

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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FIRE RISK ASSESSMENT AND FORECASTING USING REMOTE SURVEY
DATA AND GEOGRAPHICAL INFORMATION SYSTEMS

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Notation

A amplitude caused by the feeding screw

a acceleration of a mass change

α_1 the weight of distance in space

α_2 the weight of distance in time

Chapter 1

Introduction

1.1 Research problem

For the last decade in the systems related to geographic information (for the sake of simplicity let call such system as Geographic Information System) start increasingly using publicly and openly available data that can be used free of charge for a variety of purposes and tasks. Satellite data from the Sentinel program run by the European Space Agency (ESA) can be used to monitor environmental pollution parameters, soil, vegetation, forest and water resources, can be used for natural consequences management and risk identification.

The Copernicus program, developed by ESA, provides high-quality and freely available Sentinel satellite data that can be adapted to meet a variety of Geographic Information System (GIS) challenges. One example of such a task is the identification of fire damage to a forest or the classification of arid areas to prevent a potential fire.

Due to global warming, increased and prolonged heat waves, there is an increasing risk of uncontrolled fires. Uncontrolled fires are the cause of air, water pollution, and the destruction of flora and fauna.

Using multi-spectral, hyper-spectral and radio spectral cameras, chemical, thermal and biological contamination can be captured rapidly. Numerous software programs have been developed for the processing of satellite images.

However, many software programs typically consist of separate units used to solve specific tasks or work with specific data formats and do not provide a single information system that can be used to quickly and effectively assess chemical, biological or other sources of pollution and natural disaster risk. The biggest problem when working with satellite imagery is the large amount of data that takes a long time to process due to the different data formats, unclear data processing methodology, consistent data processing, and limited job automation.

A thematic data processing methodology for the analysis of multi-spectral spatial data images with respect to their fast and efficient processing of satellite images is proposed. The methodology is designed to identify environmental parameters to assess the risk of fire or other natural disasters, based on various results of electromagnetic wave reflection analysis in different ranges and selection of optimal electromagnetic wave bands. ESA's Sentinel-2 satellite imagery, which is increasingly used in European countries, is used as the main data source for the analysis.

1.2 Relevance of the work

In recent years, there has been an increasing need to effectively assess the risks (large-scale fires, oil spills, etc.) that can be caused by both natural disasters and human activities, and to take all preventive measures where possible. Large uncontrolled fires or oil spills affect climate change, soil acidification, water pollution. Increasingly, remote sensing systems are in place that can cover large areas and perform automated monitoring of the area in question.

Such an analysis requires access to constantly updated and high-resolution remote sensing data. Such data are provided by ESA (European Space Agency) under the Copernicus program. Data from remote sensing data from Sentinel-1 and Sentinel-2 satellites are widely used to address risk management challenges such as fire damage detection or prevention. The images provided by Sentinel-1 and Sentinel-2 satellites are and will be widely used for various environmental tasks, mapping of natural resources, modeling of natural processes in a large area due to their accuracy, free provision and frequent updating. The data

provided by the Sentinel-1 and Sentinel-2 satellites open up new opportunities for research.

Many applications of remote sensing to the monitoring of environmental parameters require frequent and dense coverage of spatial data in the study area. Much of the satellite imagery is free and publicly available online. Sentinel satellite imagery supplemented with data from other satellite systems can form the basis for an information system for monitoring a large area, the analysis of which can be used by public authorities, for more effective risk prevention and control.

The leading countries in the field of remote sensing in the world are the USA, Russia, France, Germany, China. For example, U.S. Forest Service has done most of its research into forest fire risk identification and management. The U.S. Forest Service also provides guidelines and various indices for assessing forest status, drought levels, and so on. The paper proposes a methodology for forest fire risk assessment by processing Sentinel satellite images with data from other remote sensing systems, using multi-spectral image classification algorithms as a basis in conjunction with learning computer neural networks. To develop a methodology for the prevention and prediction of wild fire risk. The expected result of the work is the development of a methodology for assessing the condition of forests, assessment of fire risk and prediction it spread, and the provision of recommendations on how to improve environmental monitoring.

1.3 Object of research

The object of the research is an algorithm that combines satellite data of different formats to model the risk of uncontrolled forest fires and revise fire indices that are used to assess fire risk in [insert area of concern].

