Lecture Notes on Data Engineering and Communications Technologies 149

Sergii Babichev
Volodymyr Lytvynenko *Editors*

Lecture Notes in Data Engineering, Computational Intelligence, and Decision Making

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Editors

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Preface

Data engineering, collecting, analyzing and processing information are the current directions of modern computer science. Many areas of current existence generate a wealth of information which should be stored in a structured manner, analyzed and processed appropriately in order to gain the knowledge concerning investigated process or object. Creating new modern information and computer technologies for data analysis and processing in various fields of data mining and machine learning creates the conditions for increasing the effectiveness of the information processing by both the decrease of time and the increase of accuracy of the data processing.

The international scientific conference “Intellectual Decision-Making Systems and Problems of Computational Intelligence” is a series of conferences performed in East Europe. They are very important for this geographic region since the topics of the conference cover the modern directions in the field of artificial and computational intelligence, data mining, machine learning and decision making. The aim of the conference is the reflection of the most recent research in the fields of artificial and computational intelligence used for solving problems in a variety of areas of scientific research related to computational intelligence, data mining, machine learning and decision making.

The current ISDMCI’2022 Conference held in Rivne, Ukraine, from June 14 to 16, 2022, was a continuation of the highly successful ISDMCI conference series started in 2006. For many years, ISDMCI has been attracting hundreds or even thousands of researchers and professionals working in the field of artificial intelligence and decision making. This volume consists of 39 carefully selected papers that are assigned to three thematic sections:

Section 1. **Analysis and Modeling of Hybrid Systems and Processes:**

- Methods and tools of system modeling under uncertainty
- Problems of identification of hybrid system, models and processes
- Modeling of the operating hybrid systems
- Modeling of dynamic objects of various nature
- Time series forecasting and modeling
- Information technology in education

Section 2. **Theoretical and Applied Aspects of Decision-Making Systems:**

- Decision-making methods
- Multicriterial models of decision-making under uncertainty
- Expert systems of decision-making
- Methods of artificial intelligence in decision-making systems
- Software and tools for synthesis of decision-making systems
- Applied systems of decision-making support

Section 3. **Data Engineering, Computational Intelligence and Inductive Modeling:**

- Inductive methods of hybrid systems modeling
- Data engineering
- Computational linguistics
- Data mining
- Multiagent systems
- Neural networks and fuzzy systems
- Evolutionary algorithm and artificial immune systems
- Bayesian networks
- Fractals and problems of synergetics
- Images recognition, cluster analysis and classification models

We hope that the broad scope of topics related to the fields of artificial intelligence and decision making covered in this proceedings volume will help the reader to understand that the methods of computational intelligence, data mining and machine learning are important elements of modern computer science.

June 2022

Oleh Mashkov
Yuri Krak
Sergii Babichev
Viktor Moshynskyi
Volodymyr Lytvynenko

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Contents

Neural Network Analysis of Evacuation Flows According to Video Surveillance Cameras

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Abstract. The paper is dedicated to establishing the relationship between the speed of evacuation participants and their density on the basis of neural network analysis of their movement using video surveillance systems. An analytical review of modern methods for studying the evacuation flows movement parameters war carried out. Despite the availability of modern software-simulating complexes, the movement parameters of the evacuation participants for these complexes are determined by establishing relationships between the flow density and the speed of the evacuation participants. These dependencies can be identified mainly by the results of field observations and processing of video recordings of these observations, which takes a lot of time and requires a lot of effort and indicates the need for automation and optimization of the video processing process. The tools for analyzing and classifying images, as well as detecting and classifying moving objects in a video stream deserve special attention, as they can be successfully used to study the problems of evacuation in case of fire. It was concluded that the tools of the OpenCV library are the most convenient in use. This library was applied for recognizing evacuation participants of various mobility groups. Apart from this the convolutional neural network was used for processing movement parameters. The neural network demonstrated best accuracy (81%) in the closest to the camera part of the evacuation route up to 5 m at a human flow density of up to 3 person per square meter.

