Advanced Fire-Detection Methods

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Diploma thesis
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MASTER'S THESIS ASSIGNMENT

(PROJECT, ARTWORK, ARTISTIC PERFORMANCE)

Degree, First Name and Surname:	**Olga Vozniuk**
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Thesis Topic:	**Advanced Fire-Detection Methods**
Thesis Topic in Czech:	**Pokorčilé metody detekce ohně**

Thesis Guidelines:

1. **Find and study publications about detecting fire in video from normal cameras.**
2. **Create a testing set of tagged images of fires (the ground truth).**
3. **Use the testing set for evaluation of success rates of existing fire detection algorithms or systems.**
4. **Document the results and present them in graphical form.**
5. **If necessary, propose possible improvements of the current detection methods for increasing their success rates.**

Thesis Extent:

Appendices:

Form of Thesis Elaboration: **tištěná/elektronická**

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Zlín, 28 July 2017

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ABSTRAKT

Tato diplomová práce je zaměřena na analýzu existujících metod detekce ohně, které dokáží rozpoznat oheň v časných fázích, kdy ještě není možné jej zachytit pomocí klasických senzorů.

Na práci jsem spolupracovala se studenty doktorského studia, kteří ve svých disertačních pracích vyvíjí právě nové metody detekce ohně.

Pro testování správnosti detekce jsem vytvořila databázi videí, která obsahují oheň nebo objekty podobné ohni s rizikem falešných detekcí a videí bez ohně.

Poté jsem na těchto videích testovala nový algoritmus detekce ohně a vyhodnotila jeho úspěšnost.

Kromě toho jsem pracovala také na zhotovení databáze tagovaných video rámců, které obsahují různé typy ohně. Tato další databáze je používána ke strojovému učení algoritmů s umělou inteligencí, které dokáží rozpoznat oheň v obraze.

Klíčová slova:

Detekce ohně, senzory, video, oheň, detektor, video detektor, detektor ohně, detekce.

ABSTRACT

English abstract

In this master thesis the main focus is on analysis of existing fire detection methods that can detect fire even in early stages, when it is too early to catch it by smoke sensors or IR sensors. I cooperated with doctoral students who are working on this topic as part of their dissertations. I also created a database with videos that contain fire, videos without fire and videos with objects similar to fire. After that I tested a fire detection algorithm on collected videos in order to evaluate its performance for future improvements. During this master thesis I additionally helped to tag fire on frames that were taken from videos with fire. The resulting database was used to teach an algorithm to detect fire on video.

Keywords:

Fire detection, sensors, video, fire, detector, video-detector, fire-detector, detection.

ACKNOWLEDGEMENTS

I hereby declare that the print version of my Bachelor's/Master's thesis and the electronic version of my thesis deposited in the IS/STAG system are identical.

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CONTENTS

INTRODUCTION

Fire can cause irreversible damage. It is not only destroying goods, houses, forests but also causes financial costs. Fire also takes lives that cannot be returned back. In our time there are numerous fire detection techniques that use sensors and cameras. However, they still have disadvantages. That is why many people are trying to find solutions for existing problems and some come up with new methods that would help locating fires in early stages.

According to the statistics stated by Dubner (2012), the smoke alarm usage tendency was increased since 1977. This statistic is represented in the Figure 1 below.

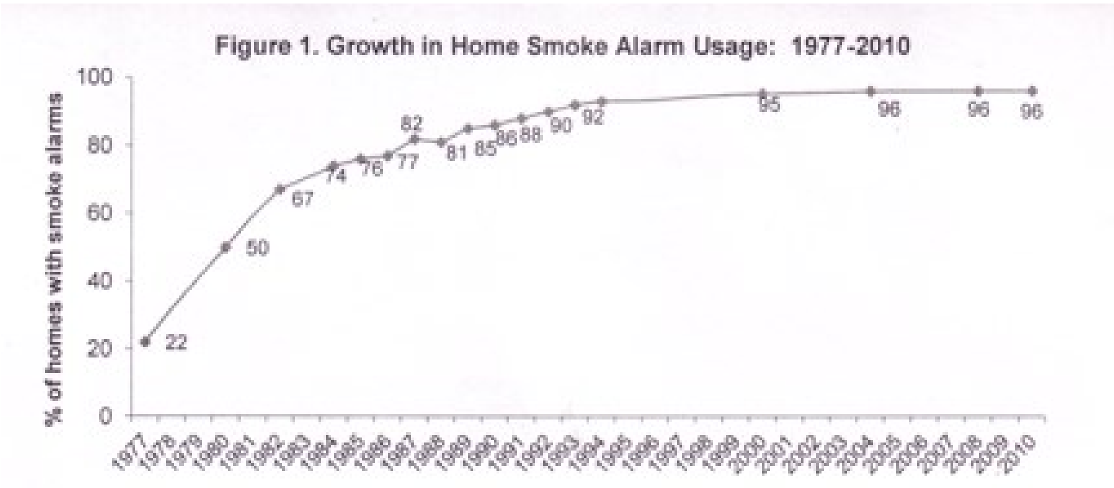

Figure 1: Growth in home smoke alarm

At the same time, according to the next chart showed by Dubner (2012), the number of deaths caused by fire significantly decreased. This is represented in Figure 2.

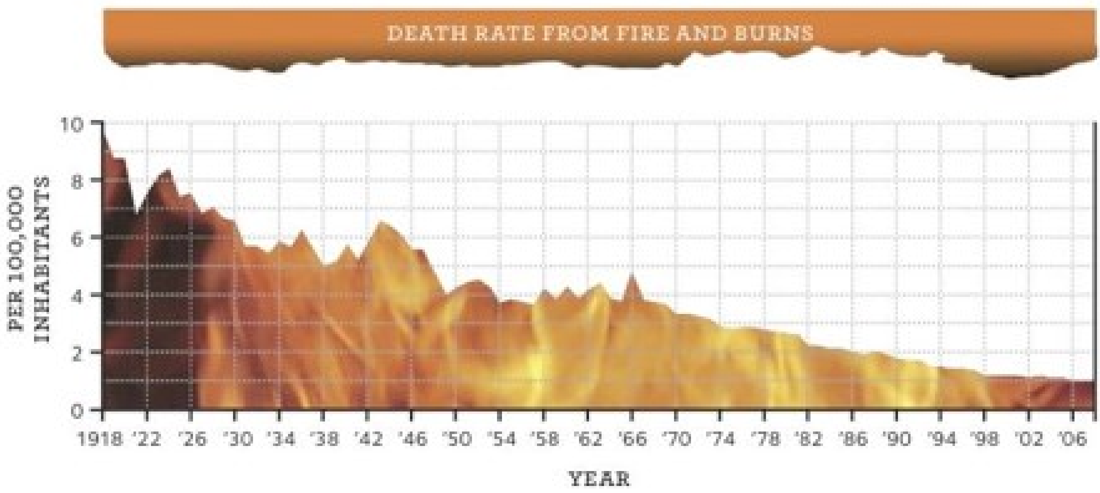

Figure 2: Death rate from fire and burns

According to the statistics above, it is clear that many people entrust their lives to the simplest smoke-detector like single-station or battery-powered ionization alarms. However, such devices have numerous drawbacks. One of them is they detect smoke when the fire is already developed. When it comes to a fire in the building, every second counts. So, it is necessary to develop a device that can detect fire on early stages, will not require additional reinforcement and would be affordable for everyone.

In some places with expensive goods, it is important to know as soon as possible about the fire and its exact location, so a fire sprinkler system will be turned on only in that particular area. At the same time there are places that use processes similar to fire on a daily basis. So the task here would be to develop system that can distinguish where the fire is and where it is not. Another example are workshops where the fire is a part of working process, which inhibits usage of classic fire or smoke detectors for unwanted fires.

It is highly important to develop artificial intelligence system with computer vision that would help to combine most common sensors like smoke detectors and thermocameras. These sensors themselves react too slow on events and are not reliable. It would be ideal to develop a surveillance system with fire analytics that would reduce fire detection time and provide fire alarm functions. The basic monitoring system components like security/surveillance cameras are not expensive and are already installed in many places like supermarket, parks and in private houses. They are used to prevent unwanted events. However, it would be too expensive to hire enough people to monitor all the cameras 24 hours without interruptions. Such a task is difficult for people, but it is quite possible for intelligent machine that can distinguish and quickly react to unwanted events.

Nowadays, most of the cameras are mounted with additional smoke and fire detectors. Such solution is not ideal, since we would need to place many sensors in order to cover whole area. Since most of the cameras have a good resolution and other important characteristics, it is not a problem to add fire detecting system to the camera to increase the fire detection reliability rate. The only problem left is the logic of software behind the system.

In this master thesis I give a brief overview about theory of fire and fire processes. Then I describe advantages and disadvantages of existing fire detection systems that use cameras, present a comparison of the current algorithms of those systems, and suggest possible improvements.

I. THEORY

1 UNDERSTANDING THE PROBLEM

This chapters gives basic information about fire and its components. It also lists existing types of fire-detecting systems, their advantages and disadvantages.

1.1 Physics of Fire

According to Harris (2002) [11], fire is a result of chemical reaction between oxygen from the air and fuel like wood or gasoline. In order to start a fire, the fuel has to be heated to its ignition temperature. [11] These are three main components of fire triangle (see Figure 3) that would keep fire on [1].

Figure 3: Fire triangle. [1]

For combustion it is necessary to have fuel, oxidant and the conditions under which the chemical oxidation reaction will be intensive and stable [11].

Every fire releases smoke, which is material decomposed to volatile gases It is a combination of hydrogen, carbon, oxygen and the rest is char and ash. [11]

Another component of fire is flame. It is burning gaseous medium that consists mostly of partially ionized particles, in which a chemical reaction develops. Result of such reaction is a "glow" and the release of heat. The color of fire depends on heat and fuel. Different color means different temperature. For example, the hottest part of flame is blue, and the cooler part is yellow or orange at the top of flame. [11]

And the last part of a flame is temperature. It depends on burning material. The heat depends on amount of energy released by gases during combustion reaction and fuel burning speed.

Also, different chemical elements can change flame color. Various fuels react faster or slower with oxygen and emit large or small amount of energy. [11]

1.2 Fire Detection Systems

A fire can start in many places: inside a building, outside on the street, or deep in the forest. Refering to Hong et al. (2012) [13], there are six enclosed fire stages: incipient phase, growth phase, flashover, fully developed phase, decay and extinction phase. There are many types of fire, and the problem here is to choose the right sensors and cameras that would help to locate and extinguish fire in early stages before it will spread around.

According to [9], there are two types of fire alarm systems: addressable and conventional. The first one assigns each fire detector with an address, so its location is easier to find. Communication can be performed between single address and control panel and between group of addresses and control panel. Also, addressable system can record system events. The second type, conventional, is a zoned system. It consists of several alarm systems that are located in one area (floor, etc.) and connected to one alarm initiating circuit. The status of alarm system can be either “Fire” or “No fire”. In case of fire, the system receives an alarm from the area where the fire started, and not from the specific sensor. This is efficient for small facilities. The most common detectors in our time are: thermal detector, smoke detector, fire-gas detector and flame detector. [9]

1.2.1 Smoke Detectors

Since it is impossible to predict a fire type that can happen in the building, it is possible to detect smoke with either photoelectric (optically) or ionization (physical). The following section briefly describes algorithms from [9], which listed three types of fire detectors that can be used: ionization, photoelectric, and combination.

Ionization smoke detector alarm works the best with clean-burning fires, because this type of fire produces small particles during combustion. This system has alpha particle, a smoke chamber, and charged detector plates. The alarm is triggered when air in the chamber becomes less conductive. It happens when smoke fragments attach themselves to the ionized air molecules, after entering a smoke chamber. The ionization smoke detectors advantages are that they can detect invisible combustion products and different aero-type smoke products and that it reveals fire in early stages. There are also disadvantages of ionization-based smoke detectors. This type of smoke detectors does not work well and provides false alarm in places with high humidity, volatile solvents and conductive material dusts. Also it does not detect toxicity. [9] The Figure 4 represents the algorithm of ionization smoke detector [10].

