Automation of EDM Machines

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***Abstract*— The automation of metal working machines is usually done for cycle time reduction and for the increase of capacity and precision. This project was started mainly to reduce the downtime between the installation of parts onto the machine. Also, the working conditions next to an electric discharge machine can be harmful to the human body in a long-term period. Collaboration of human and industrial robot will be used to create a semi-autonomous production cell of four electric discharge machining (EDM) machines.**

Keywords—robotics, manufacturing, automation, industry 4.0, electric discharge machines, industrial robot, robot cell

I. Introduction

With the use of electric discharge machining (EDM)[1], [2] we must agree with the fact, that the material remove rate is far not as fast as we are used to with CNC machines. Consequently, companies trying to fit as many workpieces into the machines as possible and they are making a mistake there. It is self-evident that they are trying to maximize their productivity but with the oversized fixtures they make the pallet and workpiece change longer. Especially if they cannot run another pallet because the short of space.

With the creation of an autonomous robot cell, we will try to reduce our downtimes caused by the change of the workpiece and the fixture. Dual education gives us the opportunity to use the resources of the university and also the industrial environment [11]. Thus, our solution can be implemented in simulation and in real-world as well. This paper focuses on the simulation environment.

II. Machined Parts

The workpieces are made of nickel-based superalloys. The electrodes what we are using for material removal are made of graphite. During the machining process relatively huge amount of metal is removed. Also, a thin layer of graphite is burned down from the electrode in each discharging process. The volume of the waste material creation under a full machining session creates about a bucket (5 liters) of sludge.

These workpieces can be found more than twenty different shapes within the area of the factory. For our project we will care about the three most identical. The smallest, the largest and the heaviest composition (see Fig. 1.).

TABLE I. Main Parameter of Workparts

Workpieces' parameters			
Part name	*Overall dimension*	*Weight/piece*	*Pieces / fixture* [a]
Part1	156x79x30 mm	1,1 kg	24
Part2	170x367x244 mm	40 kg	2
Part3	488x610x235 mm	53 kg	1

a. According to the current fixtures.

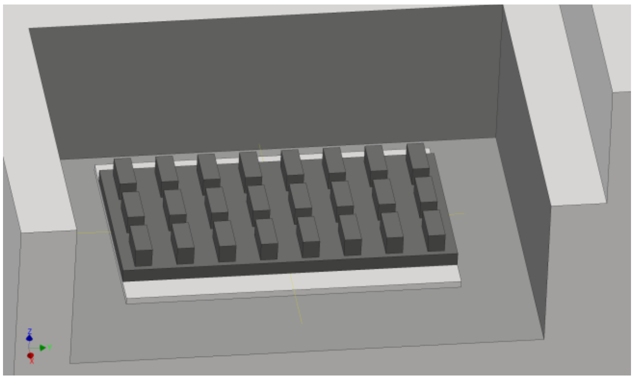

Fig. 1. The model of the largest fixture installed onto the EDM machine

According to the previously mentioned sludge accumulation the use of a conventional zero-point system is impossible. Previous experiences show that most type of commercially available zero-point sets are not sealed enough to handle this amount of waste material. While they are properly separate the dielectric liquid and all solid particles in it if the two segments are attached. As soon as the spigot is moved out of the clamp, sludge and dust can enter the clamping system (see Fig. 2.). Furthermore, the manual cleaning process were not precise enough and small amount of solid particle could get inside the clamping unit from the spigots.

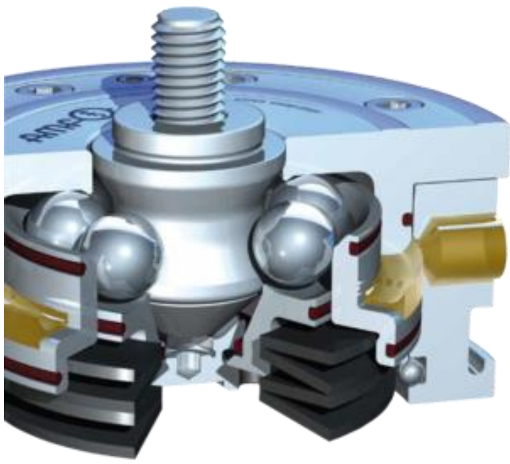

Fig. 2. Cross section of an conventional spigot-clamp assembly [9]

III. Downtimes

Currently the change of parts in the fixture happens while the fixture is installed onto the EDM machine. After the finished parts has been taken out from the fixture, the operators have to clean up its place for the next unmachined part.

