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MATHEMATICAL MODEL FOR MONITORING MYCOLYSIS OF ARCHITECTURAL MONUMENTS WOODEN STRUCTURES

Research article

Gavrilov T.A.[1, *]
[1] ORCID : 0000-0003-3671-0971;
[1] Petrozavodsk State University, Petrozavodsk, Russian Federation

* Corresponding author (gtimmo[at]mail.ru)

Abstract

The article is devoted to the urgent problem of mycological destruction of architectural monuments' wooden structures. The solution of this problem is possible through an automated system of continuous monitoring of mycolysis of architectural monuments wooden structures. In this regard, the purpose of the work is to develop a mathematical model describing the components of the monitoring system and their relations. The article proposes a top-level mathematical model and algorithm of the automated system for monitoring mycolysis of architectural monuments wooden structures, describing the components of the monitoring system and their relations. A set-theoretic approach is used in building the model. The model includes monitoring object, monitoring system infrastructure, initial data and monitoring results, relations between model components. The model allows to develop an effective and reliable system for monitoring mycolysis of architectural monuments wooden structures, allowing to detect the process of mycological destruction at the earliest stage.

Keywords: mycolysis of wood, monitoring, mathematical model, wooden structures, architectural monuments.

МАТЕМАТИЧЕСКАЯ МОДЕЛЬ МОНИТОРИНГА МИКОЛИЗА ДЕРЕВЯННЫХ КОНСТРУКЦИЙ ПАМЯТНИКОВ АРХИТЕКТУРЫ

Научная статья

Гаврилов Т.А.[1, *]
[1] ORCID : 0000-0003-3671-0971;
[1] Петрозаводский государственный университет, Петрозаводск, Российская Федерация

* Корреспондирующий автор (gtimmo[at]mail.ru)

Аннотация

Статья посвящена актуальной проблеме микологического разрушения деревянных конструкций памятников архитектуры. Решение данной проблемы возможно посредством автоматизированной системы непрерывного мониторинга миколиза деревянных конструкций памятников архитектуры. В связи с чем целью работы является разработка математической модели, описывающей компоненты системы мониторинга и их отношения. В статье предложена математическая модель верхнего уровня и алгоритм автоматизированной системы мониторинга миколиза деревянных конструкций памятников архитектуры, описывающих компоненты системы мониторинга и их отношения. При построении модели использован теоретико-множественный подход. Модель включает в себя объект мониторинга, инфраструктуру системы мониторинга, исходные данные и результаты мониторинга, отношения между компонентами модели. Модель позволяет разработать эффективную и надежную систему мониторинга миколиза деревянных конструкций памятников архитектуры, позволяющую выявить процесс микологического разрушения на самой ранней стадии.

Ключевые слова: миколиз древесины, мониторинг, математическая модель, деревянные конструкции, памятники архитектуры.

Introduction

Wood is a valuable, renewable and most affordable building material. Its cost is comparatively lower than other building materials. Therefore, wood has become widespread in the construction of buildings and structures [1], [2]. A significant number of surviving architectural monuments, especially in the north of Russia, are structures made of wood [3], [4]. Wooden structures of architectural monuments in the course of their operation are subject to mycological destruction [5], [6], leading to partial or complete loss of monuments as objects of cultural heritage. Mycological destruction is a process of degradation of components of lignocarbohydrate complex of wood under the action of enzymes of wood-destroying fungi, leading to the formation of “wood rot” and a decrease in its strength [7], [8]. Preservation and protection of architectural monuments *wooden structures* from mycological destruction is an actual and rather complicated problem. The solution of this problem is possible through automated continuous monitoring of mycolysis of architectural monuments wooden structures. To develop an effective and reliable monitoring system, it is necessary to build a mathematical model describing its components and their relations, which was the purpose of this work.

To model the automated system for monitoring mycolysis of architectural monuments wooden structures, the theoretical-multiple approach, considered in [9], [10], [11] and describing the components of the monitoring system and their relations, was used.

Main results and discussion

At the top level, the mathematical model of the automated system for monitoring mycolysis of architectural monuments *wooden structures* can be described by the tuple:

M = <O, I, D, F>,

where O is the monitoring object;

I is the infrastructure of the monitoring system;

D is the initial data and monitoring results;

F is the relations between the components of the model.