1.4 Study objective

To develop a reasonable methodology of classification algorithms combining satellite image data in different formats, allowing to identify the risk of forest fires and present it in a constantly updated thematic map as a graphical representation of fire indices. A map of forest fire risk is the graphical representation of a collection of levels of risk obtained by an index of risk. An index of risk is made up by different variables combined in such a way to obtain particular values; which are referred to be as levels of risk. [1]

An index of fire risk have different nature and methods, so index performances comparison is required in order to establish which index is best suitable to be adopted at European level.

Consequently, the European Commission has incessantly introduced proper regulations and schemes of prevention in which a production of maps of forest fire risk is required. [1]

Thus, this work presents results obtained by a retrospective analysis of long term time series of remote sensing and meteorological data. [1]

1.5 Work tasks

In order to achieve the goal of the work, the following tasks need to be solved at work:

- Selection of remote sensing (passive and active) methods and criteria for identification, investigation, monitoring and modeling of fire risk areas.
- Carry out experimental research using optical satellite images, identify the necessary indices for the identification of fire sites.
- Carry out experimental research using radar satellite images, identify the necessary indices for the identification of fire sites.
- To select criteria suitable for monitoring the fire risk in the Baltic States.

- To develop an algorithm combining satellite data of different formats for the identification and modeling of fire sites.
- Create a thematic real-time renewable fire risk map.

1.6 Research methodology

The dissertation uses theoretical and experimental research using satellite imagery, geographic information technologies, digital modeling and statistical modeling methods.

1.7 Scientific novelty of the work and its significance

During the preparation of the dissertation, the following new results important for environmental engineering science and for environmental protection:

- A methodology has been developed that allows the analysis of large areas using not only passive but also active remote sensing systems.
- The revised and selected indices are intended to determine the forest fire risk or a new methodology for calculating the indices has been developed based on experimental studies.
- An algorithm has been developed for processing satellite images of different formats by modeling fire risk.

1.8 Practical significance of the work results

The results of the research can be used to develop, prepare or use satellite imagery to assess and prevent the risk of uncontrolled forest fires or to assess

the consequences of forest fires, to select data processing software and to adapt the data to interactive digital thematic maps.

1.9 Defensive statements

Assessing the risk of large-scale uncontrolled forest fires can help avoid dire consequences for the environment. Identification of fire risks will avoid the costs associated with fire suppression and its consequences.

Chapter 2

Application of remote sensing systems for assessment and prediction of different environmental risks

The remote sensing methods are reviewed in this chapter that are used to obtain indirect quantitative and qualitative properties about objects. Passive and active research methods are reviewed. The problems related to the large-scale processing of data for the operative retrieval of results about the object under study are reviewed. Methods for obtaining data from optical and radiometric satellite images are considered.

2.1 Application of remote sensing data to the environment

Spatial data is one of the fastest growing scientific data, which poses significant computational difficulties for scientists who need to deal with the processing and analysis of large spatial data sets. With the continuous development of

sensor technology, the volume of remote sensing images has increased rapidly in recent years and is expected to continue to do so (Yan Ma et al., 2015).

Passive remote sensing data is often used for a variety of environmental challenges:

- Wildfire prevention.
- Wildfire damage assessment.
- Optimization of nitrogen fertilization.
- Etc.

For the prevention and detection of forest fire damage, a relative normalized deployment index can be applied (N. V. Rodinov), distinguishing cloud cover and hydrology from the total data array.

The so-called change detection methodology (CD) can be used to determine forest fire damage. Using the CD methodology, images of different time sections of the same area are usually compared (N. V. Rodinov. Et al., 2016). In order to reduce the images present in the triggers (cloudiness, hydrology), filters are applied to distinguish such triggers using pixel algebra. In this case, the normalized deployment index is calculated for images of different time sections of the same area by making a relative estimate - a relative normalized deployment index. Based on the obtained research results, a data model distinguishing the places where the forest may be affected or most affected is presented.

Currently, more than 100 spectral index variants used for different purposes have been described in different studies using passive remote sensing methods, but only a few of them find wide application in environmental research, monitoring (Vladimir Aleksandrovich Hamedov et al.). In many cases, the described indices do not provide an integrated approach to their complex use in observing a physical phenomenon, which is related to their applications in localized areas using empirical formulas in different ecosystems (Vladimir Aleksandrovis Hamedov et al.). It is for this reason that existing indices used to assess, for example, forest fire risk need to be adjusted for a specific area.