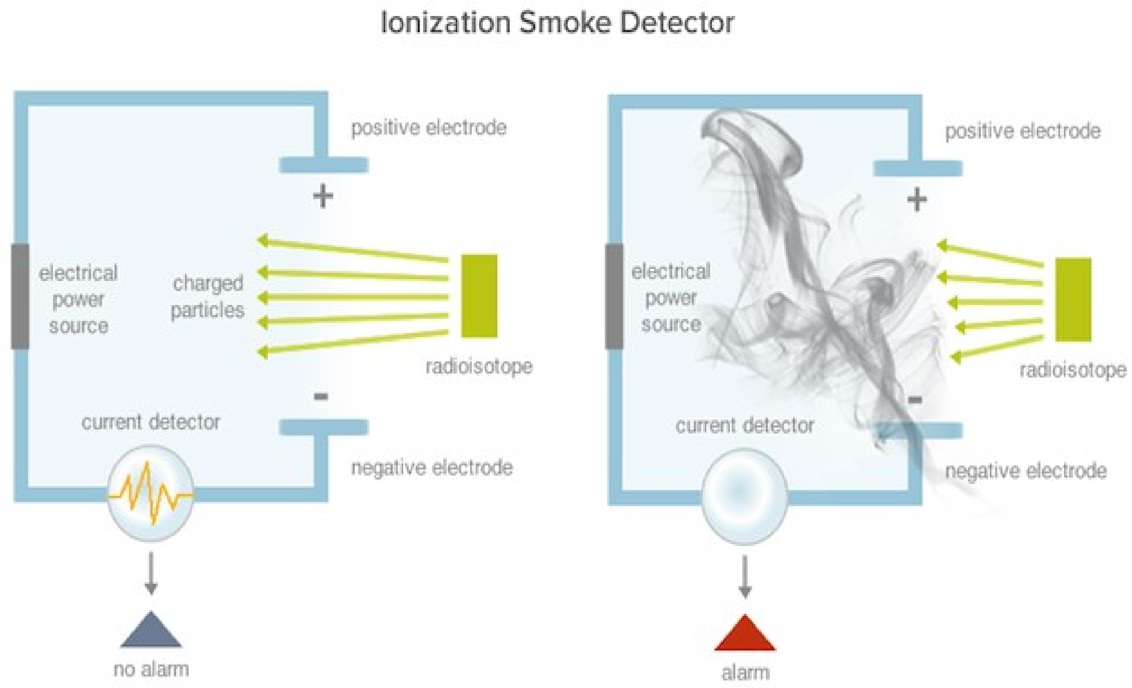

Figure 4: Photoelectric smoke detector [10]

As stated by [9], Photoelectric smoke detector uses light beam in order to detect fire. This system uses LED, a smoke chamber, and a photosensitive device. However, it is useful when fire produces large particles during combustion. There are several advantages of photoelectric smoke detectors. It is sensitive to visual fragments of smoke. Such sensor can detect low heat fire, and trigger alarm early. At the same time, photoelectric smoke detector has its disadvantages. It has low sensing due to dust presence, does not detect toxic elements, requires regular cleaning and it has high false alarm rate. [9] The Figure 5 below shows how the photoelectric smoke detector works [10].

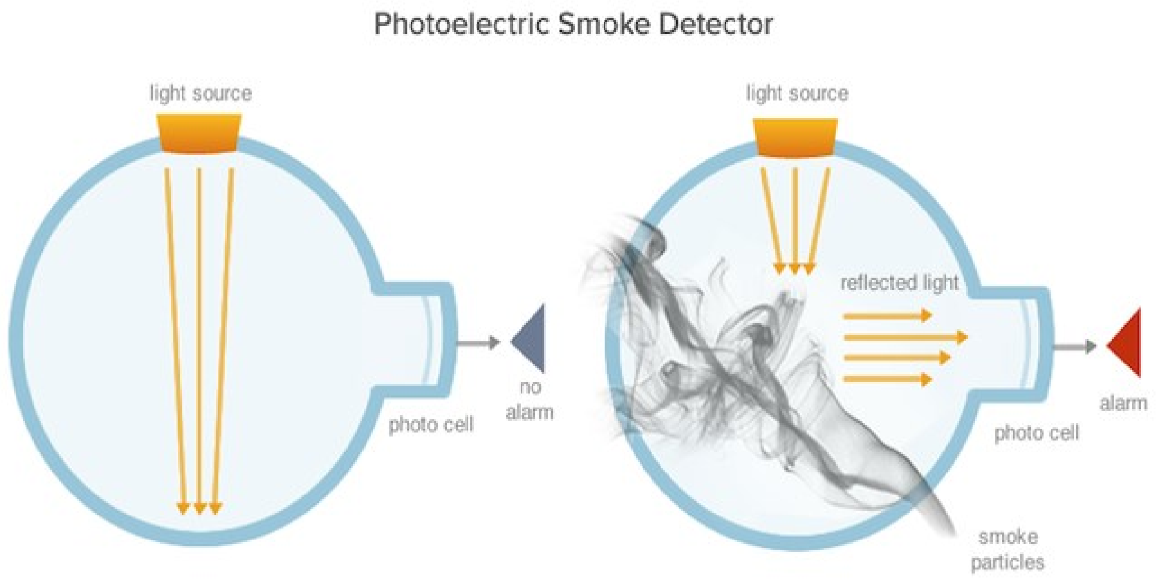

Figure 5: Photoelectric smoke detector [10]

Dual-sensor detectors have ionization and photoelectric technology in one single device, but such technology is quite expensive [10].

1.2.2 Thermal detectors

The following section briefly describes algorithms from [9]. Thermal detectors alarm is a system that recognizes temperature changes when fire is present. There are three thermal detectors: fixed temperature, rate of rise, and rate compensated[9].

The fixed temperature spot-type detectors have bimetallic switch that heats two metals that expand differently under same temperature, which causes them to bend and activate the alarm. The good things about this system are lower cost and high reliability compared to smoke detectors, and that the system is not affected by dust and requires minimal maintenance. However, it can not detect combustion products and works well only for inner property protection and has slower reaction rate in contrast to smoke detectors.

Another fire detector is rate-of-rise detector, that is checking temperature change rate during fire and gives faster alarm. The alarm reacts only to fast temperature raising in the room that happens when the fire starts. This quite affordable and reliable device, which is not affected by dusty environment and requires minimum maintenance, still has some drawbacks. Its reaction is slower than smoke detectors, it does not react on combustion products and mostly suitable for inner property protection.

The rate-compensated thermal detectors activate at specific temperature in space. They are not affected by dust, cost less than smoke detectors, have a low false alarm rate and require minimal maintenance. Unfortunately, rate-compensated thermal detectors reaction is slow compared to smoke detect products of combustion and used for protection of property. [9]

1.2.3 Flame detector

A flame detector can distinguish radiation from light component of a fire. It is done by detecting IR, UV or both types of wavelength. Flame detector has fast reaction, but it is expensive technology, has narrow vision field, needs a place with no obstacles in view and it is complicated for maintenance. For this reason, such devices are used in areas where the fire can start at any time. [9]

1.2.4 Fire-Gas detector

A fire-gas detector was developed in order to catch different gases that can be produced during combustion, such as carbon monoxide and dioxide, steam, and other types. There are two types of technology that can be used. The first type uses semiconductor materials and the second type has catalytic element inside an aluminium bead. This sensor can detect combustion products and catch gases in the air on early stages of a fire. However, fire-gas detector is not ideal. It still can give false alarm. Since it has to be placed on lower level, it is quite easy to break it. Fire-gas detector is expensive, cannot be used in area with CO and CO2. [9]

1.2.5 Artificially intelligent fire detectors

When it comes to choosing a fire detector for small place, the best choice would be conventional detectors, since they are quite affordable and reliable. With storages, factories and other large buildings it is another story. [9] According to [12], such places require more intelligent fire detection system to be used. Ideally, such system has to be fast in fire detection, reliable, it should tell location of a fire and should not be complicated to use. [12]

Intelligent systems have two common methods: analogue and addressable. The first one is more common. The control panel compares current sensors data with alarm threshold. Based on this data, the system decides whether there is a fire or not. In addressable type of intelligent system, the detector compares its current sensed data with the configured threshold. [12]

2 VIDEO-FIRE DETECTION SYSTEMS

Conventional fire detection systems have some drawbacks. According to [15] studies, a ceiling height, where a smoke detector can be placed, depends on the fire type and size. The surveillance cameras which can be found almost at every corner, could greatly improve the reliability of conventional fire detection methods, and that is why engineers and scientists have been trying to create various video fire detection systems. As was written in a paper [13], there are several steps in video fire-detection techniques. One of the steps is color-detection process, which is used during video fire and smoke (VFSD) development, and became one of the most popular part of fire detection. It is based on RGB color space and can be combined with HSI/HSV saturation approach. Another very promising step is a moving-object detection. It uses motion-segmentation algorithm that detects moving objects and then analyzes whether this motion is a result of a fire. One of the best moving-object detection approaches are: background subtraction, temporal differencing and optical flow. Background saturation identifies pixels with moving objects by applying threshold detection on result of comparison of current frame with background image. This technique is very sensitive to dynamic changes in the environment. The temporal difference technique performs threshold detection on consecutive frames that work well on changing environment, but cannot extract full moving object contours. The optical flow is complex technique and is sensitive to noise. It detects movement by estimating moving area by combining similar motion vectors. One more step that can be used for fire detection is flicker detection. However, it is counted as unreliable approach, since smoke varies within time. Also there are steps like disorder analysis of smoke regions, sub-blocking for VFSD, and energy detection techniques for fire detection. [13] Currently, some researchers are trying to find new solutions.

2.1 Video Image Detection

The following section describes the research paper written by Ding et al. (2011) [8]. They made an experiment that was performed in order to study the use of video image detection system in large buildings and atria. The test took into account different fire sources and other environmental factors. It took play in large atrium facility and a large burn. The research showed that the field of view and camera height of video image detection place an important role and may influence camera's detection function. When VID recognizes smoke or flame in its field of view, it will react immediately. It performs well even on a great distance.

Overall the results were satisfying and proved that VID can work well with fire and other environment conditions.[8]

According to Ding et al. (2011), the VID smoke/flame system can work independently, while detector performs alarm algorithm execution and video processing as well. During the research five tests were conducted: unobstructed fires, obstructed fires, under dark conditions test, disturbance source test and environmental contaminated test. A fire detector that was used in the research consisted of one color camera, IR camera, IR light source, image capture and preprocessing, and digital processor. Also optical flame sensor can be added. With such components VID can work in any weather conditions and at any part of the day. The field of view is divided into 16 sub-zones, those that have low chance of fire and key surveillance zones for precise control. At the same time digital signal processor performs with intelligent image recognition and processing, that includes background learning and modelling, digital image input and filtering, analysis of physical characteristics, calculation of alarm probability, alarm output, and data fusion. The alarm turns on only when probability of flame or smoke characteristics cross a predefined limit. During the experiments three detectors were installed at height of 5.5 m, 12 m and 20 m from the ground inside the atrium at a distance to the fire source 17.3 m, 20.3 m and 25.9 m. Also for the test inside the burn hall three detectors were placed at the eight 11.5m with a distance to the fire approximately 46.5 m. VID had a sensitivity for smoke detection at Level I and Level III for flame detection, where Level I is the highest sensitivity and Level V is the lowest respectively. Also, detectors had three different lenses of 4 m, 6 mm, and 8 mm. The Table 1 below represents sensitivity levels.