Keywords: Artificial neural networks · Computer vision · Machine learning · Emergency evacuation · Evacuation speed · Flow density

1 Introduction

At the stage of construction and operation of various facilities, it is necessary to ensure compliance with the level of fire safety of people and the individual fire risk values to the established standards [4]. The evacuation duration from buildings and structures must be taken into account when calculating these indicators [12].

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The analysis of the current methods used for calculating the evacuation duration showed that the speed and intensity of movement as well as the density of human flows are the determining parameters of evacuation process. The relationship between these parameters can be described as follows:

$$V_D = V_0 \left[1 - a \ln \frac{D}{D_O}\right], \text{ at } D > D_O \tag{1}$$

where V_D is the evacuation flow speed at flow density D, meter per second (m/s); D - the current value of the flow density, person per square meter (per/m^2); D_O - threshold value of flow density, after which the density becomes a factor influencing the evacuation flow speed, person per square meter (per/m^2); V_0 - the value of the free movement speed (when the human flow density doesn't affect the speed), which depends on the type of path and emotional state of people, meters per minute (m/min); a - coefficient that reflects the degree of influence of human flow density on its speed.

Modern software and modeling systems that allow calculating the time of evacuation from buildings and structures use such dependencies as initial data. That is, in order to ensure high accuracy of the program, it is first necessary to conduct an experimental study of the evacuation parameters on real objects.

In the paper, according to the analysis of literature, a block diagram for optimization process of forming evacuation parameters empirical databases was proposed.

Due to the proposed block diagram, using the results of research conducted by the authors, a training sample was formed and the convolutional neural network was trained.

For certain CCTV recordings a model to convert the obtained speed values into the specified units were developed.

The use of the neural network showed satisfactory results in the observation area, located at a distance of up to 5 m from the video camera and at a human flow density of up to 4 person per square meter.

The results of the work can be used to develop intelligent evacuation warning and control systems, interactive evacuation plans and to conduct research on the parameters of mixed evacuation flows.

2 Problem Statement

A significant problem is that such dependencies can differ significantly for different sections of roads (horizontal sections, stairs, ramps, etc.), as well as for different composition of the flow (e.g. for evacuation flow consisting of children values V_0, a and D_o will differ from similar values for flow consisting of adults).

In addition, the development of inclusive education and the implementation of the principle of accessibility mean that people with special needs are free to visit public facilities. This affects the change in the structure of human flows on such objects and requires intensification of the study of the mixed flows movement parameters [19].

Despite the fact that the development of modern software and modelling systems and intelligent evacuation management systems significantly improves the calculation accuracy of evacuation duration, the problem of establishing relationships between speed and density of human flows is still solved by complex and time-consuming processing the results of field observations.

Therefore, solving the problem of optimization and automation of this process is an extremely important task.

The authors of this research consider that the implementation and application of neural networks, which have become an integral part of society today, can solve this problem.

3 Literature Review

A large number of works are devoted to the study of evacuation from various buildings. Research [13] is devoted to evacuation from health care facilities and institutions for the elderly people. In [21] research was conducted in preschool education institutions, and in [20,25] - in secondary school education institutions. Much attention is also paid to the evacuation of people in wheelchairs [23,24,27] and evacuation of children with special needs [29]. In these works, the evacuation flow movement parameters were determined based on the processing of video camera recordings without the use of video stream analysis software tools.

At the same time, based on the analysis of a number of studies [7,9,11,17,26,30], it can be concluded that the tools for analyzing and classifying images, as well as detecting and classifying moving objects in a video stream, make it possible to obtain high-quality results. Studies related to the determination of the parameters of pedestrians during traffic [7] deserve special attention, as they can be successfully used to study the problems of evacuation in case of fire.

It should be noted that there are a large number of implementations of neural networks in the public domain [3,8,15,18,22]. These neural networks can be successfully used for the recognition and analysis of moving objects. This opens up good prospects for obtaining large amounts of data on the evacuation flows movement and establishing relationships between the speed of movement and the density of people in these flows.

The purpose of the paper is to increase the speed and accuracy of the formation of empirical databases of evacuation flow parameters based on the analysis of video stream data.

