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Series Title	
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Abstract	In this paper we present a preliminary version of a new software MkBGFire which is being developed for forest fire spread simulations specific to Bulgarian vegetation. The MkBGFire software is based on the paradigm of the game method for modelling. The game method for modelling is a variant of cellular automata modelling, and similar approaches have gained popularity in the last decade due to the ease of use and their relative simplicity. In particular, they use either square or hexagonal grid. The software presented here is based on a mathematical model and both approaches, vector models and cellular automata models, are implemented. The MkBGFire software uses the OpenGL technology for 2D and 3D visualization of the cells of the game model. Implemented in the preliminary version of the MkBGFire are the following parameters: for the size of the forest cells and the type of the cells – hexagon and square; for control of the speed and the angle of the wind, which is currently constant for the whole terrain; some advanced parameters for control of the fire model. We illustrate the feasibility of the software with some examples using different cell types, forest layouts and wind conditions.

Keywords Game method for modelling - Software - Visualization

MkBGFire Software – An Example of Game Modelling of Forest Fires in Bulgaria

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Abstract. In this paper we present a preliminary version of a new software MkBGFire which is being developed for forest fire spread simulations specific to Bulgarian vegetation. The MkBGFire software is based on the paradigm of the game method for modelling. The game method for modelling is a variant of cellular automata modelling, and similar approaches have gained popularity in the last decade due to the ease of use and their relative simplicity. In particular, they use either square or hexagonal grid. The software presented here is based on a mathematical model and both approaches, vector models and cellular automata models, are implemented. The MkBGFire software uses the OpenGL technology for 2D and 3D visualization of the cells of the game model. Implemented in the preliminary version of the MkBGFire are the following parameters: for the size of the forest cells and the type of the cells – hexagon and square; for control of the speed and the angle of the wind, which is currently constant for the whole terrain; some advanced parameters for control of the fire model. We illustrate the feasibility of the software with some examples using different cell types, forest layouts and wind conditions. AQ1

Keywords: Game method for modelling · Software · Visualization

1 Introduction

Forests are often called "the lungs of the planet". They function as habitats to animal species, support the biodiversity of plant and animal life forms, serve

K. T. Atanassov et al. (Eds.): IWIFSGN 2018, AISC 1081, pp. 1–11, 2020.
https://doi.org/10.1007/978-3-030-47024-1_36

as a buffer in natural disasters as floods and rainfalls. Forests absorb harmful greenhouse gasses, regulate the climate and the water cycle, not to mention what enormous economic benefit they are to humans. Forests are essential to our survival and yet they are vanishing at an alarming rate.

Fires are one of the most common reasons for forests devastation. Fire behaviour must be carefully and thoroughly studied in order to limit the number of forest fires which occur, as well as to plan strategies in case of such. The different types of fuels, the wind speed, the topography and many other influences affect the prediction of the spread of a forest fire.

The number of research on patterns of spreading of forest fires has risen significantly in the past years. Two types of models are usually involved in these research – stochastic and mathematical models.

Different mathematical models have been designed to simulate the behaviour of forest fires, to predict their spreading and intensity. These models, mostly effective, however, usually depend on some assumptions about the environmental factors, which are close to ideal ones. These assumptions are made in an attempt to simplify the system of differential equations that is used in the model. The behaviour of the fire in a mathematical model is generally deducted based on the physical laws in which the system evolves. The stochastic methods, on the other hand, try to predict the most feasible behaviour of the fire in average conditions, based on empirical correlations with actual or experimental fires.

Different techniques are employed in the mathematical models of advancing the flame front. Vector models consider a clear, unambiguous growth law which determines the flame front spreading in homogeneous environmental conditions on continuous plane. The more complex ones use wave propagation techniques with relatively high computational speed and precision. In cellular automata models, on the other hand, the fire progresses equally on a grid of square or hexagonal cells, based on logical rules defined to determine the state of each cell. The computational complexity is lower than that in vector models, as well as the computational speed. An overview of the wildland fire models, conducted in different research centers around the world by the time of publishing of paper, is presented in [6].