Table 1: Technical Information of the VID System used in the tests

Detector No.	**Sensitivity Level**		**Field of View**	**Installation Height (m)**	
	Smoke	Flame		CU	NRCC
Detector I	I	III	4 mm	5.5	11.5
Detector II	I	III	6 mm	12	11.5
Detector III	I	III	8 mm	20	11.5

The research showed that VID systems successfully detected unobstructed and obstructed early fire. Also artificial lights, chopping UV/IR source and chopping IR sources did not influence the work of fire/flame detector. VID performance almost did not change when different type of fuels and various fire sizes for unobstructed fires were used. However, in case of an obstructed fire, it took detector longer to detect fire. The research revealed that fire detector can recognize flame and smoke in dark conditions. The detection time decreased in low airflow 2.5 m/s conditions. Overall, VID cameras that were placed higher from the ground had been less influenced by the obstacles. [8]

2.2 Smoke-Detection Method by Image Processing

The research conducted in [6] used smoke-pixel analysis method for early fire detection based on video processing. Most of the early fire-detectors use techniques which included ultraviolet, infrared, measurement of temperature changes, analysis of particles in the air or humidity and others. Since smoke is usually visible earlier than flame, an idea was to develop a smoke detector based on video analysis. A camera would gather more reliable information about fire than regular smoke-detectors, and it does not have to be located near the fire source. At the same time many video detectors are based on flame recognition, which also delays the fire alarm. During the experiment, both chromatic recognition and disorder measurement techniques were used. This would give better real smoke detection and also help to omit interference of smoke-aliases. [6]

The chromatic recognition is necessary in order to distinguish actual smoke from other gray object or features similar to smoke. Since smoke can change its color from white-bluish to black-garish or even black depends on type of fuel and smoke temperature. At the same time, it can be semi-transparent or even not transparent at all. Statistical analysis can help to detect a real smoke from the image. The main decision of chromatic recognition is based on grayish color of smoke. However, since smoke can be transparent and it is not easy to define where the smoke ends in an image, the pixel-based extraction approach is helpful here. For example, smoke changes its shape, speed or spreading direction due to airflows, so there is no specific pattern that would identify smoke. The pixel-based approach decision is based on spreading attribute of smoke. [6]

2.3 Smoke-Detection Using Saturation Plane

Cervera et al. (2010) [4] conducted an experiment where robot had to follow a person. Most of the existing robots perform such function in indoor environment with good visibility. The idea was to use different sensors in particular situation for better visibility. One of the situations was a smoke environment. The robot had to detect whether there is smoke nearby and turn on the right sensors that would help to follow the person. The researchers took an algorithm mentioned in chapter 2.2. Only they decided to extract plane with the saturation of the image with smoke. Each pixel from the binary image is tested on smoke presence. This method helped to improve robot's performance in smoke environment. [4]

2.4 Smoke-Detection Using Spatial and Temporal Analysis

According to Hong et al. (2012) [13], video-based smoke-detection system has more advantages than other systems. Unlike the conventional point-base sensors that use ionization and photometry, video-based detector shows fast response, it is non-contact technique, most importantly it has no spatial limits. There are four visual features in VFSD: motion, appearance, color and energy. However, there are no single automatic video-detection techniques that would not have a false-alarm in certain conditions. The idea of smoke-detection by spatial and temporal analysis is to include analysis of energy-based and color-based features during spatial, temporal and spatial-temporal domains. This analysis takes place before the combining of all features using support vector machine classifier. Also the proposed temporal-based alarm decision unit for early smoke detection shows not only decreased false-alarm rate, but also decreases reaction time in different situations. Since the fire can happen in tunnel, indoors and outdoors, VSD has to be flexible and suitable for various conditions. The video smoke-detection system architecture has four stages:

- candidate-region extraction
- feature extraction
- classification and verification

The first one combines temporal difference, background saturation techniques and sub-blocking. The new method for background construction Gaussian Mixture Model models every pixel as a Gaussian mixture. And a block-base technique was applied for an efficient smoke detection. However, when dealing with moving object region, it is useful to understand what exactly caused this movement. The feature extraction approach achieves low false alarm rate and high detection rate by using energy-based and color-based features of selected moving regions in spatial, temporal, and spatial-temporal domains. For smoke detection a high-frequency energy was monitored by 2-D spatial wavelet transform of current image and background image. The wavelet sub-image shows the texture and edge of objects on the image. When the smoke spreads in the image, the high-frequency information, like texture and edges, becomes less visible and that would be an indication of smoke presence.

1-D spatial-temporal energy analysis is applied for detecting smoke in early ages when it is semi-transparent and less visible. 1-D temporal chromatic configuration analysis is applied in order to distinguish smoke from other moving objects. The key to determine presence of smoke here is that when the smoke start to expand then the chrominance value of pixels decreases. The classification part consists of analyzing a combination of local features by SVM algorithm. The verification approach uses a temporal-based ADU in order to reduce the false-alarm rate and avoid common problems of automatic VSD systems. In classification and verification phase 2-D spatial wavelet feature, 1-D spatial-temporal energy features and 1-D temporal chromatic configuration features are combined together before being classified by SVM. The test results show that system correctly detect smoke regions in indoor and outdoor environment even with moving objects like cars, people, bicycles. Also the tests went successfully during traffic jam and large buses situations inside a tunnel. The false alarm rate was very low during the tests. There are some drawbacks in the system like light reflection from wet ground and the continuous adjustments of the exposure value by the camera. [13]

2.5 Computer Vision Based Smoke Detection Method by Using Colour and Object Tracking

Hwang and Jeong (2016) [14] in their research tested another method of smoke detection by using labelling and object tracking algorithm for reducing false alarm detection rate. With this algorithm the program decides whether this is a smoke object only after all movement and characteristics are satisfied to make a decision. Since the first thing we can see when the fire just started is smoke, then a smoke detecting method would be better for early fire detection. On long distance people also see the smoke first, and so should do a machine. There were two situations tested during the experiments: long and short distance smoke detection. For long distance was used a pixel counting technique. Smoke pixels was defined in specific RGB color range. The algorithm, that takes movement into account, is used for short range detection. Smoke color in video is different from what people see. But, on a video smoke does not have achromatic color all the time. At the same time achromatic colors can be seen everywhere. White, black and gray colors objects can be mistakenly considered as smoke. An open and close filters were used in labeling algorithm for determining each object. The open filter uses min and max filters to remove noise pixels. The close filter is opposite of the open filter. It is used for joining together all divided smoke pixels in one object. As for the behavior detection technique, they focused on the most common smoke movements: becoming larger as it rises and going upward. However, other objects with same color as smoke and similar behavior will cause a false alarm. At the end tests were conducted with following parameters: for the long distance smoke detection, an object is considered to be smoke when smoke pixels increase continually for a movement and have similar brightness among near pixel. The object is not a smoke when it becomes bigger in frame when starts below camera view, but its position continually become lower. Since fire is considered to be under or in camera vision, then object that moves from camera to side cannot be a smoke. In case when the fire is developing, the smoke has to come first and it cannot be moved while smoke is generated. While taking into consideration that normal objects including smoke do not go far within 1/30 second. Since the camera used during the experiment has 15-30 f/s, it is possible to set a limit of changes in the size of object or its movement distance. So, when the object goes beyond this limit, it will be ignored. The final decision is made when smoke pixels are filtered, selected objects are partitioned by labels, and all objects behavior were monitored. During the experiment 11 videos with smoke and 4 without were recorded. Overall the system had false detection result two times during video with smoke, and two times during videos without smoke. Due to object based method, the system gave false alarm when objects were placed in front of the smoke. This happened because the object had shape similar to a smoke. Also this algorithm made mistakes when two similar color objects were considered as one object. [14]

II. ANALYSIS

3 STATE OF THE ART

Before I started to work on my own research, I spent some time by helping my research colleague Karel Koplik and his collective with his project. He developed a web application with images taken from videos that contain fire in it. At the beginning, user had to select a part of image that contains smoke, fire, flickering or other parts of fire. It was time consuming and difficult to analyze. Later a square frame was added to the application, which selects a part of an image and user has to select whether it contains smoke, a bit of fire (flame covers less than 50% of a frame), flickering fire (flame covers more than 50% of a frame), steady fire (flame covers 100% of a frame), hot air, or does not have fire at all. The Figure 6 below is a screenshot of this application. On a left side you can see a selected square of a frame that has two frames. The user selects one of the buttons below the square, which best represents the selected part of an image: (0) no fire at all, (1) a bit of fire, (2) flickering fire, (3) steady fire, (4) smoke, (5) hot air. The image on a right is animated. It shows three consecutive frames from video with fire. When user made his choice, he can press Enter on a keyboard or press button Finished on a web page. In case when the user cannot understand what is represented on the right image, then he can press button Do not know or press letter D on a keyboard. After that, an image on the right will be changed to a new one.

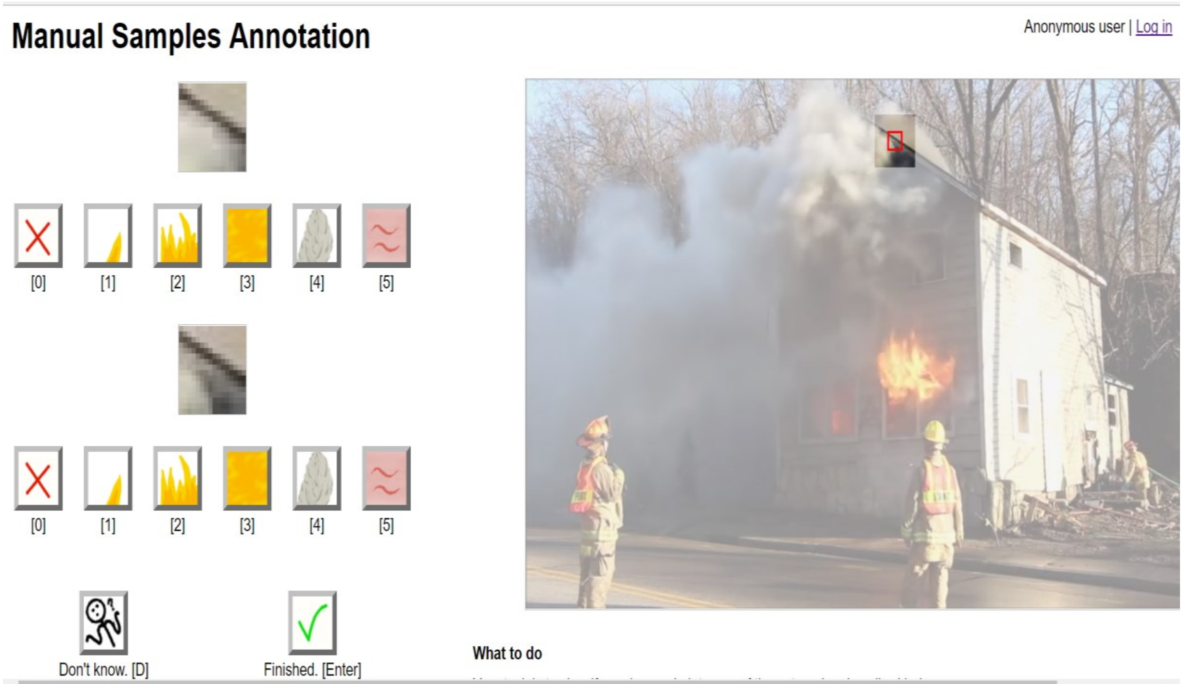

Figure 6: Screenshot of a webpage for selecting images with fire.

I tagged 293 different video frames, with 426930 total samples. I also classified 2247 different frames, with 282780 total samples. The data I produced will be used to teach machine learning algorithms to recognize fire events on video.