Let us consider the decomposition of the components of the proposed monitoring model.

A monitoring object can be described by a tuple:

O = <OD, ON, OZ, OM>,

where OD is the name and description of the monitored object: architectural monuments wooden structures (log construction, roofs, coverings and finishes, truss structures, etc. [3]);

ON is the name and description of the monitoring subject: specialists in ensuring the preservation of cultural heritage objects;

OZ is the purpose and objectives of monitoring: earlier identification of areas of architectural monuments wooden structures subject to mycological destruction, through continuous measurement and analysis of values of environmental parameters and wooden structures;

OM is the model of the monitoring object: mycological destruction of wooden structures is a biochemical process of decomposition of the main components of wood by enzymes of wood-destroying fungi, which can be described by the model [5]: $C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O$. The presented model shows that mycological destruction of wooden structures is accompanied by the release of carbon dioxide and water, therefore, the criteria that can be used to identify areas of wooden structures subject to mycological destruction are changes in the content of carbon dioxide at the surface of wooden structures and their humidity.

The infrastructure of a monitoring system can be described by a tuple:

$I = <ID_1, ID_2, ID_3, IS, IR, IT, IP>$,

where ID_1 is the information source No. 1: sensor measuring carbon dioxide content at the surface of wooden structures;

ID_2 is the information source № 2: sensor measuring absolute humidity of wooden structures;

ID_3 is the information source No. 3: sensor measuring the carbon dioxide content in the air inside the premises of the architectural monument;

IS is the data storage system: controller equipped with integrated Wi-Fi module and/or 3G (4G) modem (data measured by sensors are accumulated on the controller);

IR is the infrastructure operability: energy resources (power supply of sensors and microcontroller is provided from the stationary electric network or a backup power source – accumulator batteries, which ensures their high operability for different conditions and modes of operation of the monitoring system);

IT is the data transmission system: 3G (4G) cellular network or Wi-Fi local network (data accumulated on the controller are transmitted to the computer (or mobile device) connected to the Internet via 3G (4G) cellular network or Wi-Fi local network after a certain time interval);

IP is the data processing system: computer program algorithm (the data measured by sensors are processed on the controller by a specially developed computer program algorithm: Certificate of state registration of computer program No. RU 2024618307 Program for monitoring the condition of architectural monuments wooden structures and early detection of the process of their mycological destruction, date of registration 03.04.2024).

A sensor for measuring carbon dioxide near the surface of wooden structures can be described by a tuple:

$ID_1 = <IDD_1, IDL_1>$,

where IDD_1 is the description: infrared carbon dioxide sensor (e.g. MH-Z19B);

IDL_1 is the localization location:

1) areas of increased wood moisture *(*basements, attics, areas of possible leaks of atmospheric moisture);

2) areas with traces of activity of wood-destroying fungi;

3) other surfaces. The number of sensors should be at least 5-6 per roof, 2-4 for each floor of the building, and necessarily at least 1–2 on each group of structural elements.

The description of a sensor for measuring carbon dioxide at the surface of wooden structures can be represented by a tuple:

$IDD_1 = <IDDM_1, IDDC_1, IDDE_1, IDDT_1, IDDU_1, IDDO_1, IDDS_1>$,

where $IDDM_1$ is the sensor type, model: infrared carbon dioxide sensor MH-Z19B (detects CO_2 level by NDIR non-dispersive infrared radiation principle);

$IDDC_1$ is the sensor settings: operating voltage from 4.5 V to 5.0 V, current consumption < 60 mA (150 mA at peak load), measurement range 0~5000 ppm, measurement accuracy ±50 ppm, operating temperature 0 to 50 °C, humidity 0 to 95%;

$IDDE_1$ is the method of sensor operability support: power supply is realized from stationary electric network through power supply unit or backup power source (accumulator batteries);

$IDDT_1$ is the method of data transmission from the sensor to another subsystem responsible for data processing: data are transmitted to the controller in the form of a digital signal;

$IDDU_1$ is the installation method: the sensor is mounted on the outer surface of architectural monuments wooden structures;

$IDDO_1$ is the data preprocessing method: the sensor consists of an IR radiation source, a measuring chamber where the gas mixture under test is supplied, a wavelength filter and an IR detector. When the gas enters the chamber, certain wavelengths are absorbed in the IR spectrum, filtered out by the filter and the radiation enters the photodetector. Here the light intensity is converted into a proportional signal, which is then pre-amplified;

$IDDS_1$ is the data storage method in case the data are not immediately transferred to other subsystems: the data are immediately transferred to the controller.