In case of installing another fixture to the machine the operators first must have the zero point of the pallet.

The following table shows the downtimes caused by the three most inefficient fixture/part change.

TABLE II. MOST UNEFFICIENT PART CHANGES

Downtimes			
Part name	***Part1***	***Part2***	***Part4***
Number of machined parts	24	6	8
Part change/setup time	1:00:00	0:30:00	0:40:00
Electrode change/setup time	0:15:00	0:10:00	0:05:00
Overall setup time	1:15:00	0:40:00	0:45:00
Machine work time	2:40:00	3:00:00	2:00:00
Cycle time	3:55:00	3:40:00	2:45:00
Downtime percentage	31,90%	18,20%	27,30%

b. All time values should be read as hh:mm:ss.

It is visible that the downtime rate is about an average of 26% in these cases.

IV. ELEMENTS OF THE ROBOTIC CELL

First of all, to eliminate as much downtime as possible, we would like to use custom, self-made pallets. The currently used fixtures would be implemented into the new pallets. A relatively small size pallet would accommodate 6 to 8 pieces from the smallest parts and only one from the largest (see Fig. 3. and 4.).

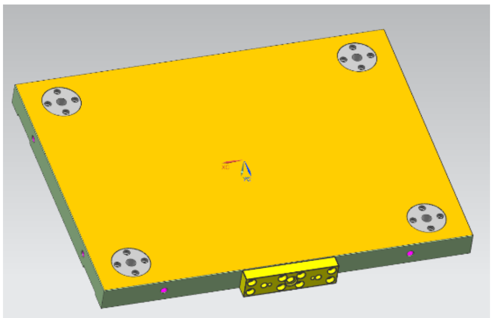

Fig. 3. Bottom side of the coustom pallet

TABLE III. MAIN PARAMETERS OF PALLET

Custom pallet	
Material	EN AW-5083 / AlMg4,5Mn0,7
Dimensions	600x450x40 mm
Weight	31 kg

These pallets should be installed with self-centering cones for easier zero-point measurement. The simple fitting geometry provides easier cleaning too. Since the pallets should be made of aluminum to be lightweight, clamping inserts should be used where the pallets will be fixed by the hydraulic clamp.

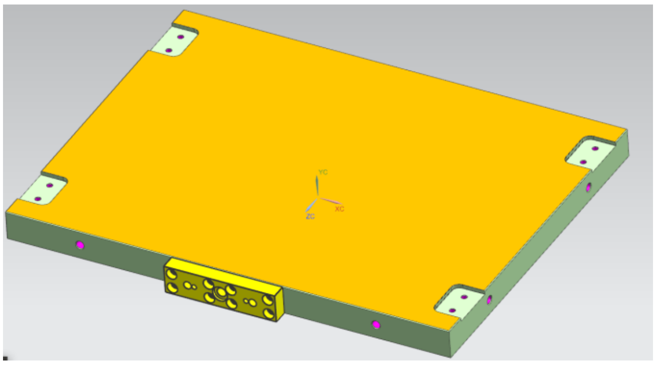

Fig. 4. Top side of the coustom pallet

For the pallet handling we would like to use EROWA's RCS5 GripperLink system which is a pneumatic operated coupling with optional electric feedback (see Fig. 5.). The allowed payload for this gripper is 250 kg (F2) and can handle up to 610 Nm of torque in the center of clamping (M1). [10]

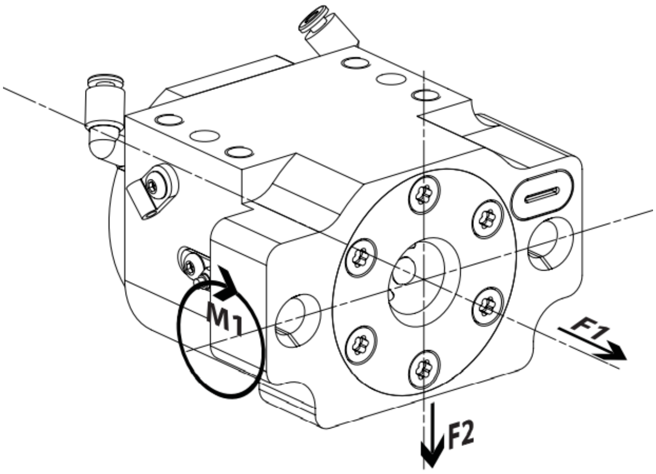

Fig. 5. Allowable maximum payload of robotside RCS5 Gripperlink

For smaller electrodes we would like to use EROWA Gripper S what can be directly attached to the RCS5 robot side GripperLink. This is a very simple two finger, form and force fitting gripper.