3.1 Algorithm

This is another experiment, for which I used a program Firetracking developed by Karel Koplik. The main goal was to create an innovative and simple algorithm that would help to detect fire in video without requiring an expensive hardware and at the same lowering false alarm rate. Despite the old fire detecting systems that use sensors, this new method tracks suspicious regions in time and statistically analyses of their trajectory. In this case, a new fire detecting system can be placed anywhere, so there is no need to place sensor's equipment as close as possible to the fire source. The main algorithm of a Firetracking follows next structure: detecting suspicious regions, finding bounding rectangles, tracking rectangles in time, analyzing trajectories and checking for persistency. In order to detect suspicious regions, it first search for pixels that contains fire-like color. This is done by using RGB. The saturation (S) is calculated after extracting red (R), green (G), and blue (B) channels. After that the system applies rules $R > G > B$ and $S > S_T$, where S_T is a saturation threshold. The following Figure 7 shows image with a burning tree and its fire color map. [2]

Figure 7: Burning tree image and created color map

The algorithms is one frame behind the real time since it requires three consecutive frames in order to detect movements. In order to subtruct background the algorithms finds difference from current frame and the previous one. Then it calculates difference between current and the next frame for information update. And finally, in order to get information about movement in the foreground it applies binary AND operator on the two calculated differences. The final step is noise reduction from the movement map. The Figure 8 and Figure 9 below show a movement map of an image with burning tree and a movement map of suspicious regions. [2]

Figure 8: Movement map

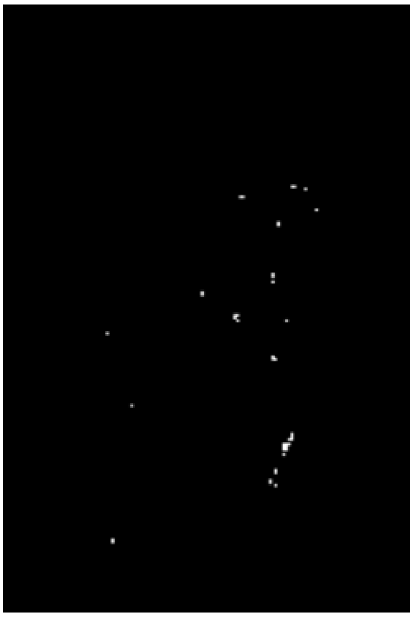

Figure 9: Suspicious region movement map

There was applied dilatation, in order to reduce algorithm speed during determination of bounding rectangles. As a result, the algorithm needs to find much fewer bounding rectangules that significantly decreases processing time. For tracking suspicious regions in time, the method aggregates all found areas in space and then link and track them in time. Then, it analyses trajectories. In this case, there is no need to list spectrum of objects that is similar to fire. Since it is quite difficult to find yellow and bright object that, at the beginning, staying in one place and constantly changing its shape. During tracking regions in time, it connects bounding rectangles in following frames. The Figure 10 represents suspicious region's trajectory. [2]

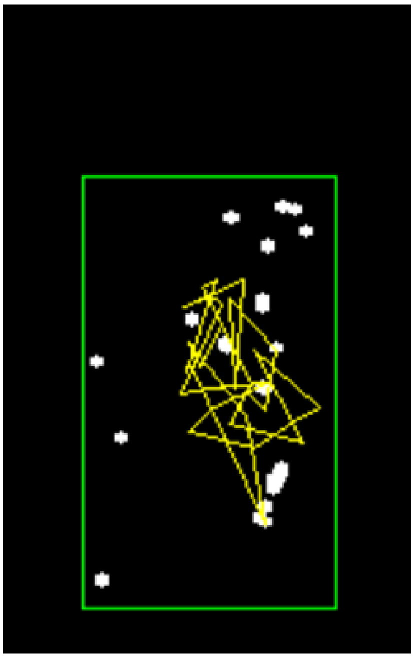

Figure 10: Suspicious region's trajectory

When the rectangles overlap, it means they contain the same object and object's trajectory can be updated by adding another centre point to already existing list of centre points. Then the system is analyzing trajectories. Since fire at the beginning has constant flickering, an algorithms finds an object that constantly changing shape while staying in one location. It calculates the mean value μ and the standard deviation σ for each axis. Then it checks if the distribution is normal which means that 68.2% of values should belong to the interval $(\mu-\sigma, \mu+\sigma)$. Next step is to check for persistency, by setting its limit to specific interval and then analyzing how often the trajectory had normal distribution in the set interval. For this evaluation, there is no need of positive test on the normal distribution in each frame. The algorithm also has several settings that can be changed during the test:

- **Brightness threshold (BrighMin).** It defines the minimum brightness needed for classifying pixels as fire-colored. The best value of minimum brightness for classifying pixels fire-colored pixel is around 225. However, this value may change when the fire is too dark. Minimum value for this setting is 0, maximum value is 255.
- **Movement threshold (MoveMin).** In order to reduce some noise, the parameter sets the noise threshold for the motion detection method. Since noise has normal distribution, the threshold helps to reduce false alarm rate, caused by noise. In dark areas the threshold is set higher than normally. Minimum value for this setting is 0, maximum value is 255.
- **Small regions gap size (ContDil).** The maximum distance between two small regions' bounding rectangles, which can be aggregated, has to be a small value and depends on video resolution. Minimum value for this setting is 0, maximum value is 10.
- **Regions minimal size (ContTol).** Sometimes, due to camera noise, there are too many very small regions. Then it is better to set minimal bounding rectangle size. It will help to reduce the number of small regions. However, when the bounding rectangle size is too high, the algorithm will not see small flames. And in case when it is too low, the noise can cause a false alarm. Minimum value for this setting is 0, maximum value is 64.
- **Region's right to live (ContRTL).** In order to choose right moving regions, it is considered that the fire is constantly moving and will not stop for more than few frames. This number can be set for example to 3 frames. In case when there is a gap between frames, where contours disappear completely, the value will indecate for how many frames the gap will be ignored. And it has to be increased if contours disappear more often. Minimum value for this setting 0, maximum value is 1000.
- **Number of middle points (ContMinSize).** It is possible to set a number of length of trajectory being evaluated, before the normal distribution testing. Most of the time this number was set to 100. Minimum value for this setting is 0, maximum value is 100000.
- **Persistency interval (PersLen).** It is possible to set a number of frames that persist to give positive result on a fire presence, before turning on the alarm. When the number is higher the algorithm gives less false alarm, but it has bigger delay. During the test the sufficient minimal length was 15 seconds. Minimum value for this setting 0, maximum value is 1000. [2]

The Figure 11 below represents "Settings window" of a program, where all the parameters, mentioned in a bulleted list above, can be changed.

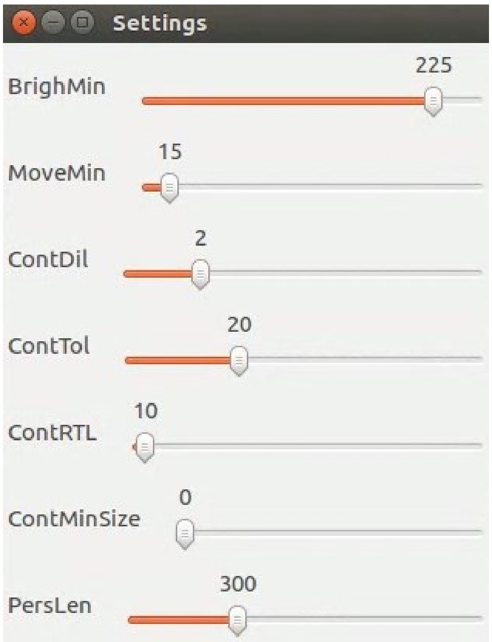

Figure 11: Settings window of an algorithm

Overall, an algorithm can run on average hardware and does not rely on fire flickering frequency. The algorithm speed is mostly depending on scene characteristics and camera settings. However, the best situation is when the speed depends only on the length of the minimal persistency interval. Different types of videos were used during the test. As the result, videos with dancing people were close to trigger the alarm. The problem was when the objects move in front of the bright background. This makes an algorithm to concentrate on bright area that changing shape. The false alarm was triggered on during the videos of sunset over sea. However, it works perfectly indoors, for example in factories or tunnels. [2]

In order to make an improvement in the method mentioned above, the algorithm developed by Bosch [3] engineers for their fire-detecting camera was taken as inspiration. This camera helps to detect fire in real-time even in complicated environment. It detects flame and smoke at the source. The intelligent algorithm used for analyzing and processing image is based on physical fire model. This system can be easily adjusted to any requirements from the customer side. There are several advantages of Bosch camera:

- does not need compression or transmission since it is working with raw data
- monitoring the entire camera's field of view
- fast detection of a fire source
- identifies hidden fires, smoldering fires and burning liquids
- has root-cause analysis of vide-records

Bosch camera not only detect fire and predicts its behavior, but also decrease fire-detection time and reduce false alarm. [3]

3.2 Research requirements

For my research I needed a computer with Linux Ubuntu OS, Net Beans IDE 8.2, Firetracking program from Karel Koplik and his team, and videos which contain fire, with fire-like objects and without elements similar to fire. All videos were downloaded from YouTube, Vimeo channels and database created by Karel Koplik and his team. The last one was a group of folders with consistent frame-images, taken from real videos. If it was necessary, some videos were cropped by online-video-cutter.com. The list of video links can be found in Appendices chapter. All videos had to be recorded on stabilized camera and at least 30 seconds long.

4 ANALYSIS OF THE RESULT

The experiment had to evaluate video with four different evaluation ratios: true positive (TP), false positive (FP), true negative (TN) and false negative (FN). When algorithm persistency did not cross value of 75 percent, this behavior was considered a suspicion (S). Another thing that has to be recorded is the speed of an algorithm. It is important to know how many frames and seconds does it take to give the TP or FP results. The collected videos contained: flickering light, car lights, flashes, driving cars at night, driving cars during the rain, dancing people in bright clothes, dancing people with bright background, waving flags, sunset over sea, sunset over fields with no water, walking people on a street, Christmas illuminations, north lights, fireworks, shops surveillance, tunnel live video, repair shop.

During the experiments I worked with 64 videos, where 20 videos were with fire, 22 videos were with objects similar to fire and 22 videos with no fire. The videos with items similar to fire had bright elements, objects with similar movements and phenomena similar to fire that can be falsely classified as fire by the fire-detecting algorithm. All video had the same input parameters: BrighMin = 225, MoveMin = 15, ContDil = 2, ContTol =20, ContRTL = 10, ContMinSize =0 and PersLen = 300. Since, most of the videos had frame rate 25-30 frames/second, I set the settings PersLen to 300, in order to have a persistency interval at least 10 seconds.

The experiment followed straight structure. After collecting necessary videos and running Firetracking program on Ubuntu OS, by using NetBeans IDE, I applied an algorithm on all downloaded videos and folders with consistent frame-images. As a result, I received text files with frame number and persistency rate for each video, and folder with graphical output of each frame. These helped me to not only see the frame when the alarm started, but also analyze an object that caused this alarm. The image of a specific frame shows screenshots of program graphical windows outputs: real video, output, fire color map and contours windows. The black and white output window selects with a rectangle the places of fire suspicion. When the persistency becomes higher than 25% it shows an exclamation mark at the top left corner, when persistency crosses 50% it shows two mark and when persistency is more than 75 percent, it writes “Alarm!”. The fire color map window shows intersection of two criteria: fire color and movement. And the contours window shows the suspicious map with applied dilatation, and inside the bounding rectangle is a trajectory of an object defined by center points. The Figure 12 below represents the graphical output screenshot from the video with fire in the middle of a screen.