4 Stepwise Procedure of the Evacuation's Parameters Determining Optimisation

The processing of the results in the above evacuation studies occurred in the following sequence:

- a frame from each camera was transferred to a random graphics editor, in which a grid was applied to the image. This grid divided the entire observation area into squares of 1×1 m (or larger);

- the grid (without the frame) was saved in PNG format;
- the grid was superimposed on the corresponding video using an arbitrary application for video editing;
- the grid was used for determination both the distance passed by the flow participant for the corresponding period of time (and therefore - the speed), and the number of people in a certain section of the area (the flow density) (Fig. 1)

Fig. 1. Examples of grids for processing video recordings [28]

Speed values obtained due to the results of field observations were grouped by density and variation interval arrays were formed in the order of the density growth. Based on the obtained values, the regression dependencies of the movement speed on the density were determined. The results were checked by the way of the CCTV camera records analysis on real objects. It is possible to increase the speed and accuracy of the empirical data obtaining process through neural network analysis of evacuation flows.

The optimization scheme for this process is shown in Fig. 2.

The task of recognizing evacuation participants on video can be represented by a sequence of several stages:

- at the first stage, it is necessary to split the video stream into frames and prepare the frames for object recognition;
- the second stage involves the process of recognizing the participants in the evacuation in each frame by the means of neural network;
- at the third stage, the evacuation participants identified in the each frame are compared with the evacuation participants detected in previous frames;
- the fourth stage - highlighting the detected objects on the video.

As already noted, there are ready-made software libraries that allow recognizing objects in a video stream. Based on the analysis of these resources, we can conclude that the tools of the OpenCV library are the most convenient in

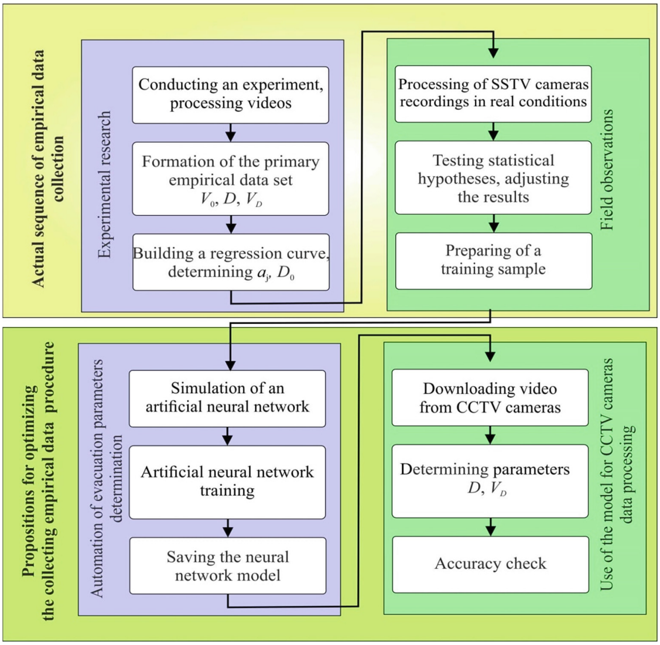

Fig. 2. General block diagram for optimization of the evacuation parameters determining process

use [2]. This library can be applied for recognizing evacuation participants of various mobility groups (including those who use wheelchairs and those who use crutches supports). Apart from this the convolutional neural network has to be used for processing movement parameters.

5 Experiment, Results and Discussion

To process the video stream, the architecture of the convolutional neural network proposed in [5] was chosen. The architecture is freely available.

The initial data set for the neural network were frames processed using OpenCV. Since the video stream was obtained using a stationary video surveillance camera, frame masking was applied to the sections where evacuation participants were not detected (Fig. 3).

To train the neural network, the results of the experiments conducted at the Lviv State University of Life Safety [19] were used. The sample consisted of videos, the total number of participants on the frames was more than 35,000 people. The training duration was 400 epochs.

In the training set, all participants in the evacuation were divided into 2 categories: participants moving independently ($M1$) and uncategorized (atypical) participants ($M5$), which include participants using wheelchairs, participants using crutches etc.).

a b c

Fig. 3. Image masking: a) the frame of a CCTV camera; b) the mask used in OpenCV; c) applying the mask to the frame

The network was trained using tensor processors on the cloud platform for machine learning Google Colaboratory [1]. All the detected participants were bounded with a rectangular box with the coordinates of the geometric center $(\dot{x}, \dot{y})$.