Both the pallets and the electrodes should be identified with RFID chips. [3]–[5]

V. LAYOUT CONCEPTS

At the first step of the layout design, we had to consider the environment and all its obstacles. The most important aspect was the crane. It limited our free space because all the four EDM machines should be able to be planted with the crane in case of manual operations (see dashed red line in Fig. 6.).

Furthermore, we had to give enough space for the transfer operations, such as workshop carriages and forklifts. Also we had to leave enough space around the machines for maintenance and cleaning purpose.

A. Layout A

According to the first concept the machines would be placed around the robot (see Fig. 6.). This way the neighbor machines shouldn't be moved. Implementing this plan, we would need the shortest rail. Otherwise, to keep at least one machine manually operatable the robot should be able to bend over the wall of the EDM machine. This also means that in this case the pallet should be attached to the robot along its short side. However, the allowable payload would let us to move pallets this way the additional stress wouldn't be favorable. Thus, the pallet storage systems size would be very limited, and hard to access in case of a manually operated machine.

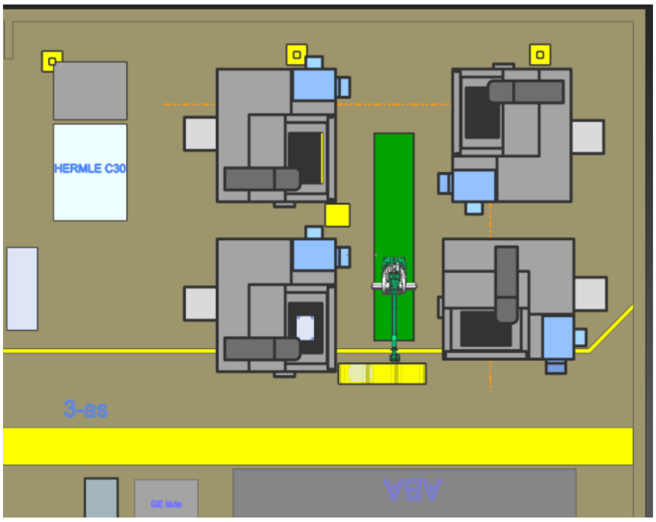

Fig. 6. The first concept of the cell

B. Layout B

In this case the machines are placed very similarly but rotated 90 degrees clockwise (see Fig. 7.). Also, a passageway should be created on the wall, between the 3rd and 4th facility. At the other end of the rail a square shaped storage system should be created. The bottom left machine would be the one that is ready for manual operations, but it still requires to pick the pallets along its longer side and to place it to the machine table over its side.

Although, this plan would ensure all the slots for the pallets that we required, the length of the linear rail would be unbearably long.

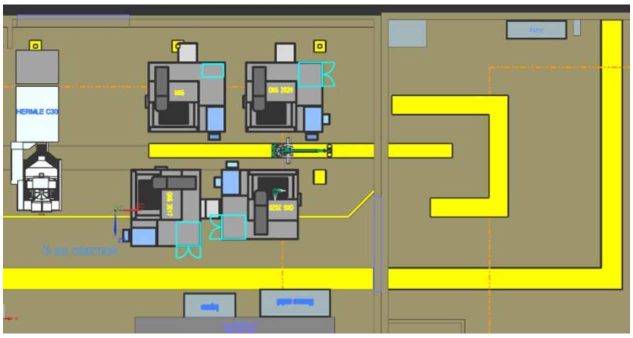

Fig. 7. Second conception of the cell

C. Layout C

The third layout was the most preferred (see Fig. 8.). In this case the EDM machines are horizontally planted next to each other. In front of them the linear rail takes place the overall length of which is 12 meters. Behind the rail the pallet and electrode storing system would be placed. With this concept, an about 1 meter wide "corridor" could be left behind the machines, where the operators can empty the slung cartridge. Also, the sequential separation of the machine is available for manual operation. Not to mention, the cell won't be inside the working area.