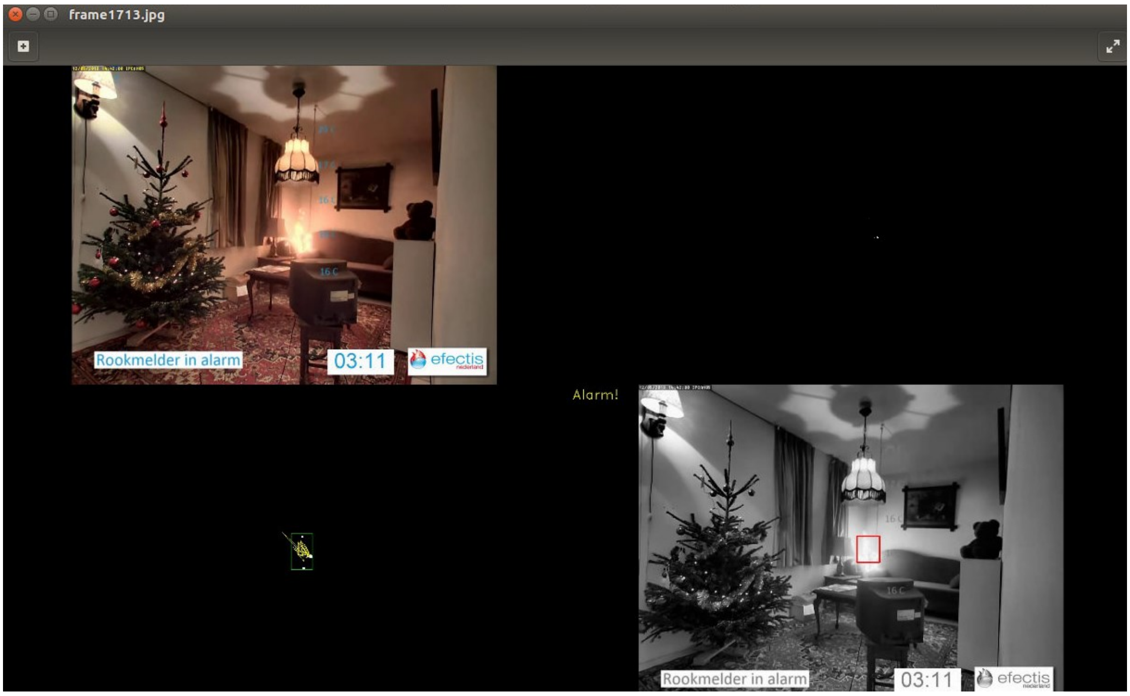

Figure 12: Firetracking output screenshots of video with fire

I also used text files to calculate total number of frames, each result percentage, and detect time and frame when the alarm was triggered. All information was organized into tables for better visualization. After analyses of received output from the Firetracking, I come up with several solutions and run all video again with new input parameters. At the end new and old results were compared, in order to come with conclusion and valuable solutions.

4.1 Changes to the code

I applied slight changes to the code of Firetraking program. First, I added the line of code that would make a program to save all output frames screenshots into one folder for future analysis. Next changes were applied to BrighMin settings in order to run videos with different brightness. The last change made a program to create and save output text files and screenshot files into separate folders, depends on brightness settings. These changes helped me organize received output from the program.

4.2 Collecting videos

In order to test an experiment on a wide range of situations I downloaded videos that contained fire, without fire and with objects similar to fire. Videos with fire were used to test an algorithm on real fire, where fire source had various size and was located in different places like: kitchen, bedroom, living room, car repair shop, tunnel, and other sites. In order to find how an algorithm would react on the regular life situations I collected videos with daily events: birds, musical instruments, cars, shops, restaurants, fair, people, busy streets, beach. Also, I downloaded videos with moving objects that have bright elements closer to yellow and white colors: waving flags, fireworks, car lights, dancing people, juggling, sunsets, Christmas lightning, North light. These videos would help to see how the Firetracking program would react on common in our life objects that has movement and color similar to the fire.

4.3 Results of an experiment

In order to analyze received information all videos were separated on categories "Videos with fire", "Videos without fire" and "Videos with objects similar to fire". For each category I created a table with videos name, test result, total number of frames, number of a frame and time in seconds when the alarm was triggered, and comments sections. Also, several graphs with persistency rate were created for the most interesting situations.

The Table 1 below represents tests results from video with fire.

Table 2: Test result for videos with fire

Video description	Test result	Total number of frames	Frame number and time when alarm started	Comments
Electric fire	TP	32765	2052 71 sec.	Did not react on a small fire since it was far away. The alarm was turned on when fire became bigger.
Car repair shop with fire	FN	5297	-	**Problem:** the fire on the video is not bright enough to trigger the alarm.
Fire in the box	FN	4322	-	**Problem:** The fire is too small and located behind the glass, which makes it not so bright in order to be detected by the Firetracking.
Hotel fire	FN	9644	-	**Problem:** The video quality is too poor to give all fire brightness and also it

				has gaps. On the other hand, fire source was small and located far away from the camera.
Track explosion at night	FN	3684	-	**Problem:** The video was black and white with poor quality. The fire was located far away from the camera, which might cause FN result.
Tunnel accident	FN	1947	-	**Experiment:** The alarm was triggered only when BrighMin was 190 or lower. However, the algorithm was concentrated only on fire reflection on cars. **Problem:** the fire source was located far away from the camera. Also, tunnel has too many lights, in order to concentrate on fire.
Bedroom fire tests	TP	14376	1550 51.5 sec.	There algorithm did not react on fire. The alarm was triggered because of dark smoke movement in front of the white frame. **Problem:** the fire had orange and red colors, and no bright colors.
Bedroom fire 3	FN	1163	-	**Problem:** the fire was not bright enough to be detected.
Bedroom 2	FN	755	-	**Problem:** the fire color was not bright enough to trigger the algorithm.
Booth	FN	1241	-	**Problem:** the program concentrated mostly on the brightest part of the fire. However, there was not so many of them because it was at night and most of the fire flames were more red and orange, than bright yellow or white.

Room fire	FN	1059	-	**Problem:** The very bright fire was only for only 6 second, which is not enough to trigger the alarm.
Fireplace	TP	838	301 12 sec.	
Real candle	FN	3382	-	The real candle might trigger the alarm, if there is a wind movement around.
Kitchen fire	TP	2424	1547 62 sec.	Even though, the video was not a good quality, the fire was bright enough for the algorithm to detect it.
House in fire	TP	772	543 22 sec.	The algorithm concentrated on the bottom of a fire, where fire shows the brightest colors. **Problem:** The fire was big. If it was only the middle or top part of the fire, the Firetracking most probably will not detect it as a fire because those parts are not bright enough.
Living room	TP	6354	1700 68 sec.	Fire was located far away. Probably that is why it took a time for the algorithm to detect it.
Christmas tree fire	TP	834	733 29 sec.	There were too many bright elements, which distracted an algorithm. Also, video contained a clock down, which also was a part of suspicion. However, the change occurs once per second, and that hardly satisfies the persistency criterion.
Fire recorded on 360 camera	TP	1177	301 12 sec.	The fire was bright enough for enough time in order to be detected.

				Problem: the hanging lamps were moving, and that made that an objects for suspicion.
Fully developed fire	FN	1267	-	**Problem:** video contains too many bright moving objects and even noise correction does not help an algorithm to detect right area of suspicion.
Tunnel fire 2	FN	2662	-	**Problem:** the video had too many bright objects like blinking lights that distracted an algorithm.

The Table 3 below represents tests results from video with objects similar to fire.

Table 3: Test result for videos with fire-like objects

Video description	Test result	Total number of frames	Frame number and time when alarm started	Comment
Back lights of a car	TN	3331	-	
Waving black and white flag	FP	1569	311 10 sec.	Most of the concentration was on a moving boy with yellow T-shirt. The persistency rate went up to 96% **Problem:** the algorithm concentrates on the brightest moving parts of dancers.
Christmas light on a house with a blinking star	TN	1517	-	
Christmas light on a house	TN	6162	-	
Fireworks 1	FP	3582	301 12 sec	An algorithm did not count two-tree single flashes from the fireworks as a fire. However, it reacted when there were many flashes at the same time. The alarm can be avoided by increasing BrighMin

Fireworks 2	FP	3609	404 16 sec.	An algorithm recognizes as a fire a group of flushes on a dark background. Color of the fireworks does not matter here.
Four people dancing in yellow T-shirts	FP	3582	301 12 sec.	The false alarm was triggered when dancers are either near each other or when dancer makes the same repeating elements in one place. The false alarm can be avoided by increasing BrighMin **Problem:** algorithm finds the brightest part of dancers, and takes their movement as a fire.
Flickering LED	TN	2319	-	
Light Dance	TN	2838	-	
Waving green and white flags	FP	792	301 12 sec.	**Problem: t**he Firetracking concentrates on bright parts of yellow T-shirt and white flag when it is not in shadow.
Fair	TN	2814	-	There was suspicion about some light on a fair.
Lava Lamp	FP	1501	302 12 sec.	The algorithm selected as area of suspicion only lamps with yellow and white colors. **Problem:** the algorithm finds bright color closer to yellow and white, and takes its movement as fire movement.
North light	TN	1872	-	
Electric candle	TN	1092	-	
Waving red flag	FP	981	301 12 sec.	Algorithm concentrates on a bright part of the T-shirt, moving arm and white stick of a flag. **Problem:** movement of bright parts of objects are mistaken with fire movements.
Dancing samba in yellow T-shirt	FP	3327	301 12 sec.	Firetracking selected only bright yellow area as a fire.

				Problem: algorithm finds bright colors closer to white and yellow and takes their movement as fire.
Dance school with yellow back-ground	FP	1457	301 12 sec.	The alarm happened when dancers were going up and down in one place. **Problem:** bright parts of clothes were moving like a fire flames up and down.
Sunset over field	TN	4245	-	
Sunset over forest	FP	7664	2566 102 sec.	The alarm happened when the sun was near the horizon and the tea contour in front of it became more visible. The algorithm concentrated on sun movement in front of the sun. **Problem:** dark moving con-tour in front of bright sun was very similar to the fire.
Sunset over sea	TN	9192	-	
Waving Ameri-can flag	FP	2349	1722 69 sec.	The alarm was turned on when the white stripes on a flag were not in shadow. **Problem:** a flag stripes came out of shadow and became bright white, and also had slow movement similar to fire.
Waving yellow flag	FP	971	301 12 sec	The concentration was on bright part of yellow flag and T-shirt, and white stick of a flag. **Problem:** bright parts of an object was considered a fire.

The Table 4 below represents tests results from video without fire.

Table 4: Test result for videos with objects not similar to fire

Video descrip-tion	Test result	Total number of frames	Frame num-ber and time when alarm started	Comment

Busy people on a street	TN	5022	-	
Dance in black T-shirt	TN	3099	-	When there are no bright elements in video, then there is nothing to trigger the alarm.
Dancing people in a green clothes	TN	3292	-	The algorithm was mostly concentrating on a white wall behind the dancer.
Dancing people in front red-gray wall	TN	782	-	There was suspicion about fire, up to 69%. The object of suspicion was a girl in red with black and white checkered dress.
Car repair shop without fire	TN	1444	-	
Falling leaves	TN	2549	-	
Guitar playing	FP	1281	957 38 sec.	Algorithm reacted on hand movement near guitar neck because it was in sun. **Problem:** guitar neck was bright due to sun lighting and was slightly moving. That is why it was mistaken with fire.
In the restaurant	TN	3574	-	
In the shop	FP	4462	321 13 sec.	The Firetracking considered moving people in bright white cloth as a fire. **Problem:** bright cloth behind other people were disappearing and again appearing like fire.
Fight in the shop	TN	949	-	
Fast guitar playing	FP	1897	453 18 sec.	Movement of bright parts of palms and white guitar chops triggered the alarm. **Problem:** bright parts of a guitar were slightly moving. This movement caused an alarm.

