

Introducing robotics with computer neural network technologies to increase the interest and inventiveness of students

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ABSTRACT: To improve students' understanding of robotics and their diverse application, the authors developed a training course on robotics, where students can translate their ideas on solving global problems into reality, using the latest achievements of artificial intelligence, computer neural network technology, machine learning, space technology and microelectronics. In the development and subsequent delivery of the training course, particular attention was paid to the choice of problems that would attract students' interest, and thus increase their involvement and motivation in generating and implementing their ideas. In this article, the authors present one of those ideas, where the teacher and students together created a prototype of a small spacecraft (nanosatellite), which backed up by artificial intelligence and neural networks was able to observe, find and warn about forest fires from space. This example demonstrates the key role of students' interest and engagement in increasing their inventiveness.

INTRODUCTION

Robotics in education can be viewed as a new interdisciplinary direction of teaching students, which integrates knowledge about physics, mechatronics, neural network technology, mathematics, cybernetics, and information and communication technologies. In this approach, students of different ages can be involved in problem solving based on innovative scientific and technical creativity. Competency in robotics increases competitiveness on the labour market where such specialists are in high demand.

The latest advances in electronics, microelectronics, information technology and computer science have impacted on every sphere of life. In the last ten years, new areas like artificial intelligence, neural networks, and machine learning have rapidly progressed. These latest discoveries have a huge range of applications now and will have even more in the future.

The tandem of space technology and new advances in digital technology is very promising. It is hoped that artificial intelligence, neural networks and machine learning will help to find the latest solutions in the aerospace industry [1].

At *L.N. Gumilyov* Eurasian National University, Nur-Sultan, Kazakhstan, one of the main goals is to equip students with the knowledge and competencies required in the 21st Century. Within this goal, several initiatives have been undertaken. One of them was the introduction of robotics into the curriculum, which provided an opportunity for students to create a prototype of a small spacecraft (nanosatellite) in the CubeSat format, equipped with electronics and artificial intelligence, capable of performing at least half, and hopefully most, of the functionalities of a nanosatellite; namely:

- Power itself through solar panels;
- Use a neural network to detect forest fires from space;
- Transmit signals and certain types of data;
- Change and determine its orientation, position in space and trajectory;
- Receive and process the nanosatellite flight data.

LITERATURE REVIEW

A literature review was undertaken to support both the teacher and students in their creation of a neural network to be installed in the on-board computer software and capable of detecting forest fires from space using the on-board camera of the nanosatellite. A few basic definitions that underpinned this development are included below.

What is a neural network? A neural network is a sequence of neurons connected by synapses. The structure of a neural network came into the world of programming from biology. Due to this structure, a machine acquires the ability to analyse and even remember various information. Neural networks are capable of not only analysing incoming information, but also of reproducing it from its memory [2].

A neural network is a machine interpretation of the human brain, which contains millions of neurons transmitting information in the form of electrical impulses.

What are neural networks for? Neural networks are used to solve complex problems that require analytical calculations similar to what the human brain does. The most common applications of neural networks are:

- Classification - assigning data to parameters.
- Prediction - the ability to predict the next step.
- Recognition - currently, the most widespread application of neural networks.

Neural networks can qualitatively analyse data to eliminate human error. They are needed to solve mainly two types of tasks: to predict some events and to recognise objects [3].

TRAINING COURSE DESIGN

In this article, the neural network discussed is a convolutional network. It is a type of neural network that is trained first with a teacher. Convolutional neural networks (CNNs) are some of the most influential innovations in computer vision. What exactly do CNNs do? They take an image, run it through a series of convolutional, nonlinear, union and full-connection layers, and generate an output.

As mentioned before, the output can be a class or a probability of classes that best describes the image.

> …*Convolutional networks are a good middle ground between biologically plausible networks and the conventional multilayer perceptron. To date, the best results in image recognition are obtained using them. On average, the recognition accuracy of such networks exceeds conventional ANNs by 10-15%. ANNs are a key technology of deep learning* [4].

A convolution is an operation on a pair of matrices A (of size nx×ny) and B (of size mx×my), the result of which is a matrix C = A∗B of size (nx-mx+1)×(ny-my+1). Each element of the result is calculated as the scalar product of matrix B and some submatrix A of the same size (the submatrix is determined by the position of the element in the result).