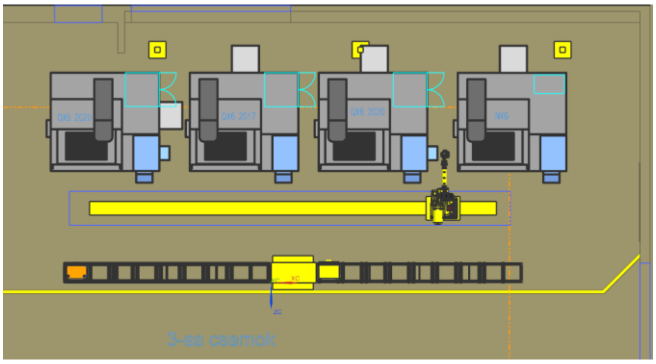

Fig. 8. The most favored layout

The pallet storage system is currently designed as a welded frame which is 6 meters long, 3,5 meters high and 600mm wide (see Fig. 9.). With these dimensions the system could accommodate about 80 pallets equipped with the tallest workpieces on it.

The feed of the storage system would be executed by the robot. The operators should plant the filled and checked pallet to a dedicated slot, next to the system. From this place the robot takes it and places it onto one of the previously defined shelves.

Also, the same method should be applied to the electrodes.

Outside the cell a workplace should be created where the operators can previously install the workpieces into the pallet.

After that a Coordinate Measuring Machine (CMM) should be used to ensure the correct installation of the parts and to obtain main information of the filled pallet. Such as zero points. [6]

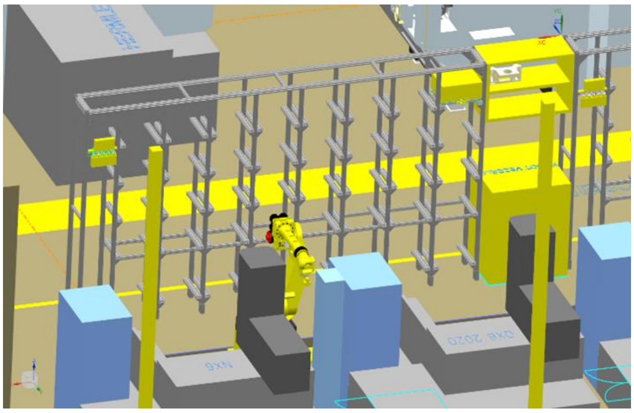

Fig. 9. The pallet storage shelves

VI. ROBOTIC CELL

With the help of Fanuc Hungary, we found that the Fanuc R-2000iC/165F could be an optimal choice for our application. [7]

This is one of the most commonly used type of industrial Fanuc robot due to its great price/performance ratio. Featuring its following properties:

TABLE IV. MAIN PARAMETERS OF ROBOT

R-2000iC/165F	
Controlled axes	6
Repeatability[c]	±0,05 mm
Payload	165 kg
Maximum reach	2655 mm

c. Based on ISO9283.

Both its impressive payload and reach makes it available for the palletizing functions, while the 6 joint makes the electrode change easier.

For the linear rail system, a Hungarian company could be in our help. They are specialized for making welding jigs and mounting appliances for automation and robot systems. The 12 meters long rail could be built up from 6 pieces two-meter-long segments. This way the rail can be extended, so the cell can easily be adapted for the future needs.[8]

The production cell should obey all occupational safety rules. Not only simulated walls and restricted areas should control the robot's work area, but from every side the cell should be enclosed with safety fence.

Moreover, additional safety systems, such as area scanners and monitoring switches would be advised to use where human interference could happen.

For the synchronized work of each element in the cell we are planning to use Siemens S7 PLC with a 10-inch HMI. The network communication of the production cell should be maintained with PROFINET connection.

In the era of industry 4.0 in case such a valuable system the implementation of predictive maintenance is also recommended [12].

VII. RETURN ON INVESTEMENT

The overall projects capital requirement is 350.000 EUR what according to our calculations, in case of all 4 machines working 24 hours a day and 7 days a week with an hourly rate of 34 EUR per machine, and an average 30% of downtime, it would take about 1,5 years to return. Calculated with an 80% of exploitation because of the summer downtime, holidays, maintenance and other unforeseeable downtimes.

VIII. CONCLUSION

The paper introduces the automation of four EDM machines. The main requirements as decrease of downtime, cost effective solution, ergonomic workplace are fulfilled and discussed through several layouts. The return on investment of the proposed solution would is 1,5 years.