In addition to passive remote sensing, active satellite surveys are increasingly being used, which, for example, make it possible to determine quite accurately:

- Water surface contamination by oil products.
- Water surface contamination with plastic (plastic).
- Fire damage assessment.
- Improving fire risk indices.
- Etc.

There are a lot of example of successful applying of remote sensing for monitoring and assessment various risk for different environmental purposes:

Example 2.1.1 (Oil detection). *Petroleum products form a film on the surface of the water that is impermeable to sunlight. Without sunlight, the oxidation of bacteria and the multiplication and life of small organisms cease. The death of animal organisms damages the food web. The sea is often polluted by oil products during tanker accidents, but mainly due to sewage from tankers and refineries. Oil products pollute beaches, killing birds and fish.*

Large spills of oil products at sea can have significant biological and economic impacts. Public and media surveillance is usually intensive after a spill. Remote sensing is playing an increasingly important role in oil monitoring. Active satellite sensors SAR are commonly used to monitor marine oil spills. It is a more effective tool that can penetrate through clouds, rain and snow. The sensor emits microwave radiation that is reflected from the object and the received signal can be determined by the reversible scattering function (Merv Fing et al., 2014).

Active satellite remote sensing has been successfully applied to simulate the 2010 oil spill in Dalian, Japan. In this study, a support vector machine was adapted to monitor oil spills based on high radiometric resolution SAR images (Jianchao Fana et al., 2015).

Under different weather conditions in different places, the reflection and scattering properties of radio waves from the oil differ. On this basis, a vector machine can be

constructed that can automatically classify oil spill zones (Jianchao Fana et al., 2015). In recent years, water has been increasingly contaminated with plastic products, which need to be monitored and identified to determine the extent of the contamination.

Example 2.1.2 (Plastic detection). Plastic pollution in the ocean has been identified as a threat to various coastal areas. Many marine organisms can swallow or become entangled in plastic and this can pose a fatal risk to them. Although high concentrations of floating plastic debris are observed as they travel from inland waters to the open ocean, a detailed analysis of the spatial scale and abundance of waste is lacking and monitoring tools are not well developed to determine the distribution of pollution. Remote-sensing images with medium and high temporal, spectral, and spatial resolutions would be a great additional tool to quantify the distribution of floating marine plastic debris (Shungudzemwoyo P. Garabaa et al., 2017).

Identifying plastics at sea is difficult because there are many different plastics in the marine environment. The size of the plastic can range from microplastics (less than 5 mm) to large plastic parts such as “ghost nets” (lost or discarded fishing nets). In the first case, the plastic material can be toxic through the absorption of contaminants into the plastic, and in the second case, the plastic contaminants can injure animals and endanger seafarers. Plastics can be made from granules used in manufacturing, from certain cosmetic and personal care products, from textile fibers (Lonneke Goddijn-Murphy et al., 2017).

The rays of the sun falling on the surface of the water are partly reflected and the other partially penetrates through the surface. In water, light photons are absorbed and scattered in all directions. Due to the scattering and even distribution of repetitive light rays in all directions, it is possible to identify objects on the water surface. If the water is optically deep (the bottom is invisible), the fraction of light that is scattered and penetrates through the water into the air medium provides information on optically active (e.g., plankton) constituents of the water. Optically active components determine the apparent color of water, and their concentration can be calculated from spectral reflection measurements. In this case, the concentration of plastics can be identified in places where optically active water components cannot be identified (Lonneke Goddijn-Murphy et al., 2017).

Satellites that have sensors that can detect the color of the ocean also provide instruments

to identify the plastic, such as Sentinel-3 working in conjunction with Sentinel-3 SLSTR comparing nine bands VIS-SWIR 0.55–12 μm (Lonneke Goddijn-Murphy et al., 2017).

Example 2.1.3 (Nitrogen of plants detection). *Optical satellite imagery is by far the most suitable for determining the nitrogen content of plants to reduce the use of fertilizers in crop production.*

Example 2.1.4 (Title). *Write more about how remote sensing is used for fire assessment and prediction*

2.2 ESO (European Space Agency) is developing a Sentinel satellite system under the Copernicus program

There is an increasing need for operative analysis in the territory in question to solve various environmental, landscaping and risk management tasks. Such an analysis requires access to constantly updated and high-resolution remote sensing data. Such data are provided by ESO (European Space Agency) under the Copernicus program. The paper examines the application of open Sentinel-1 and Sentinel-2 satellite remote sensing data to address a risk management task, such as fire damage detection.