Cars driving at night during the rain	FP	2052	310 12.5 sec.	The persistency rate went up to 79%. The concentration of an algorithm was on a light reflection in a big puddle. **Experiment:** With BrighMin equal to 245, the persistency rate was 0 during whole video. **Problem:** bright moving object as puddle and driving cars with lights through it causes an alarm.
Cars driving at night	TN	2742	-	There was suspicion about a group of lights from the moving cars.
Kindergarten	TN	2682	-	
Beach	TN	4957	-	
Walking people on a street	TN	5018	-	
DJ	TN	2959	-	
Jail	TN	2222	-	**Problem:** the area of suspicion was bright area from the sun on a bold head and white T-shits.
Regular birds	FP	2889	1700	**Problem:** moving birds in front of bright orange seeds triggered an alarm.
Juggling	TN	1559	-	
Colorful birds	TN	2942	-	
Violin	TN	2664	-	

I set a persistency rate that triggers alarm to be equal to 75%, as it seems to be a reasonable line between videos without fire or with fire-like and videos with fire. However, I had to check if this is correct value. For this I calculated average persistency for fire video that triggered alarm that appeared to be 74.8%. This shows that chosen alarm persistency has correct value.

I also calculated whether the program works correctly. For this I created a Table 5 below, that represents an average persistency rate for videos with fire, without fire and videos with fire-like objects.

Table 5: Average persistency rate for different video types.

The average persistency for video with fire	The average persistency for video with fire-like objects	The average persistency for video with no fire
39%	53%	30%

The average persistency 53% shows that these videos are tricky for Firetracking algorithm. The video average with fire is higher than for video without fire, which means that the algorithm works correctly.

In order to show algorithm behavior, I created several charts for the most interesting and difficult videos of each category. The Figure 13 below represents changes in persistency rate for fireplace video. The TP alarm reaction was on 301 frame that is approximately 12 second.

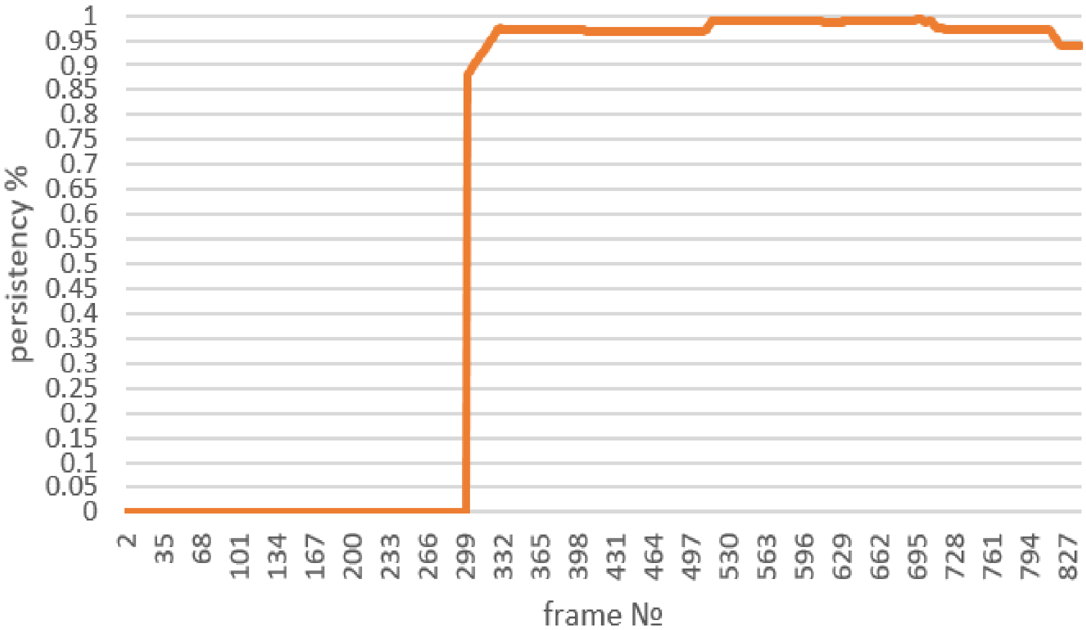

Figure 13: Persistency rate for video with fireplace

The Figure 14 below represents the change in persistency through the all video frames. It was a video with cars driving during the rainy night with thunderstorm. Through the chart is possible to notice that the persistency rate crossed 0,75 line several times. That caused FP alarm multiple times.

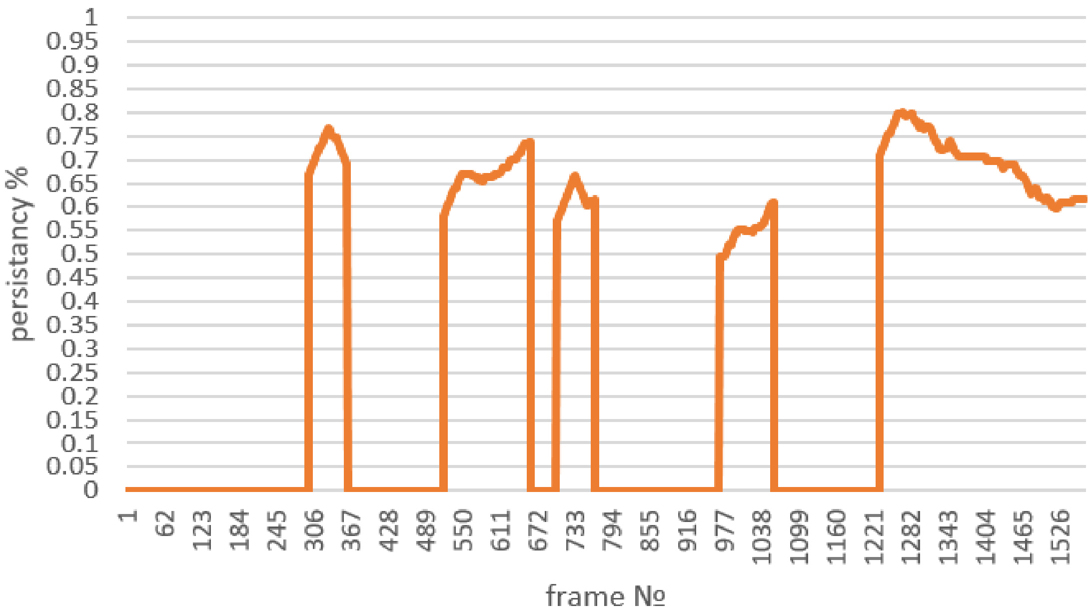

Figure 14: Persistency rate for video with cars driving at night during the thunderstorm

The Figure 15 below represents persistency rate for beach video. An algorithm had suspicion about three people walking in a bright cloth. This moment is visible on the chart, when orange line went up, but did not cross the point of 0.75 and did not trigger FP alarm.

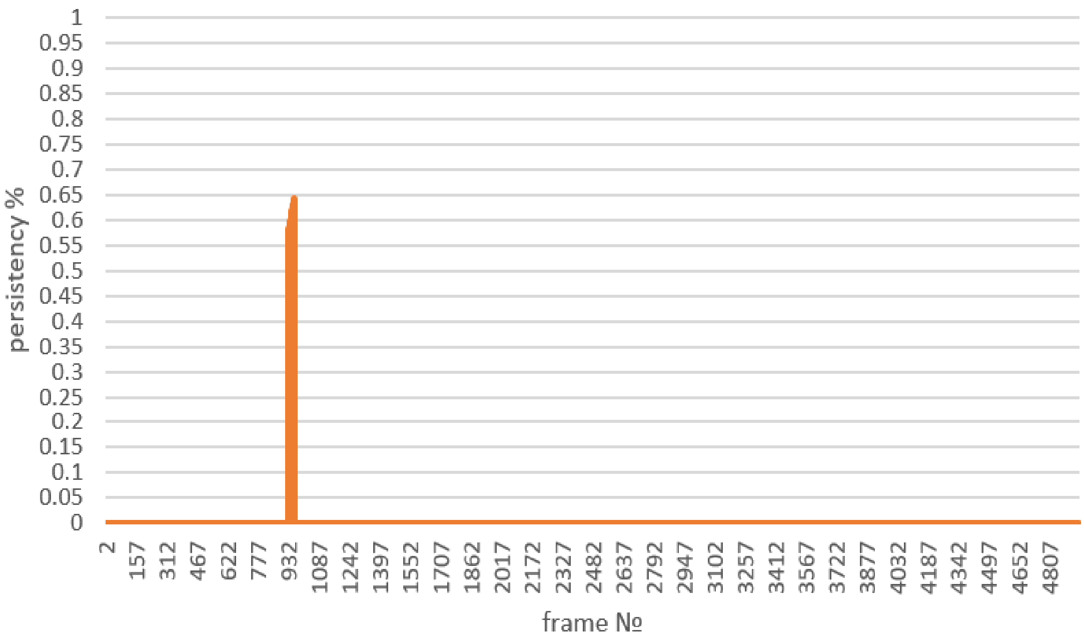

Figure 15: Persistency rate for the beach video

Overall, with persistency alarm point 75% and BrighMin = 225, Firetracking algorithm showed a speed of 301 frame, approximately 12 seconds, for reaction on fire event or elements similar to the fire.

4.4 Problems and suggestions for improvement

The experiment showed several common problems with detecting fire. One of them was a video brightness. The algorithm finds the brightest part of moving object and considers it as a fire movement. Especially that happened during dance movement or when object was moving in front of bright background like white wall or going down sun. For this reason, I created three table for each video categories that show whether different brightness causes better results from Firetracking program. The parameter BrighMin was slightly changed to 245 brightness and to 205 brightness. All videos were run for each brightness accordingly. The Table 6 below represents results for different brightness when videos contained fire. The cells with red color letters mean that there was no improvement from the first settings when BrighMin equals 225, and cells with green color means that there was improvement.

Table 6: Results from videos with fire with different BrighMin

Name	Brigh Min 225	BrighMin 225	Bright-Min 245	BrighMin 245	BrighMin 205	BrighMin 205
Electric fire	TP	FN – 53% S – 16% TP – 31%	TP	FN – 57% S – 25% TP – 16%	TP	FN – 73% S – 9% TP – 18%
Car repair shop with fire	FN	FN – 100%	FN	FN – 100%	TP	FN – 93% S – 2% TP – 5%
Fire in the box	FN	FN – 100%	TP	FN – 96% S – 3.8% TP – 0.2%	TP	FN – 95% S – 3% TP – 2%
Hotel fire	FN	FN – 100%	FN	FN – 100%	FN	FN – 100%
Track explosion at night	FN	FN – 100%	FN	FN – 100%	FN	FN – 100%
Tunnel accident	FN	FN – 100%	FN	FN – 100%	FN	FN – 100%

Bedroom fire tests	TP	FN – 100%	FN	FN – 100%	TP	FN – 72% S – 7% TP – 21%
Bedroom fire 3	FN	FN – 100%	FN	FN – 100%	TP	FN – 40% TP – 60%
Bedroom 2	FN	FN – 100%	FN	FN – 100%	TP	FN – 57% TP – 43%
Booth	FN	FN – 89% S – 11%	FN	FN – 100%	TP	FN – 46% S – 9% TP – 45%
Room fire	FN	FN – 84% S – 16%	FN	FN – 100%	TP	FN – 58% TP – 42%
Fireplace	TP	FN – 36% TP – 64%	FN	FN – 100%	TP	TN – 36% S – 10% TP – 54%
Real candle	FN	FN – 100%	FN	FN – 100%	TP	TN – 98% S – 0.2% TP – 1.8%
Kitchen fire	TP	FN – 53% S – 24% TP – 23%	FN	FN – 98% S – 2%	TP	FN – 34% S – 20% TP – 46%
House in fire	TP	FN – 70%, S – 16% TP – 14%	FN	FN – 100%	TP	FN – 88% TP – 12%
Living room	TP	FN – 41%, S – 32% TP – 27%	TP	FN – 80% S – 17% TP – 3%	TP	FN – 44% S – 13% TP – 43%
Christmas tree fire	TP	FN – 97% S – 2% TP – 1%	FN	FN – 100%	TP	FN – 42% TP – 58%
Fire recorded on 360 camera	TP	FN – 25% S – 40% TP – 35%	TP	FN – 25% S – 44% TP – 31%	TP	FN – 25% S – 35% TP – 40%
Fully developed fire	FN	FN – 100%	FN	FN – 100%	TP	FN – 87%

						S – 10% TP – 3%
Tunnel fire 2	FN	FN – 100%	FN	FN – 100%	TP	FN – 79% S – 6% TP – 15%

The Table 7 represents results of different brightness when videos had objects similar to fire.