> …*When the computer sees an image (receives input), it sees an array of pixels. Depending on the resolution and size of the image, for example, the size of the array could be 32 x 32 x 3 (where 3 is the RGB channel values). To be clearer, let's imagine we have a colour image in JPG format, and its size is 480 x 480. The corresponding array will be 480 x 480 x 3. Each of these numbers is assigned a value from 0 to 255, which describes the pixel intensity at that point* [5].

These numbers are the only inputs available to the computer. Figure 1 shows the idea that by passing this matrix to the computer, it outputs the numbers that describe the probability of an image class (0.80 for a cat, 0.15 for a dog, 0.05 for a bird, etc).

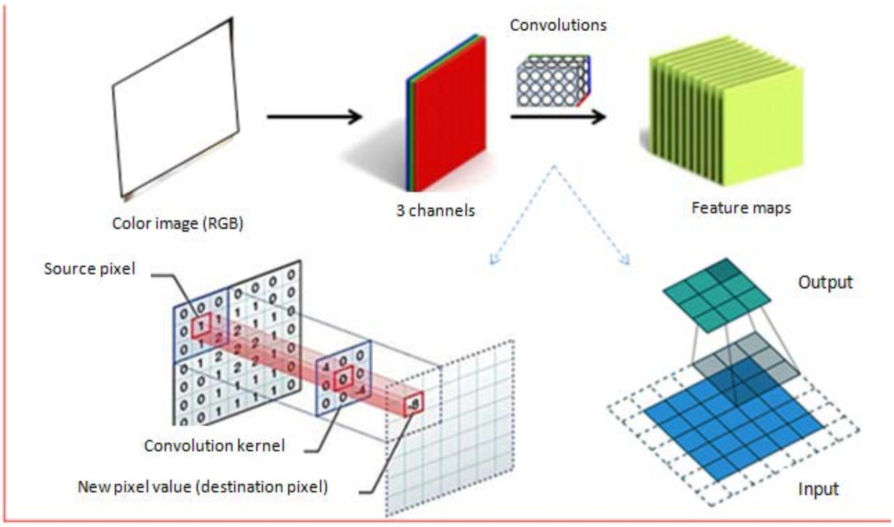

Figure 1: Operation of convolutional neural networks.

The neural network needs to be trained. To train it, the authors collected 943 photos of various forest fires, from different angles and heights, with photographs exclusively from a more or less considerable height (helicopter, quadcopter) and even from space. The minimum number for training is 500, but 900+ were uploaded for even more effectiveness.

> *…It is worth mentioning such notion as Histogram of Directional Gradients - descriptors of special points, which are used in computer vision and image processing for the purpose of object recognition. This technique is based on counting the number of gradient directions in local areas of the image. The basic idea of the algorithm is the assumption that the appearance and shape of an object in a section of the image can be described by the distribution of intensity gradients or edge directions. The implementation of these descriptors can be done by dividing the image into small coherent regions, called cells, and calculating for each cell a histogram of gradient directions or edge directions for the pixels within the cell. The combination of these histograms is the descriptor. To increase the accuracy, the local histograms are subjected to contrast normalisation* [6].

For this purpose, an intensity measure on a larger image fragment as seen in Figure 2, called a block, is calculated, and the resulting value is used for normalisation. Normalised descriptors have better invariance with respect to illumination.

Figure 2: Selecting objects for recognition.

A Python programming environment was required for the entire process of loading, allocating and training the dataset. After completing the training, the operation of the SNS was tested. But before providing a photograph timeline of the performance testing, the training schedule was examined (Figure 3).