The movement of the object in the interval between two adjacent frames was determined using the SORT (Simple Online and Real-time Tracking) algorithm [6]. This algorithm provides the ability to calculate the participant movement speed (in pixels per unit of time). The specified characteristics of each box (the ratio between the height and width and the area) in each frame are compared with the characteristics of the boxes in the previous frame. The use of the SORT algorithm makes it possible to identify boxes that existed in previous frames and to determine their movement, as well as identify evacuation participants who appeared in the frame for the first time.

After that it was necessary to convert the obtained values in pixels per second to values in meters per minute. To implement these calculations, a horizontal section of the evacuation route measuring 22×2.4 m was chosen. This section was located in the frame of a video surveillance camera.

It should be noted that the distance traveled in pixels in the section of the evacuation route that is more distant from the camera is significantly greater in meters than the same distance in pixels in the section located near the surveillance camera. To avoid conversion errors the evacuation area in the frame was divided into 4 equal parts (I–IV) 5.5 m long each [14].

Split points 1–10 were plotted on a CCTV camera frame. This made it possible to compare the coordinates of these points on the image and the real object (Fig. 4).

The model presented in [10] was used. According to this model, the position of each evacuation participant in real coordinates can be determined as follows:

$$x = \frac{k_1\dot{x} + k_2\dot{y} + k_3}{k_7\dot{x} + k_8\dot{y} + 1}, \tag{2}$$

$$y = \frac{k_4\dot{x} + k_5\dot{y} + k_6}{k_7\dot{x} + k_8\dot{y} + 1}, \tag{3}$$

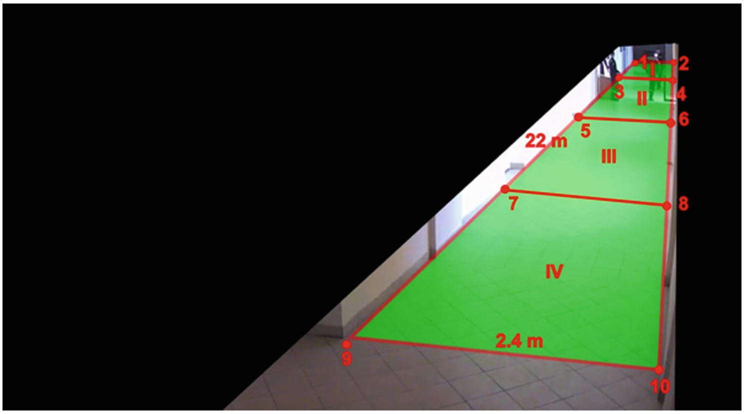

Fig. 4. The section of the evacuation route in the frame of the CCTV camera and its actual size

where (x, y) are the real coordinates of the evacuation participant; $(\dot{x}, \dot{y})$ - coordinates of the box center in the frame; $k_1, k_2, k_3, k_4, k_5, k_6, k_7, k_8$ - conversion coefficients.

From Eqs. (2) and (3) for each of the points 1–10 the system of two equations was written:

$$k_1\dot{x} + k_2\dot{y} + k_3 - k_7\dot{x}x - k_8\dot{y}x - x = 0 \tag{4}$$

$$k_4\dot{x} + k_5\dot{y} + k_6 - k_7\dot{x}y - k_8\dot{y}y - y = 0 \tag{5}$$

Thus, we obtain 10 systems of equations. Substituting the known values for each of the 10 points, we can solve the systems of equations and find the values of the transformation coefficients. Using the obtained coefficients it is possible to calculate the movement of the evacuation participant between two adjacent frames of the video stream.

Each evacuation participant after identification gets a certain number and spends a certain amount of time on the evacuation area (field of view of the camera). This time, consequently, can be written as a certain number of frames n. Immediately after the object is identified, the distance it moves between two adjacent frames can be calculated:

$$l_{n+1} = \sqrt{(x_{n+1} - x_n)^2 + (y_{n+1} - y_n)^2} \tag{6}$$

If the evacuation participant is found for the first time, his initial movement is accepted as $l_1 = 0$.