Table 7: Results from videos with fire-like objects with different BrighMin

Name	Brigh Min 225	BrighMin 225	Bright-Min 245	BrighMin 245	BrighMin 205	BrighMin 205
Back lights of a car	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Waving black and white flag	FP	TN – 44% FP – 56%	TN	TN – 100%	FP	TN – 21% S – 10% FP – 69%
Christmas light on a house with a blinking star	TN	TN – 100%	TN	TN – 94% S – 6%	TN	TN – 100%
Christmas light on a house	TN	TN – 100%	TN	TN – 100%	TN	TN – 99% S – 1%
Fireworks 1	FP	TN – 54% S – 24% FP – 22%	FP, 301	TN – 85% FP – 15%	FP, 329	TN – 59% S – 23% FP – 19%
Fireworks 2	FP	TN – 80% S – 8% FP – 12%	FP	TN – 79% S – 11% FP – 10%	FP	TN – 52% S – 29% FP – 19%
Four people dancing in yellow T-shirts	FP	TN – 52% S – 12% FP – 36%	FP	TN – 96% S – 2% FP – 2%	FP	TN – 20% S – 24% FP – 56%
Flickering LED	TN	TN – 100%	TN	TN – 100%	FP	TN – 57% S – 3% FP – 50%

Light Dance	TN	TN – 100%	TN	TN – 100%	FP	TN – 75% S – 14% FP – 11%
Waving green and white flags	FP	TN – 71% FP – 29%	TN	TN – 100%	FP	TN – 38% FP – 62%
Lava Lamp	FP	TN – 59% FP – 41%	TN	TN – 100%	FP	TN – 20% S – 6% FP – 74%
North light	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Electric candle	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Waving red flag	FP	TN – 90% FP – 10%	TN	TN – 100%	FP	TN – 56% S – 36% FP – 8%
Dancing samba in yellow T-shirt	FP	TN – 30% S – 5% FP – 65%	TN	TN – 100%	FP	TN – 9% S – 17% FP – 34%
Dance school with yellow background	FP	TN – 75% S – 0.1% FP – 24.9%	TN	TN – 100%	FP	TN – 22% FP – 78%
Sunset over field	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Sunset over forest	FP	TN – 89% S – 1% FP – 10%	TN	TN – 100%	FP	TN – 67% S – 5% FP – 28%
Sunset over sea	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Waving American flag	FP	TN – 73% S – 20% FP – 7%	TN	TN – 100%	FP	TN – 68% S – 31% FP – 1%
Waving yel-low flag	FP	TN –31% S – 5% FP – 64%	TN	TN – 100%	FP	TN – 31% S – 28% FP – 41%

Fair	TN	TN – 95% S - 5%	TN	TN – 95% S – 5%	TN	TN – 94% S – 6%

The Table 8 shows results of different brightness when videos did not contain fire.

Table 8: Results from videos without fire and with different BrighMin

Name	Brigh Min 225	BrighMin 225	Bright-Min 245	BrighMin 245	BrighMin 205	BrighMin 205
Busy people on a street	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Car repair shop without fire	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Falling leaves	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Guitar play-ing	FP	TN – 60% S – 14% FP – 26%	FP	TN – 82% S – 2% FP – 16%	FP	TN – 92% FP – 8%
In the res-taurant	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
In the shop	FP	TN – 12% S – 56% FP – 32%	FP	TN – 32% S – 20% FP – 48%	FP	TN – 38% S – 54% FP – 8%
Fight in the shop	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Fast guitar playing	FP	TN – 68% S – 20% FP – 12%	TN	TN – 100%	FP	TN – 81% S – 2% FP – 17%
Cars driving at night dur-ing the rain	FP	TN – 57% S – 37% FP – 6%	TN	TN – 99.8% S – 0.2%	FP	TN – 45% S – 40% FP – 15%
Cars driving at night	TN	TN – 41% S – 59%	FP	TN – 36% S – 50% FP – 14%	TN	TN – 47% S – 53%
Kindergar-ten	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%

Juggling	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Beach	TN	TN – 99.5% S – 0.5%	TN	TN – 100%	FP	TN – 93% S – 1% FP – 6%
Walking people on a street	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
DJ	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Jail	TN	TN – 96% S – 4%	TN	TN – 100%	FP	TN – 70%, S – 16% FP –14%
Regular birds	FP	TN – 42% S – 31% FP – 27%	TN	TN – 100%	FP	TN – 30%, S – 23% FP – 47%
Colorful birds	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Violin	TN	TN – 100%	TN	TN – 100%	FP	TN – 49.7%, S – 0.3% FP – 50%
Dance in black T-shirt	TN	TN – 100%	TN	TN – 100%	TN	TN – 100%
Dancing people in a green clothes	TN	TN – 100%	TN	TN – 100%	TN	TN – 31% S – 1% FP – 68%
Dancing people in front of a red-gray wall	TN	TN – 96% S – 4%	TN	TN – 100%	FP	TN – 40% S – 57% FP – 3%

The tables with different brightness show that the changes in parameter BrighMin give good results for one type of videos and bad result for other type. For example, when BrighMin = 205 is useful for indoor videos that contain fire, but completely useless for the indoor videos that does not include fire. On the other hand, when the brightness was set to 245 the algorithm worked well for videos without fire or with objects similar to fire, but did not work well for video with fire. Also, change in brightness setting showed different results in day and night videos. The Figure 16 shows false positive alarm that was triggered by moving track at night with BrighMin equal 205.

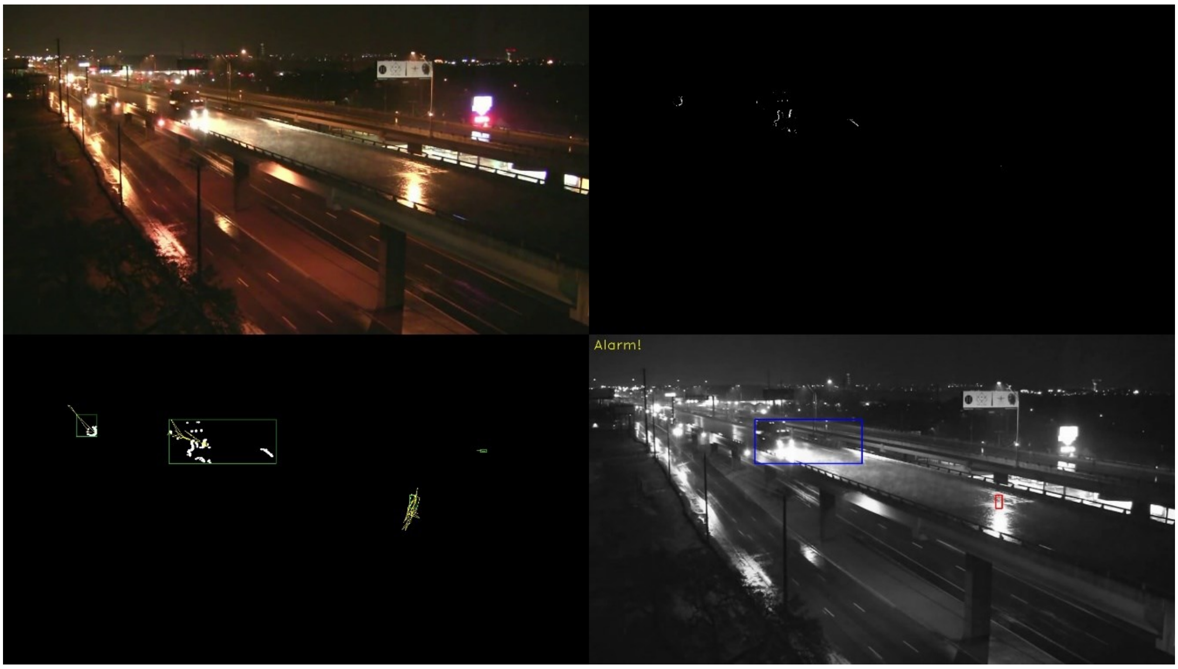

Figure 16: False positive alarm for video with BrighMin equal 245

In order to compare results in different situation I created tables for each BrighMin value in situations like dark and bright conditions and indoor and outdoor conditions. The following Table 9 shows result for videos recorded indoor and outdoor with different BrighMin.

Table 9: Results for videos recorded indoor and out door with different BrgihtMin

Number of videos	Result in percentage for BrighMin = 245	Result in percentage for BrighMin = 205
35 videos recorded in-door	48.5% – negative result 51.5% – positive result	40% – negative result 60% – positive result
33 videos recorded out-door	13.7% – negative result 86.3% – positive result	54.5% – negative result 45.5% – positive result

The Table 10 represents result for videos recorded in dark and bright conditions with different BrighMin.

Table 10: Results for videos recorded indoor and out door with different BrgihtMin

Number of videos	Result in percentage for BrighMin = 245	Result in percentage for BrighMin = 205
39 videos recorded in dark conditions	51.2% – negative result 48.8% – positive result	3.6% – negative result 96.4% – positive result
29 videos recorded in bright conditions	13.7% – negative result 86.3% – positive result	60.7% – negative result 39.3% – positive result

The results from the above tables show that setting BrighMin to 245 points is good for bright condition video and videos recorded outside the buildings. The BrighMin equals 205 is good for dark condition videos and videos recorded inside the buildings. The best solution here is to allow camera dynamically adjust brightness, when video brightness condition has changed.

Also the experiment reviled that the algorithm chooses the brightest moving point on the video, with color closer to bright yellow and white, and mistakes them with fire movement. As an example, the algorithm suspected several single moving people, wearing for example a white T-shirt, a scarf and a cap, to be a fire movement. The Figure 17 below shows how moving guitar neck in sun lighting triggered an alarm. The rectangle selected the end of a guitar neck.

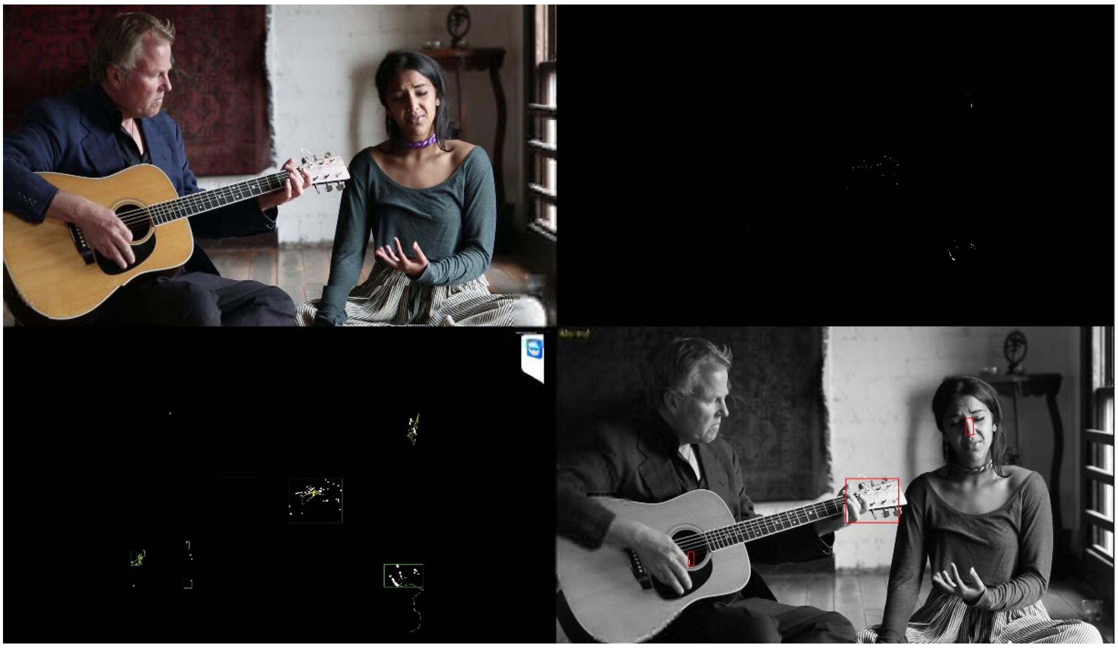

Figure 17: Example of false alarm caused by bright moving part of an object

Also, when fire in the image was without right bright yellow or white colors, and had only red, orange and yellow color, the algorithm did not recognize fire in such situation. It happens because those colors can pass the algorithm color selection setting, but do not pass the brightness settings. As a solution in such situation would be to adjust brightness for specific colors. The Figure 18 below shows how the Firetracking selects with rectangle only bright area at the bottom of a fire and does not see orange and red flames. In case when the bottom of a fire is not visible, the fire would not be detected.