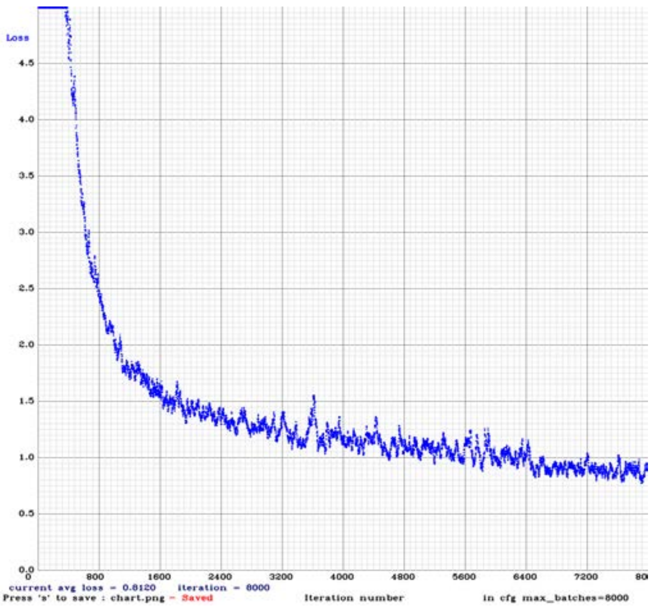

Figure 3: Training graph of the convolutional neural network.

Loss is indicated by a loss function. When calculating the error of the model in the optimisation process, it is necessary to choose the loss function, which is a measure of the neural network's errors and its accuracy. In the context of the optimisation algorithm, the function used to estimate the candidate solution (i.e. the set of weights) is called the target function.

The cost or loss function is crucial, because it must accurately reduce all aspects of the model to a single number, so that an improvement in that number is a sign of a better model.

In Figure 3, it has been demonstrated that at first the *loss* was 4.5, but after a while it decreased to values less than 1. This is a very good result, which means that the neural network is accurate and recognition misfires are unlikely. The results are very good, the neural network can see even small fires, despite the variation in accuracy values. It is worth mentioning that it also does not highlight unnecessary aspects and does not create phantom frames, there are no other errors or disturbances. The neural network coped with the task and did not produce errors.

The nanosatellite has different frame configurations. The basic unit is 1U, *U* coming naturally from the word unit. 1U has dimensions of 10cm*10cm*10cm. By combining units with each other, it is possible to create configurations of 2U, 3U, 4U [7].

A 3U configuration was chosen for this development, with the possibility of further adding an additional unit, due to the tasks and objectives. It was envisaged that the first unit would contain the on-board nanosatellite computer, the second system of orientation in space and the third camera and some scientific instruments.

RESEARCH RESULTS

A group of students from *L.N. Gumilyov* Eurasian National University developed and modelled the frame in the Fusion 360 program. The frame was printed on a 3D printer, according to the developed 3D model (Figure 4).

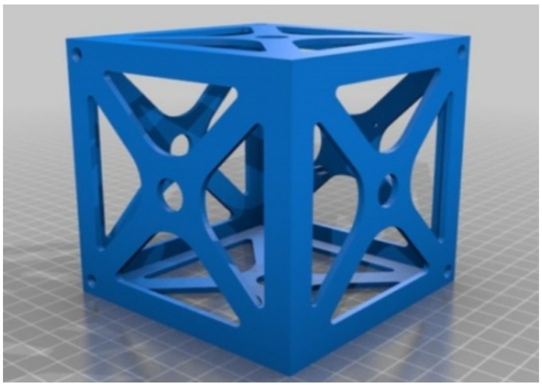

Figure 4: Assembled form.

The printing material is biodegradable and biocompatible plastic Pla+.

Electronics and subsystems - the nanosatellite has five subsystems that are necessary for the functioning of the nanosatellite itself.

The subsystems can be briefly explained as follows:

1. On-board computer - to control and monitor the rest of the subsystems. It is the *brain* of the nanosatellite.
2. Communication system - to provide exchange and transfer of data from and to the nanosatellite.
3. Power supply system - to supply all systems with energy via solar panels, as well as control the energy itself.
4. Position and orientation system in space - is responsible for orientation of the nanosatellite in space, determination of parameters, as well as possible changes of orientation and position through some instruments.
5. Structure: frame configuration, technical layout and the configuration of solar panels.

An Arduino Uno microcontroller (Figure 5) and a RaspberryPi 3B+ microcomputer (Figure 6) were taken as the basis for the on-board computer. Teensy microcontrollers can be added to them in the future.

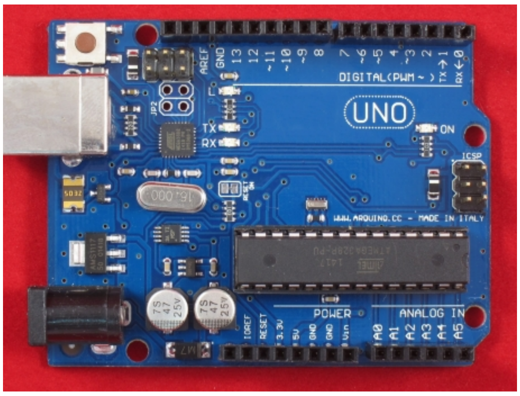

Figure 5: Arduino Uno R3.