The instantaneous speed of the evacuation participant is determined by:

$$v_{n+1} = l_{n+1}w, \tag{7}$$

where w is the camera frequency, frames per second $(fr./s)$.

This value is not convenient to use, because in the process of walking a person's speed changes abruptly and differs in each frame. To get the smoothed speed value the Kalman filter [16] was used:

$$V_{n+1} = K \cdot v_{n+1} + (1 - K) \cdot v_n, \tag{8}$$

where K is the Kalman transfer coefficient.

Since, after processing the video stream by the neural network, all data about the detected evacuation participants were recorded in a separate file, it was important to achieve better visualization. For this purpose a special application was developed. After processing the video file by the neural network the application allows submitting a similar video file, in which all the evacuation participants are highlighted with frames with the calculated speed values above (Fig. 5).

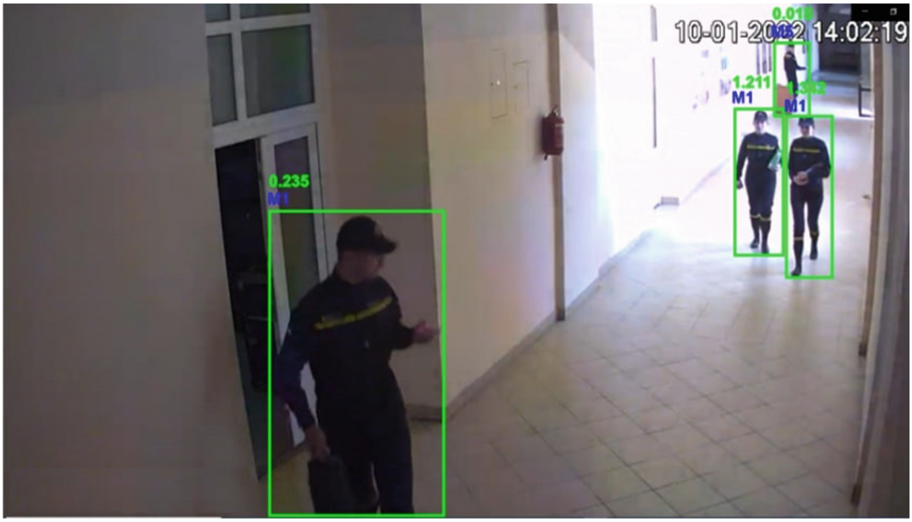

Fig. 5. The result of processing the video stream by the neural network

To verify the accuracy of speed determination, other results of the already mentioned studies [19] were used, where the movement parameters were determined personally by the authors. Figure 6 presents the comparative results of determining the evacuation speed depending on the human flow density.

Evacuation speed values were grouped into variation series by density. An average value was determined for each density interval. This made it possible to compare the results obtained using the neural network with the above results (Table 1).

Figure 7 presents the comparative results of determining the evacuation speed depending on the human flow density.