Sentinel remote sensing data are being developed by ESA under the Copernicus program. This data is free and freely available. In recent years, the need for access to open, free, and frequently updated time-lapse remote sensing data has been growing. Sentinel is divided into 6 groups of satellites, each of which has 2 satellites that can be used to solve various environmental, landscaping and risk management tasks.

One of the most common tasks is risk management. Sentinel data, due to their accuracy and frequent updating in the time section, can be used, for example, to determine fire damage.

ESA has launched two satellites from each Sentinel family into orbit under the ongoing Copernicus program:

- Sentinel-1 - satellites using active remote sensing sensors. Sentinel-1A launched into orbit in 2014 and Sentinel-1B in 2016.
- Sentinel-2 - satellites using multi-spectral high-resolution passive remote sensing sensors. Sentinel-2A was launched into orbit in 2015, and Sentinel-2B in 2017.
- Sentinel-3 - multi-functional satellites are used for seabed topography, sea and land surface temperature determination. Used to monitor the environment and climate change. Sentinel-3A was released in 2016 and Sentinel-3B was released in 2018.
- Sentinel-4 - geostationary orbit satellites for atmospheric observation.
- Sentinel-5 - polar orbit satellites for atmospheric monitoring.
- Sentinel-6 is a satellite using an altimeter radar that measures the world's sea level. Used for oceanography and climate research.

Sentinel satellite data is free and publicly available. To receive them, it is necessary to register on the Copernicus Hub website and download them according to the selected search criteria (time, place, etc.). Figure 2.1 shows a graphical user interface that can be used to download data.

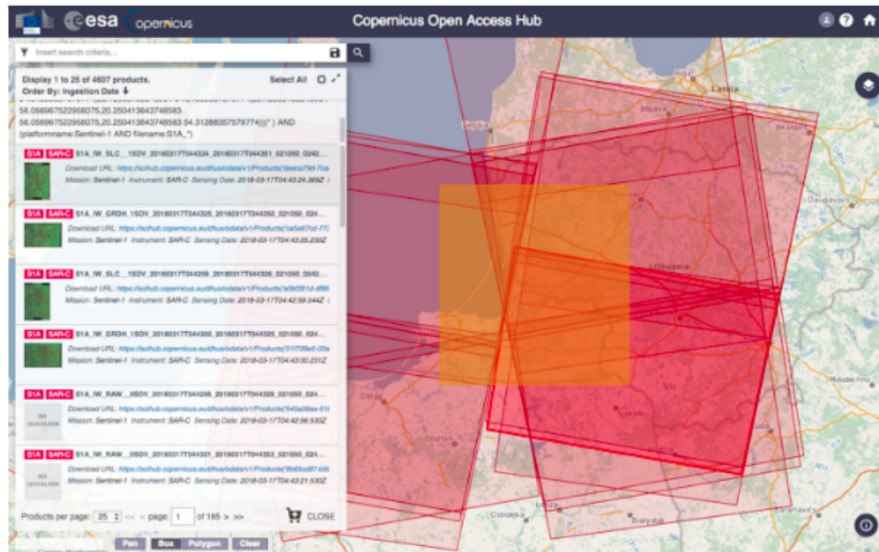


Figure 2.1: Sentinel data download via the Copernicus Hub website

Also the Copernicus Hub programming interface can be used to automate data downloads by specified parameters.

Sentinel data is provided in SAFE (Standard Archive Format for Europe) format. This format stores not only raster information but also textual information that can be used to correct raster data.