ACKNOWLEDGMENT

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Monitoring Of The State Of A Person At Hazardous Work

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***Abstract*—The relevance of increasing the level of safety of the population at work is obvious today. A special place is occupied by work associated with increased danger in the case of monotonous, routine work, when a person ceases to adequately control the situation due to fatigue or distraction of attention, for example, when guarding objects in front of monitors of security cameras, when the driver of a vehicle is driving for a long time, etc. The use of modern digital technologies in this area is a promising area of research. The results of the work are aimed at improving the safety of people engaged in monotonous activities in real time using neural networks. Application area is operational monitoring of the state of a person at hazardous work, for example security of objects or driver of a vehicle. In this study, the design of an intelligent system for monitoring a person's condition during hazardous work (awake or asleep) is considered.**

Keywords—neural networks, emotions recognition, software development

I. INTRODUCTION

Currently, there is a rapid growth in the use of video surveillance systems, which is explained by a wide range of tasks solved by such systems and the constantly increasing availability of surveillance and communication facilities. Video surveillance systems are used in a wide variety of areas: monitoring of road transport systems, security and law enforcement, unmanned aircraft, control of production processes, as well as in many other areas. A person, his life and health are the highest value. The analysis of industrial accidents, injuries, accidents, as well as occupational diseases shows that the main reason for them is non-compliance with safety requirements, human ignorance of man-made hazards and methods of protection against them. The use of video surveillance systems allows you to analyse the behaviour of the observed objects, increase the efficiency of their control, the reliability and quality of the results obtained, and provide support in decision-making. With the development of computer methods for processing visual information, intelligent video surveillance systems capable of automatically analysing incoming information are becoming more and more attractive. Computerization of the process allows dramatically increasing the scale of monitoring and reducing the use of human resources, while increasing the reliability and impartiality of observation.

II. IMAGE PROCESSING FOR RECOGNIZING HUMAN EMOTIONS

There are two approaches to the recognition of human emotions based on the use of neural networks. The classical approach to the problem of classification of emotions is based on the classification of key points of the human face. The location of key points fixes hard and non-rigid deformations of the face due to head movements and facial expressions. Algorithms such as PDM, CML, AAM, DPM, or CNN can be used to obtain key points of a human face [3, 6]. The next stage of recognition in the classical approach is the classification of key points. Support vector machines are well suited for the classification of key points. At the moment, the problem of finding key points is quite well studied and there are a large number of algorithms that allow you to obtain key points with accuracy sufficient for further classification by these points of human emotions. But, to use the classic approach, it is necessary that the position of the face in the image be aligned. An alternative to using the classical approach is the approach based on convolutional neural networks. A convolutional neural network is architecture of artificial neural networks aimed at efficient pattern recognition, aimed at the operation of calculating a new value of a selected pixel, taking into account the values of the surrounding pixels. Convolutional networks are a good basic solution for classifying various visual data, which was used in this work.

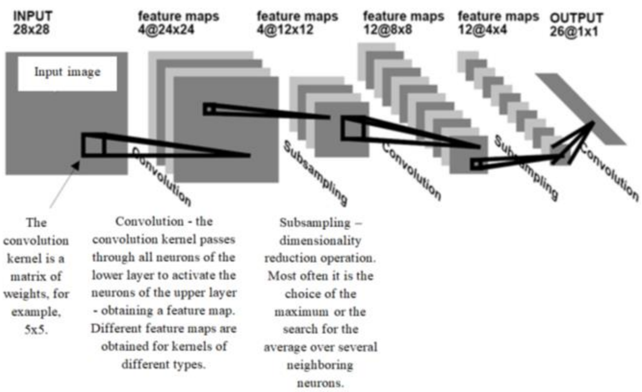

Fig. 1. Network architecture, Yann LeCun [6]

The convolution kernel, which is a square n * n matrix, is used to calculate the value. When processing images, matrices of RGB-channels of pixels in rectangular coordinates are used as initial ones. Image filtering is one of the most fundamental operations of computer vision, pattern recognition, and image processing.

The convolutional neural network (CNN, LeNet) was introduced in 1998 by French researcher Yann LeCun as an extension of the neocognitron model [6] (see Figure 1).

The convolutional network model used consists of three types of layers:

- convolutional layers,

- subsampling layers and
- layers of a "normal" neural network - perceptron (see Figure 2).