Figure 18: Seclected bright area of a fire in the image

There are also situations when the scene contains objects that have the color and movement similar to the fire. It can be a lamp or sun. The following Figure 19 shows the moment when forest in front of the sun was considered to be a fire.

Figure 19: False alarm caused by forest in front of the sun

This problem can be solved by setting a blind spot for the camera, so it will not react to bright objects that regularly appear at certain places.

4.5 Summary

During the experiment I ran the algorithm on more than 60 videos with fire, without fire and with objects similar to fire. The experiment showed that the algorithm gives good results and can be used either as a support sub-algorithm to improve the final decision of some more complex algorithm or as part of existing camera system which requires constant human attention in case of alarm (true and false). At the same time, the Firetracking algorithm showed some problems with brightness and color conditions, and these parameters have to be adjusted in specific situations in order to achieve correct results.

5 CONCLUSION

The main goal of this research was to find weaknesses in Firetracking algorithm and come up with possible solution for revealed problems. I also helped to teach our fire-detecting algorithm to recognize fire in images taken from video cameras. I had to select whether an image has: (0) no fire at all, (1) a bit of fire, (2) flickering fire, (3) steady fire, (4) smoke, (5) hot air.

My research revealed that our algorithm gives false alarm on moving bright objects or items that move in front of bright background. Another problem was that our Firedetector did not recognize fire if it only had orange and red colors.

The analysis of data collected by me showed common problems in fire detection and gave a valuable information for our algorithm improvement.

5.1 Database

During the experiment I used videos with fire from a database provided to me by my colleague - Karel Koplik. I also created my own database of 58 videos, downloaded from Youtube and Vimeo channels that contained fire, were without fire or had moving objects similar to fire. The videos without fire and with fire-like objects displayed different regular situations: fireworks, Christmas lights, shops, restaurants, etc. The videos with fire were recorded in such places like: living room, bedrooms, car repair shops, tunnels, kitchens.

The variety of videos gave a chance to see Firetracking program reaction on different daily situations with fire and without it.

5.2 Methods and tools

For this research I used a computer with Linux Ubuntu OS, Net Beans IDE 8.2 and Firetracking program. The algorithm was run on collected videos with the same input parameters: BrighMin = 225, MoveMin = 15, ContDil = 2, ContTol =20, ContRTL = 10, ContMinSize =0 and PersLen = 300. As an output I received text files with persistency rate for each frame from the video, and also a folder with screenshots output for each frame. These helped me calculate total number of frames for each video, result percentage, and find the time and frame when the alarm started. All videos were grouped into categories “Videos with fire”, “Videos without fire” and “Videos with objects similar to fire”, and for each category I created a table with algorithm output. After that, a received information from

Firetracking program which helped to find solutions for revealed problems. Some of the solutions were tested in the experiment again.

5.3 Research findings

During the experiment, my research colleagues found several problems with brightness and fire color detection. The algorithm considered bright moving objects, or only a part of them, to be fire movements. Also, moving element in front of the bright background could trigger the alarm. At the same time, the algorithm did not turn on the alarm when videos contained not enough bright fire. This problem can be solved by changing brightness parameter for specific videos. In this research I tried to check this solution for brightness levels between 205 and 245. The result shows that brightness 245 works best for bright condition video and videos recorded outside the buildings. And when brightness is set to 205, it is good for dark condition videos and videos recorded indoor.

Also, there was a problem that algorithm searched only for bright yellow and white colors and did not see fire when it had only red and orange colors. This can be solved by setting right brightness parameters for fire colors. This solution has to be further tested.

Another problem was with objects that have color and movement similar to fire. For example, a slightly moving lamp can cause an alarm. This problem can be solved by using blind spot, so that algorithm will not analyze areas with object that trigger an alarm.

5.4 Limitations of this research

During the research there were several limitations:

- I only had one computer to analyze the videos, which could run only 8 videos at a time. That increased the time for the whole experiment.
- I was the only person who worked on this research and analyzed the received data. If there were more participants in the analysis process, the list of problems and proposed solutions might have been different.
- All the videos were downloaded from online video channels and had different video quality and frame rate. Some of the video was recorded on old video cameras. If all videos were recorded on new cameras, probably the research would show better result.

5.5 Summary

Overall this research showed that our Firetracking program can detect fire in different life situations with minimum fire detection speed of twelve seconds. It also showed that the algorithm needs brightness adjustment for specific video brightness condition. Also, it would be better to use a blind spot on video with regular objects similar to fire. At the same time, Firetracking program needs to adjust brightness for fire color like red and orange. In the future this algorithm can be very useful either to support more complex sub-algorithm to improve the final decision or it can replace human attention presence in existing fire-detecting cameras.

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LIST OF ABBREVIATIONS

IR	Infrared
LED	Light-emitting diode
UV	Ultraviolet
VFSD	Video fire and smoke development
TP	True positive
FP	False positive
TN	True negative
FN	False negative
CO	Carbon monoxide
CO2	Carbon dioxide
HSI	Hue Saturation Intensity
HSV	Hue Saturation Value
RGB	Red Green Blue
VID	Video Image Detection
VSD	Video-based smoke-detection
SVM	Support Vector Machine
ADU	Alarm Decision Unit
GMM	Gaussian Mixture Model
OS	Operating System
S	Suspicion
NRCC	National Research Council Canada
CU	Carleton University
BrighMin	Brightness threshold
MoveMin	Movement threshold

ContDil	Small regions gap size
ContTol	Regions minimal size
ContRTL	Region’s right to live
ContMinSize	Number of middle points
PersLen	Persistency interval

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APPENDICES

List of downloaded videos with their links

Electric fire	https://www.youtube.com/watch?v=TNEXZVKl5Vs
Car repair shop with fire	https://www.youtube.com/watch?v=a410EbKtxK0
Fire in the box	https://www.youtube.com/watch?v=JdEI7g2i1ZU
Hotel fire	https://www.youtube.com/watch?v=kvx4OQJ3kFE
Track explosion at night	https://www.youtube.com/watch?v=TGC3qXyBgBo
Tunnel accident	https://www.youtube.com/watch?v=iCpeN4pUciw
Bedroom fire tests	https://www.youtube.com/watch?v=507gj_JWWSs
Real candle	https://www.youtube.com/watch?v=CDvFKkBt_QQ&spfreload=1
Kitchen fire	https://www.youtube.com/watch?v=50NN3B7jjDk
Living room	https://www.youtube.com/watch?v=mjCIPguK7GM
Christmas tree fire	https://www.youtube.com/watch?v=ZLHhG65fLeY
Fire recorded on 360 camera	http://en.savefrom.net/1-how-to-download-youtube-video/
Fireplace	https://www.youtube.com/watch?v=3ohDcpxVK74
Tunnel fire 2	https://www.youtube.com/watch?v=uHxMab0dQtc&t=79s
Back lights of a car	https://www.youtube.com/watch?v=2dApl0BGL9I
Waving black and white flag	https://www.youtube.com/watch?v=fgIG7FNbjz4
Christmas light on a house with a blinking star	https://www.youtube.com/watch?v=mnk0KjWxgMA
Christmas light on a house	https://www.youtube.com/watch?v=90oZ52M4IC0
Fireworks 1	https://www.youtube.com/watch?v=9HTNx7TRsWw&t=402s
Fireworks 2	https://www.youtube.com/watch?v=GsKnPDeU9vI&t=1086s
Four people dancing in yellow T-shirts	https://www.youtube.com/watch?v=Y8BC2gIhjD0
Flickering LED	https://www.youtube.com/watch?v=VC_URf-y9U0

Light Dance	https://www.youtube.com/watch?v=-Rot9uaVO8s
Waving green and white flags	https://www.youtube.com/watch?v=FWsAkUH5NxI
Juggling	https://www.youtube.com/watch?v=YhAWdWcSWYQ
Lava Lamp	https://www.youtube.com/watch?v=q3BMSOslAQY
North light	https://www.youtube.com/watch?v=AcVE7m8xu_k
Electric candle	https://www.youtube.com/watch?v=PVzc3RFCM4g
Waving red flag	https://www.youtube.com/watch?v=PcDZ0MC-3Ag
Dancing samba in yellow T-shirt	https://www.youtube.com/watch?v=zJwtGvKUpgA
Dance school with yellow background	https://www.youtube.com/watch?v=KgGFck4cJOs
Dance in black T-shirt	https://www.youtube.com/watch?v=d26s2yvBUZM
Sunset over field	https://www.youtube.com/watch?v=1jt5Y7BNcd8
Sunset over forest	https://www.youtube.com/watch?v=PU2J4PIesSk
Sunset over sea	https://www.youtube.com/watch?v=d4qhtSYbEL4
Waving American flag	https://www.youtube.com/watch?v=pghu0lVm6uE
Waving yellow flag	https://www.youtube.com/watch?v=LKtwbPZAbFo
Dancing people in front red-gray wall	https://vimeo.com/361535
Fair	https://www.youtube.com/watch?v=-lcGWny4yrI
Busy people on a street	https://www.youtube.com/watch?v=6iuNSa4lJoA
Dancing people in a bright green clothes	https://www.youtube.com/watch?v=OTW_ak9_ORg
Falling leaves	https://www.youtube.com/watch?v=HZA9Gbb8zcI
Guitar playing	https://vimeo.com/172832596
In the restaurant	https://www.youtube.com/watch?v=1a6W6fXqDhg

In the shop	https://www.youtube.com/watch?v=CqxyHJTWi70
Fight in the shop	https://www.youtube.com/watch?v=C4SQF-UZzkA&t=106s
Fast guitar playing	https://www.youtube.com/watch?v=k4ixAfJ1LuI
Cars driving at night during the rain	https://www.youtube.com/watch?v=cDNETgwyQSI
Cars driving at night	https://www.youtube.com/watch?v=0PK0ipTvfH0
Kindergarten	https://www.youtube.com/watch?v=xjS4-njFopQ
Beach	https://www.youtube.com/watch?v=aKLfYF0ofJw
Walking people on a street	https://www.youtube.com/watch?v=VUrddMw2Qso
DJ	https://www.youtube.com/watch?v=vy-k0FopsmY&t=94s
Jail	https://www.youtube.com/watch?v=W7_Peyt5DuI
Regular birds	https://www.youtube.com/watch?v=elXRFIRun20
Colorful birds	https://www.youtube.com/watch?v=s-q0q1D2Hvk
Violin	https://www.youtube.com/watch?v=6zz5XRVkRiY

APPENDIX P I: APPENDIX TITLE