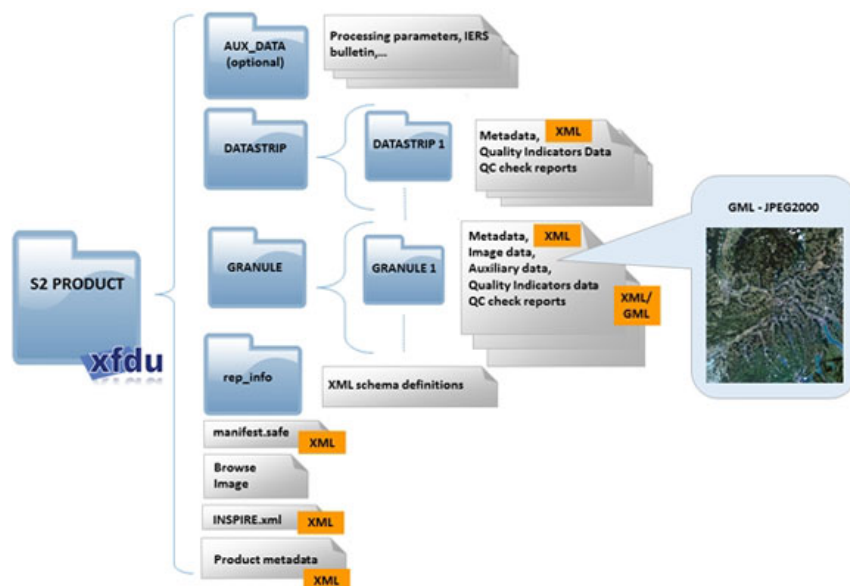


Figure 2.2: Example of Sentinel-2 data format

The Copernicus program, developed by ESA, provides high-quality and freely available Sentinel satellite data that can be adapted to meet a variety of GIS challenges. One example of such tasks is the identification of fire damage to the forest, the detection of oil spills at sea, the identification of plastic sites at sea. ESA provides all the tools needed for data retrieval (Copernicus Hub data download portal) and GIS analysis (SNAP software). Sentinel data is high quality, frequently updated, and SNAP free software provides all the tools to perform GIS analysis for both scientific and commercial purposes.

2.3 Sentinel passive and active remote sensing systems

Remote sensing is the process of obtaining qualitative and quantitative data about a particular object without physical contact. Remote sensing systems can be divided into passive and active systems using electromagnetic radiation:

- Passive remote sensing systems use an external source of electromagnetic radiation, usually the sun.
- Active remote sensing systems have their own light source, which is an electromagnetic wave generator that emits waves from a satellite to the earth's surface. The reflected waves from the earth's surface are captured by a satellite.

ESA has launched two satellites from each Sentinel family into orbit under the ongoing Copernicus program:

- Sentinel-1 - satellites using active remote sensing sensors. Sentinel-1A launched into orbit in 2014 and Sentinel-1B in 2016.
- Sentinel-2 - satellites using multi-spectral high-resolution passive remote sensing sensors. Sentinel-2A was launched into orbit in 2015, and Sentinel-2B in 2017.

Sentinel data is presented in SAFE (Standard Archive Format for Europe) format, which stores not only raster information but also text that can be used to correct raster data, such as cloud cover, so ESA recommends the use of SNAP (Figure 4) open source software for the processing and analysis of their data (http://www.eo4sd-eastern.eu/sites/default/files/publications/snap_workbook_english.pdf).

Since 2014, radar data (SAR) from the European satellite Sentinel-1A have been freely available, opening up new opportunities for research. The Copernicus portal provides many examples of where they can be applied, ranging from the detection of forest fire damage to the detection of oil spills in water bodies. The main parameters, for example, of Sentinel-1A radar photos (E.A. Baldina et al., 2016):

Table 2.1: Sentinel-1A satellite data parameters (E.A. Baldina et al., 2016)

Mode	Coverage area, km	Spatial resolution, m	Polarization (H - horizontal; V - vertical)
Stripmap (SM)	80	5x5	HH, VV, HH+VV, VV+VH
Interferometric Wide Swath (IW)	250	5x20	HHH, VV, HH+HV, VV+VH
Extra-Wide Swath (EW)	400	20x40	HH, VV, HH+HV, VV+VH
Wave (WV)	20x20	5x5	HH, VV

The resolution of the data received by the Sentinel-2A satellite depends on the color wave captured by the sensor and ranges from 10 m to 60 m (2.2)).

Table 2.2: Sentinel-2A satellite data resolution (Du, Y et al., 2016)

Physical band	Pixel resolution, m	Wave length, nm
B1	60	443
B2	10	490
B3	10	560
B4	10	665
B5	20	705
B6	20	740
B7	20	783
B8	10	842
B8A	20	865
B9	60	945
B10	60	1375
B11	20	1610
B12	20	2190

Appendix A

Algorithms

In this Appendix we present pseudo codes and the settings used for the peer algorithms, which we implemented and used in experimental evaluation through the thesis.