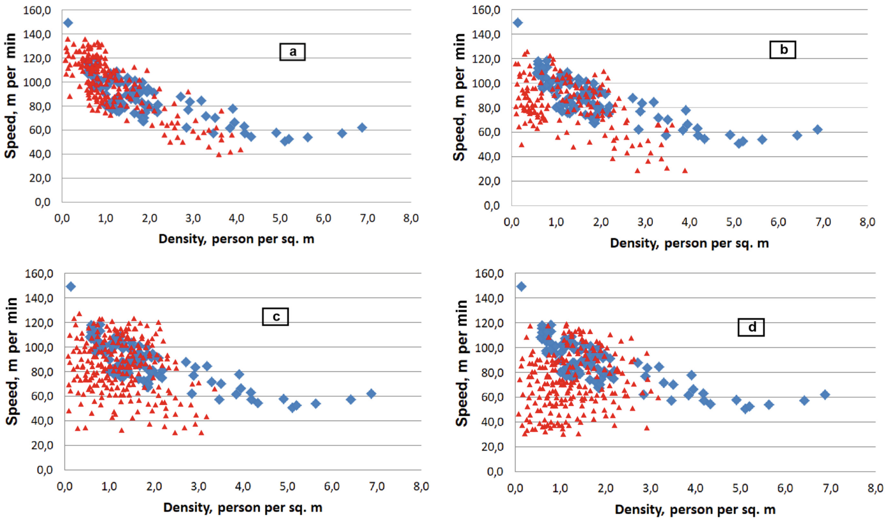

Fig. 6. Evacuation speed and flow density, determined by the neural network (red) and during the experiment (blue): a) section IV; b) section III; c) section II; d) section I

Table 1. Experimental study of the evacuation speed

Density, *person per* m^2	Speed obtained without CNN	Results, obtained with CNN							
		Section IV		Section III		Section II		Section I	
		Speed, m/min	Acc., %	Speed, m/min	Acc., %	Speed, m/min	Acc., %	Speed, m/min	Acc., %
0-1	111	106	95,28	82	73,71	80	71,91	61	54,83
1-2	88	92	95,41	83	94,36	82	93,23	66	69,18
2-3	77	62	80,38	47	60,94	50	64,83	63	78,37
3-4	70	57	81,43	45	64,29	–	–	–	–

Analysis of the results shows that the neural network demonstrated best accuracy (more than 80%) in the closest to the camera part of the evacuation route (IV) at a human flow density of up to 4 person per square meter.

At higher values of the flow density, the participants are placed very tightly, due to which the quality of recognition deteriorates. As the distance to the camera increases, the dispersion of the results increases and the accuracy of speed determination decreases to 54% in section I. It should also be noted that in sections I and II the neural network is not able to correctly identify evacuation participants at a density of more than 3 person per square meter.

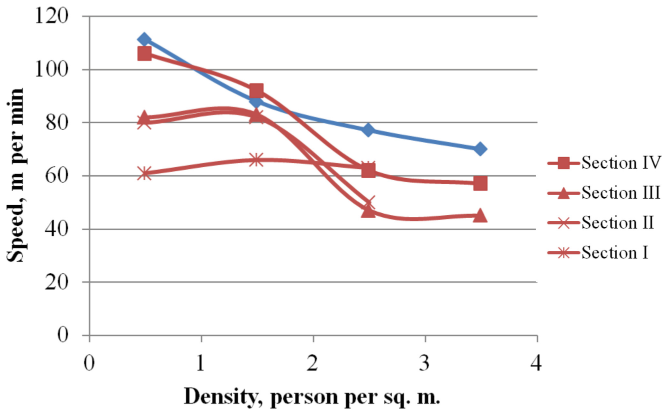

Fig. 7. Dependence of evacuation speed on flow density, determined by the neural network (red), and during the experiment (blue)

6 Conclusions

The conducted research deals with neural network analysis of evacuation flows according to video surveillance cameras.

Methods and means for calculating the evacuation time in case of fire are constantly evolving. This is especially true for software-simulating complexes. Modern technologies always open up new possibilities. At the same time, the acquisition of initial data for calculation in most cases is still carried out by researchers through the processing of video recordings and takes a lot of time. It should be noted a large number of implementations of neural networks. These networks can be successfully used for the recognition and analysis of moving objects, giving good prospects for obtaining large amounts of data on the evacuation flow movement and establishing relationships between the speed of movement and the density of people in these flows.

Authors of the research proposed optimization scheme of the evacuation parameters determining process. A convolutional neural network was used to determine the speed of evacuation participants. Simple Online and Real-time Tracking algorithm was used to calculate the participant movement speed.

The results, obtained using a convolutional neural network, were compared with similar data determined directly by the authors of the paper. For human density up to 4 person per square meter at a distance of up to 5 m from the camera more than 80% accuracy was achieved. Determining the parameters of human flow by means of a convolutional neural network can significantly accelerate experimental research and the formation of an empirical evacuation parameters database.

Further research should be aimed at improving the accuracy of the neural network at higher values of human flow density, as well as to determine the parameters of movement of people with limited mobility.

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