A mathematical model for predicting the spread of a fire front in homogeneous and heterogeneous environment, based on two dimensional cellular automata model with hexagonal grid, is proposed in [3]. A dynamic simulation model of the spread of a forest fire is implemented in [10]. The rules of the environmental factors influencing the pattern of the forest fire are expressed with cellular automata with a square grid.

The game method for modelling (GMM) [1] is a variation of cellular automata modelling, where the landscape is presented as a finite (or infinite) grid of square or hexagonal cells. This and similar approaches have gained popularity in the last decade due to the ease of use and their relative simplicity.

A simple field fire simulation, where the GMM has been employed, is proposed in [4,5]. The field is represented by hexagonal cells, and no wind or slope are considered in the model.

A mathematical model for predicting the advancing of a fire front in homogeneous and heterogeneous forest is presented in [8]. The GMM has been applied there, the forest is represented by a hexagonal grid. The results show that as far as forest areas are considered, the use of hexagonal cells is more appropriate. The model, defined in [8], is extended in [7] with intuitionistic fuzzy estimations for a homogeneous area of the fire.

In the present work we demonstrate the software MkBGFire, based on a mathematical model implementing both vector and cellular automata approaches. The OpenGL technology for 2D and 3D visualization of the cells of the game model are used in the MkBGFire software.

The rest of the paper is organized as follows: In Sect. 2 the software MkBGFire is briefly introduced; some examples using different cell types, forest layouts and wind conditions are simulated by MkBGFire and the results are discussed in Sect. 3; and, finally, the conclusions are presented in Sect. 4.

2 MkBGFire Software

MkBGFire is a software application for simulating game models of forest fires in Bulgaria.

The mathematical model and the algorithm used in the MkBGFire software will be presented in details by the authors in a future publication. The aim of the present paper is to demonstrate some of the capabilities of the software through some simple scenarios.

MkBGFire software has a simple user-friendly interface, shown in Fig. 1. The main window is separated into several control panels which are responsible for setting the parameters of the current terrain, the preview and the factors affecting the propagation of the fire front during a simulation. The preview of the current terrain is in the center of the main window. The control panels are situated to the left and right of this preview.

The terrain is displayed as a finite square grid of square or hexagonal cells. The type of the cells is determined by the value specified in the *Forest cell type* field. Only two values are allowed here, 4 and 6, respectively for square and hexagonal type of cells. The number of the cells along the width and the height of the terrain is determined by the value in the *Forest cell size* field. The acceptable values here are between 40 and 200, with a step 10. Once the values of these parameters are set, the terrain can be created using the *New Forest* button. Initially, the generated terrain is a grass field only.

Drawing elements on the current terrain is enabled by the *Draw* button. Different terrain patters like grass, oak or pine trees, water and a starting point of a fire are chosen from a drop down box. The brush size is specified in the *Brush* field. The drawing on the terrain is performed with the mouse.

3D rotation of the view is enabled by the *Rotate* button. The angle of the rotation is set in the *Angle* field. The rotation is performed by using the mouse. The *Lock* button prevents the preview of the terrain from rotation. The open GL axes on the display are shown when the *Show axes* checkbox is selected.