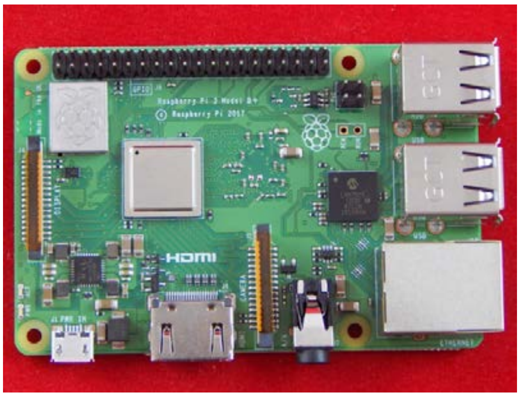

Figure 6: RaspberryPi 3B+.

The performance of these three microcontrollers is enough for a good and functioning prototype (Figure 7).

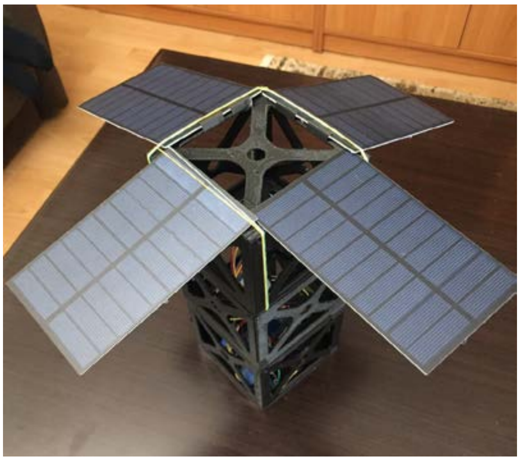

Figure 7: Nanosatellite prototype.

The use of robots in learning created an interdisciplinary connection. This approach is not just about such subjects as computer science, mathematics or physics, but it is an excellent opportunity for students to learn the history of the development of robotics in the world and in their home country.

The integration of software solutions in the content of training courses as a result of socio-economic demands has a positive effect on improving the training of students and their preparedness for future professional activities. However, the latest achievements in hardware and software are often not included in the content of high education curricula in a timely manner. Therefore, this research is yet another attempt by the authors to improve the content of student training by the inclusion of the latest technologies [8].

When conducting a robotics training course for students of educational programmes: 6B01511 - Computer Science, and 7M01511 - Computer Science, the following results were achieved:

- the neural network worked properly, recognising fires, both large, medium and small, down to the details;
- neural network together with the on-board camera of the nanosatellite worked properly;
- power supply system worked properly, the nanosatellite could draw power from the panels, as well as from the reserve stock - batteries;
- the frame was designed successfully and met the requirements;
- the design and configuration of the nanosatellite was well engineered and effectively implemented;
- reaction wheels were working properly;
- sub-systems were co-ordinated and synchronised.

CONCLUSIONS

Robotics and computer neural network technologies have great potential for the implementation of many ideas in any industry, particularly space technology. During the robotics course, students created a prototype of a small spacecraft capable of performing the work of a nanosatellite. Lectures and practical sessions reflected the instrumental role of visualisation in the development of computer neural network technologies.

Practical classes in new technologies are aimed at achieving the planned learning outcomes and meeting the requirements of the set competencies, where the leader should:

- apply the basics of computer science in professional activities and take into account the age-related anatomical, physiological and socio-psychological characteristics of students;
- develop an algorithm for solving a specific computer neural network technology problem;
- debug a program and use various modern programming languages;
- be able to visualise objects and build a neural network to accurately identify the object;
- apply modern information and telecommunication technologies in their pedagogical activities: build computer neural networks, use them in professional activities, master the basics of distance learning technologies and e-learning;
- have an idea of visualisation and technology of neural network model development.

Based on the experience form the training course on robotics and computer neural network technology, it is evident that creating one's own project increases the level of creative thinking and practical skills.

The authors hope that future specialists, equipped with new skills upon the course completion will have plenty of opportunities to implement their own ideas for both educational and recreational purposes.

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