensive computations are executed using CUDA. The high quality of real SAR images reproduction is confirmed by the results of object recognition. The modeled images are used in training algorithms and in the result probability
of tank recognition using MSTAR images equals 80.24%. The performance results shows the implementation ability of proposed modelling and recognition technology in real time.

6. References
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