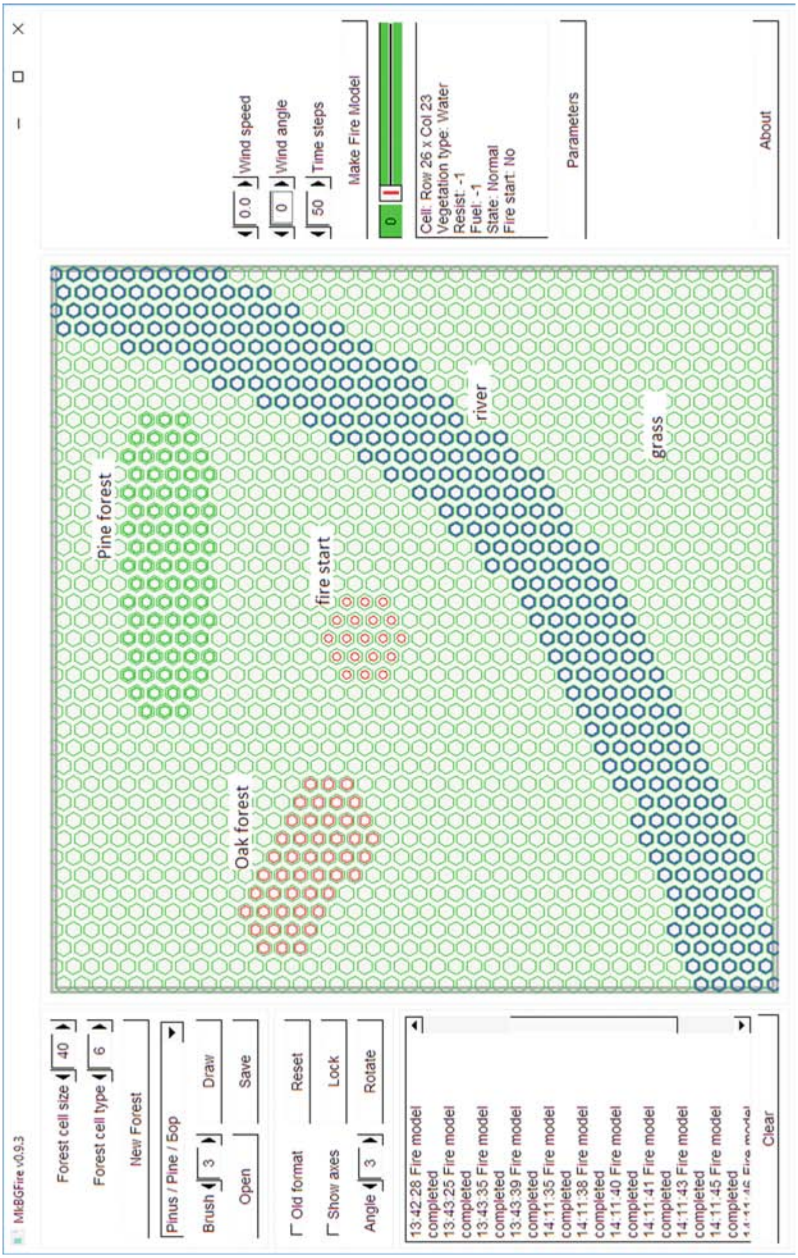


Fig. 1. Screenshot of the MkBGFire with the terrain

Reset button is used to restore the view of the terrain. A screenshot from the software (Fig. 1) in 3D view is presented in Fig. 2. The currently visible terrain can be saved in a text file with *.mff extension using the *Save* button. This is a standard text file which can be edited in a text editor. The preview of the terrain is saved in a *.png file. An already existing terrain, saved in a *.mff file, can be loaded again in the application by the *Open* button.

The history of the actions performed for the currently displayed landscape is shown in an additional panel to the left of the preview. The content of this panel can be cleared using the *Clear* button.

The additional environmental factors, which affect the advancing of a fire, are specified in the model panel to the right of the preview. The factors considered in this preliminary version of the MkBGFire software are the wind speed, the wind angle and some advanced parameters to determine the shape of the fire front, the number of non-burnable cells that the fire can jump through, and others.

The maximum number of steps for the simulation of the fire propagation on the current terrain is determined by the value in the *Time steps* field. The acceptable values are between 50 and 1000, with a step 50.

The *Make Fire Model* button is used to create the fire model based on the specified factors and additional parameters. The slider below this button is used to track the changes on the current terrain at a particular time step of the simulation. Information about each of the cells is displayed when hovering over the cell with the mouse.

3 Field Fire Spread Simulation Scenarios Using MkBGFire Software

Different field fire spread scenarios are discussed below in order to demonstrate the capabilities of the MkBGFire software.

The terrain used in each of the simulation scenarios consists of a pine forest, an oak forest, a grass field and a river. The preview of this terrain in the MkBG-Fire application environment is shown in Fig. 1. The ignition points are marked in red.