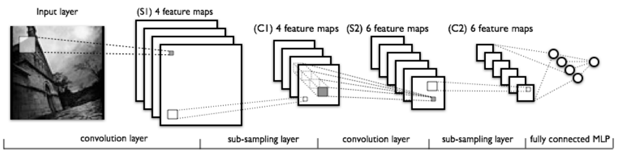

Fig. 2. Example of a Diagram of a convolutional network [6]

The first two types of layers form the input feature vector for the multilayer perceptron. The network can be trained using gradient methods.

The convolution operation can be described by the following formula [1, 4, 6].

$$(f * g)[m,n] = \sum_{k,l} f[m-k, n-l] \cdot g[k,l] \tag{1}$$

Here *f* is the original image matrix; *g* is the kernel (matrix) of the convolution.

Depending on the method of processing the edges of the original matrix, the result may be smaller than the original image, the same size or larger.

The convolutional layer implements the idea of local receptive fields, i.e. each output neuron is connected only to a certain (small) region of the input matrix and thus simulates some of the features of human vision.

In a simplified form, this layer can be described by the following formula.

$$x^l = f\left(x^{l-1} * k^l + b^l\right) \tag{2}$$

Here *x* is the output of layer *l, f()* is the activation function, *b* is the shift coefficient, and the symbol ∗ denotes the operation of convolution of the input x with the kernel *k*.

At the same time, due to edge effects, the size of the original matrices is reduced.

$$x_j^l = f\left(\sum_i x_i^{l-1} * k_j^l + b_j^l\right) \tag{3}$$

Here x_j^l is the feature map *j* (output of layer *l*), *f()* is the activation function, b_j is the shift coefficient for the feature map *j*, k_j is the kernel of convolution number *j*, x_i^{l-1} is the feature map of the previous layer.

Using a subsampling layer can improve the recognition of zoomed samples (reduced or enlarged). Layers of this type reduce the size of the input feature map (usually by a factor of 2). This can be done in different ways, in this program the method of selecting the maximum element (max-pooling) was used - the entire feature map is divided into cells of 2x2 elements, from which the maximum by value are selected. Formally, the layer can be described as follows.

$$x^l = f\left(a^l \cdot subsample(x^{l-1}) + b^l\right) \tag{4}$$

Here *x* is the output of the layer *l()* is the activation function, *a, b* are the coefficients, *subsample()* is the operation of sampling local maximum values.

The last of the types of layers is the layer of a "regular" multilayer perceptron (MLP), it can be described by the following relationship.

$$x_j^l = f\left(\sum_i x_i^{l-1} \cdot w_{ij}^{l-1} + b_j^{l-1}\right) \tag{5}$$

Here x^l is the output of layer *l, f()* is the activation function, *b* is the shift coefficient, *w* is the matrix of weight coefficients.

Consider the topology of a 7-layer convolutional network, the order of which is described below.

- input layer - image matrix;
- convolutional layer - a set of matrices of the same type (feature maps);
- subsampling layer – the previous set of matrices reduced by 2 times;
- convolutional layer – the previous set of matrices is combined into one in accordance with the scheme for connecting layers, then a new set is generated;
- subsampling layer – the previous set of matrices reduced by 2 times;
- MLP layer – the previous set of matrices is expanded into a vector and processed as MLP;
- MLP layer (output).

In this case, neurons (feature maps) of the second subsampling layer and the third convolutional layer are selectively connected, i.e. according to the adjacency matrix, which is specified as a network parameter. For a network with the number of feature maps in the second layer 7 and 9 in the third layer, it may look like this (see Table 1).

TABLE I. AN EXAMPLE OF AN ADJACENCY MATRIX OF CONVOLUTIONAL LAYERS CONNECTIONS

N	1	2	3	4	5	6	7	8	9
1	1	0	0	0	0	1	1	1	0
2	1	1	0	0	0	0	1	1	1
3	1	1	1	0	0	0	0	1	1
4	0	1	1	1	0	0	0	1	1
5	0	0	1	1	1		0	0	1
6	0	0	0	1	1	1	0	0	0
7	0	0	0	0	1	1	1	0	0

Thus, each output map is formed by a partial sum of the results of the convolutions of the input maps, for each such partial sum its own set of convolution kernels.

In order to ensure the full flow of mental processes, a person must be in a state of wakefulness. Only in conditions of optimal wakefulness can a person [3, 5]:

- the best way to receive and process information;
- recall the necessary electoral communication systems;
- program activities;
- exercise control over activities;
- correct errors;
- maintain the chosen direction of activity.