Appendix B

Derivations and Computation Details

B.1 Change Detection Using Hotelling T-test

Suppose that we have the labeled sequence of observations labeled in c classes. To estimate the likelihood of a change at time d , where $1 \leq d \leq t$, we assume that the class means migrate independently of one another. Then the probability that there is a change at time d is

$$P(\text{change}|d) = 1 - \prod_{k=1}^c P(\text{no change in } \mu_k|d),$$

where μ_k is the mean for class k , $k = 1, \dots, c$. Given that the data lives in \mathbb{R}^n , the value of $P(\text{no change in } \mu_k|d)$ can be estimated using the p-value of the Hotelling multivariate T^2 -test. This test compares the means for class k before and after the hypothetical change at d .

The mean before the change, $\mu_k^{(1)}$, is estimated from the streaming data from 1 to d labeled in class k ; the mean after the change, $\mu_k^{(2)}$, is estimated from the streaming data from $d + 1$ to t labeled in class k . Let $\hat{\Sigma}$ be the unbiased pooled covariance matrix estimated from the data and N_1 and N_2 be the respective sizes

of the two samples. The T^2 statistic is

$$T^2 = \frac{(N_1 + N_2 - n - 1)}{n(N_1 + N_2 - 2)} \frac{N_1 N_2}{(N_1 + N_2)} \hat{\delta}^2 \quad (\text{B.1})$$

where $\hat{\delta}^2$ is the squared Euclidean distance $\hat{\delta}^2 = \left(\hat{\mu}_k^{(1)} - \hat{\mu}_k^{(2)} \right)^T \hat{\Sigma}^{-1} \left(\hat{\mu}_k^{(1)} - \hat{\mu}_k^{(2)} \right)$.

If the two means come from the same distribution, T^2 has F -distribution with degrees of freedom $(n, N_1 + N_2 - 1 - n)$.

If we use the notation $p_k(d)$ as the p -value returned by the Hotelling T^2 -test comparing class k samples before and after time moment d , the probability of change at d can be estimated as

$$P(\text{change}|d) = 1 - \prod_{i=1}^c p_k(d). \quad (\text{B.2})$$

To arrive at a probability distribution over t_1, \dots, t_i , we can normalize by dividing the conditional probability (??) by

$$P(\text{change}, t_k) = \frac{P(\text{change}|t_k)}{\sum_{d=1}^i P(\text{change}|t_d)}. \quad (\text{B.3})$$

In order to calculate the distribution, we need to check all possible split points between t_1 and t_n , as done in other studies performing retrospective change detection [1–3].

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Curriculum Vitae

Viktor Nareiko graduated from ...

Vocabulary - Žodynėlis

base learner - bazinis klasifikatorius
baseline - bazinis metodas
change point - pokyčio taškas
concept drift - koncepcijos pokytis
context aware - kontekstinis
data mining - duomenų gavyba
data source - duomenų šaltinis
gradual drift - palaipsnis pokytis
instance - vektorius
instance based learning - mokymas pagal vektorius
label - klasė
moving average - slenkantis vidurkis
peer methods - lyginamieji metodai
recurring concepts - pasikartojantis pokytis (pasikartojančios koncepcijos)
sequential learning - mokymas paeiliui
source - šaltinis
sudden drift - staigus pokytis
supervised learning - mokymas su mokytoju
training window - mokymo langas
unsupervised learning - mokymasis

Summary in Lithuanian (Santrauka)

Tiriamąjį darbo objektą yra adaptyvūs mokymo metodai, kurie remiasi kryptingu mokymo imties formavimu. Patobulintos žinomos mokymo strategijos esant staigiems, palaipsniams ir pasikartojantiems pokyčiams. Sukurti ir eksperimentiškai aprobuoti keturi adaptyvaus mokymo imties formavimo algoritmai, kurie leidžia pagerinti klasifikavimo bei prognozavimo tikslumą besikeičiančiose aplinkose, esant atitinkamai kiekvienam iš trijų pokyčių tipų. Naudojant generuotus bei realius duomenis, eksperimentiškai parodytas klasifikavimo bei prognozavimo tikslumo pagerėjimas, lyginant su visų istorinių duomenų naudojimu mokymui, bei žinomais šioje srityje naudojamais adaptyviais mokymo algoritmais. Sukurta metodika pritaikyta pramoninio katilo atvejui, jungiančiam kelis aplinkos pokyčių tipus.

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