3.1 Field Fire Spread in Case of the Absence of Wind

A field fire spread simulation scenario in the absence of wind is considered here. Four screenshots have been taken at different time steps of the simulation – 10^{th}, 20^{th}, 35^{th} and 55^{th} step, respectively. The obtained results can be seen in Fig. 3. The fire has reached the two forests at the tenth time step. The simulation shows that parts of the oak and the pine forests are already burning. The cells in bright red color in the figure denote the vegetation on fire. There is already burnt grass at the epicenter of the fire denoted by cells with white outlines.

By the time step 20, the whole terrain above the river is burning, including the oak and the pine forests, with more than half of the grass already burnt out.

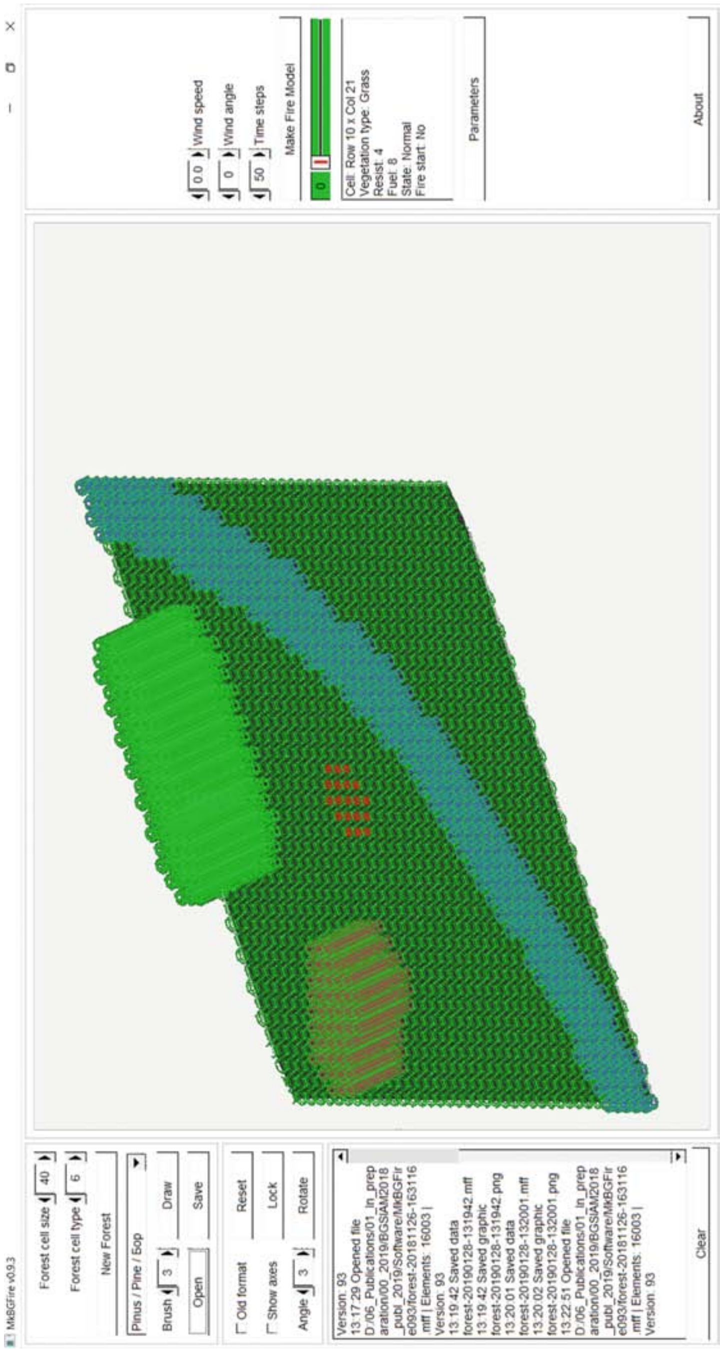
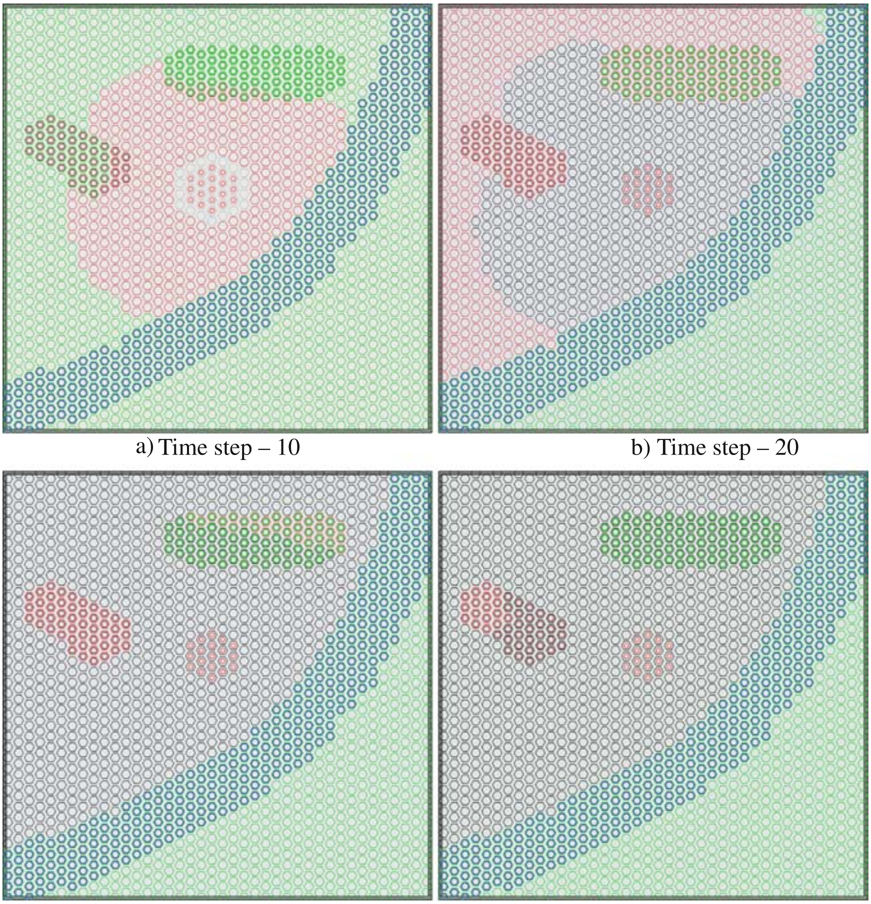


Fig. 2. Screenshot of the MkBGFire with the terrain 3D view



a) Time step – 10　　b) Time step – 20

c) Time step – 35　　d) Time step – 55

Fig. 3. 2D visualization of field fire spread scenario in case of the absence of wind

Part of the pine forest has already burnt out by the time step 35. Due to the greater resistance of the oak trees, they are still burning. There are no completely burnt oak trees yet. All of the grass at this point has already burnt out.

At the time step 55, the whole pine forest has burnt out, while the oak forest has burnt out only in half. The oak forest is totally burnt out at the 59^{th} time step.

The characteristics of any part of the terrain at each step of the simulation can be observed by hovering the mouse over the respective cells.

The presence of wind is considered for the next scenarios. In the following subsection, the fire spread simulation scenarios depending on the strength and the direction of the wind are discussed. To illustrate the examples, 45° of wind angle is used (0° corresponds to northward wind starting from the center and angles are incremented in clockwise direction). The magnitude of wind is currently denoted by a number signifying the rate of the cell-wise propagation of fire.

3.2 Field Fire Spread in Case of Wind

Wind Speed – 2.00, Angle – 45°. The results of the simulation of this particular scenario are presented in four screenshots taken at time steps 10, 20, 35 and 55. The results are summarized in Fig. 4. At the tenth time step, in this particular scenario, the fire has reached only the pine forest. Almost all of the trees there are on fire. The damage of the fire as expected is higher in the direction of the wind.

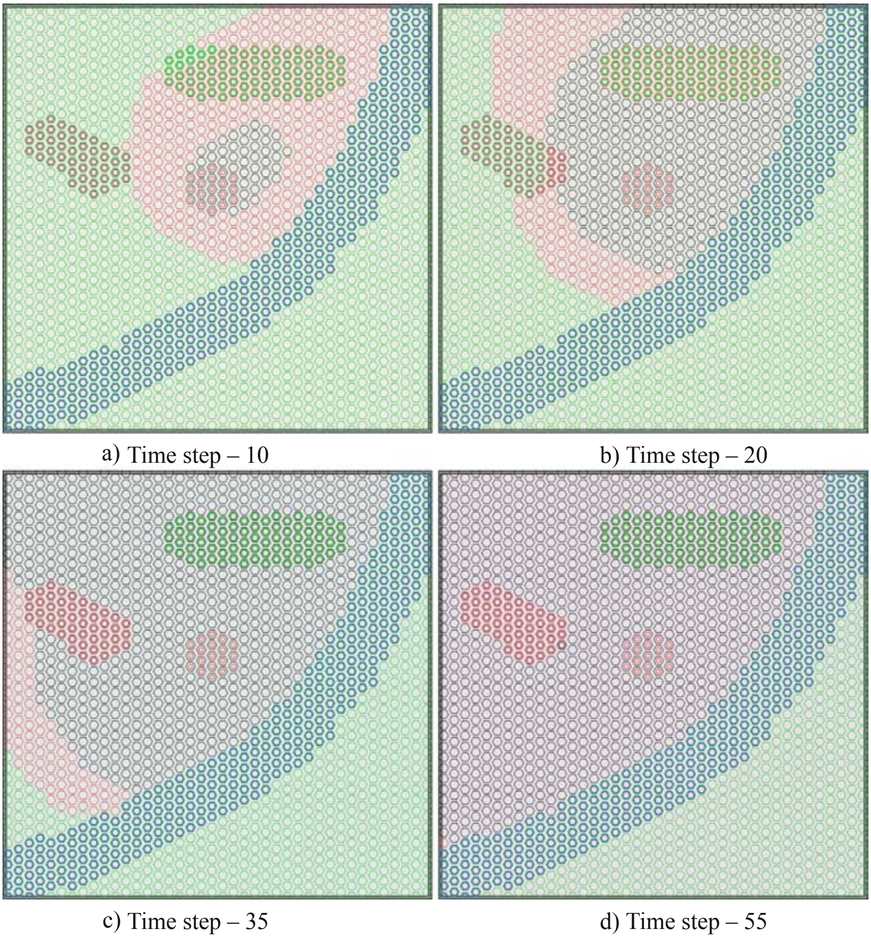


Fig. 4. 2D visualization of field fire spread scenario in case of wind 2.00 and angle 45°

At the next time step which is observed – the 20^{th} – only a small part of the oak forest is burning. It is shown again that because of the resistance of the oak trees, at this specific moment, only a small part of the oak forest is on fire, while the surrounding terrain is, for the most part, already burning.

Here, at time step 35, unlike the case without wind, all of the pine forest has already burnt out. Without the presence of wind, only half of the trees in the pine forest have burnt out. All of the oak forest is on fire, but there are no completely burnt trees there yet. Meanwhile, almost all of the grass above the river has burnt out.

At time step 55, the whole oak forest is burning with only a single cell that has already burnt out completely. For comparison, in the case without wind, slightly more than half of the forest has burnt out. The oak forest is totally burnt out at the 73^{th} time step.

This example shows the capability of the model to predict the fire propagation while taking into consideration the strength and direction of the wind.

The next example shows the advancing of the fire in case of twice stronger wind and the same wind angle.

Wind Speed – 4.00, Angle – 45°. As it can be seen from Fig. 5, in the case of stronger wind, at the tenth time step the fire has not yet reached the oak forest. Due to the specified wind direction (45°) and the strength of the wind, a larger part of the pine forest is not yet burning compared to the case of wind speed 2.00. At time step 20, the oak forest is not yet burning, whereas all of the pine trees have caught fire. Almost half of the grass is burning or completely burnt out.

All of the pine forest has already burnt out at time step 35, like in the case with wind 2.00. Unlike the previous case, however, only a small part of the oak forest has started to burn.

At time step 55, as opposed to the case of wind speed 2.00, there are parts of the field that are burning and those which are not yet affected by the fire. The entire oak forest is burning.

In this case the oak forest has totally burnt out at the 85^{th} time step.

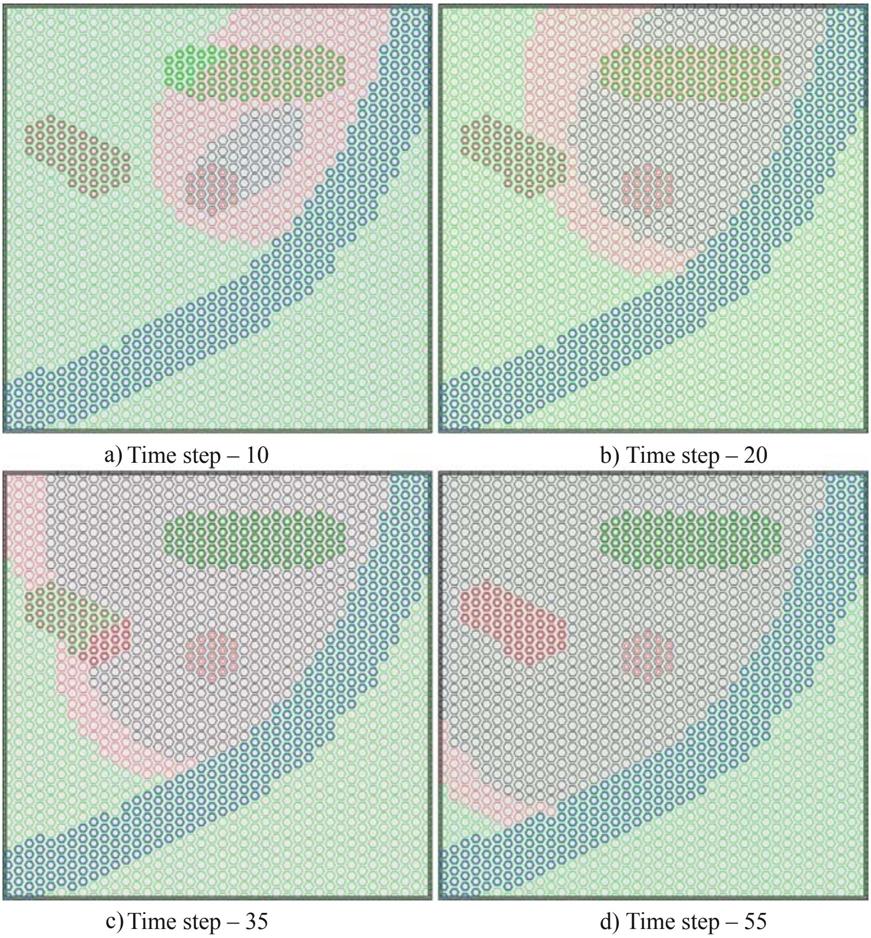


Fig. 5. 2D visualization of field fire spread scenario in case of wind 4.00 and angle 45°

4 Conclusion

A preliminary version of a new software MkBGFire is demonstrated in the present paper. The MkBGFire is being developed for forest fire spread simulations specific to the Bulgarian vegetation. The MkBGFire software is based on the paradigm of the game method for modelling. Vector models and cellular automata models are implemented in the software. The 2D and 3D visualization of the cells of the game model in the MkBGFire software uses the OpenGL technology.

Three example scenarios are considered here to illustrate the use of the MkBGFire software: field fire spreading in case of the absence of wind and the fire propagation in case of wind (wind speed - 2.00, angle - 45° and wind speed - 4.00, angle - 45°). The results, which are presented and discussed here, are encouraging. The simulations show that the software is capable of predicting the advancement of the fire front with respect to the wind speed and direction.

In a future research an intuitionistic fuzzy estimations could be introduced in the considered game models as it is presented in [2,9].

Acknowledgments. This work was supported by the Bulgarian National Science Fund Project DN16/6, 2017 "Integrated approach for modeling of the forest fires spread".

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