A sensor for measuring the absolute moisture content of wooden structures can be described by a tuple:

$$ID_2 = <IDD_2, IDL_2>,$$

where IDD_2 is the description: electronic absolute humidity sensor (e.g. humidity sensor on LM393 comparator chip);

IDL_2 is the localization location:

1) areas of high humidity of wood (basements, attics, areas of possible leaks of atmospheric moisture);

2) areas with traces of activity of wood-destroying fungi;

3) other surfaces. The number of sensors should be at least 5-6 per roof, 2-4 for each floor of the building, and necessarily at least 1-2 on each group of structural elements.

The description of a sensor for measuring the absolute moisture content of wooden structures can be represented by a tuple:

$$IDD_2 = <IDDM_2, IDDC_2, IDDE_2, IDDT_2, IDDU_2, IDDO_2, IDDS_2>,$$

where $IDDM_2$ is the sensor type, model: electronic absolute humidity sensor on LM393 comparator chip;

$IDDC_2$ is the sensor settings: operating voltage from 3.3 V to 5.0 V, current consumption in the mode of no signal 3 mA and in the mode of water signal 6 mA, output type discrete and analog, measurement range 0~100%, measurement accuracy ±1 %, operating temperature from 0 to 70 °C;

$IDDE_2$ is the method of sensor operability support: power supply is realized from stationary electric network through power supply unit or backup power source (accumulator batteries);

$IDDT_2$ is the method of data transmission from the sensor to another subsystem responsible for data processing: data are transmitted to the controller in the form of an analog signal;

$IDDU_2$ is the method of installation: the sensor is mounted inside wooden constructions of architectural monuments at a depth of about 20 mm;

$IDDO_2$ is the data preprocessing method: the sensor has no built-in algorithm for processing the read data;

$IDDS_2$ is the method of data storage in case the data are not immediately transferred to other subsystems: the data are immediately transferred to the controller.

A sensor for measuring carbon dioxide in the air inside a monument room can be described by the tuple:

$$ID_3 = <IDD_3, IDL_3>,$$

where IDD_3 is the description: infrared carbon dioxide sensor (e.g. MH-Z19B);

IDL_3 is the localization location: inside each room of the monument at a distance from the wooden structures.

The description of the sensor for measuring the carbon dioxide content in the indoor air of a monument can be represented by the tuplet:

$$IDD_3 = <IDDM_3, IDDC_3, IDDE_3, IDDT_3, IDDU_3, IDDO_3, IDDS_3>.$$

All components of the IDD_3 sensor description fully correspond to the components of the IDD_1 sensor description.

The raw data and monitoring results can be described by a tuple:

$$D = < DI_1, DI_2, DI_3, DO_1, DO_2, DM_1, DM_2, DV>,$$

where DI_1 is the data coming from information sources No. 1 (initial data): carbon dioxide content at the surface of wooden structures CO_2^{WS};

DI_2 is the data coming from information sources No. 2 (initial data): absolute humidity of wooden structures Wabs;

DI_3 is the data coming from information sources No. 3 (baseline data): carbon dioxide content in the air inside the premises of the architectural monument CO_2^{AIR};

DO_1 is the data formed on the basis of data coming from information sources No. 1 and 3 (calculated data): signal about exceeding the critical value of relative deviation of carbon dioxide content at the surface of wooden structures over the content of carbon dioxide inside the room of the monument;

DO_2 is the data formed on the basis of data coming from information source No. 2 (calculation data): a signal about exceeding the critical value of absolute humidity of wooden structures;

DM_1 is the method by which the calculated data DO_1 are obtained: comparison of the relative deviation of carbon dioxide content at the surface of wooden structures over the content of carbon dioxide in the air inside the room of the monument ΔCO_2 with the critical value ΔCO_2^{CRIT} = 26%, at which the process of mycological destruction of wooden structures is identified. The relative deviation of carbon dioxide content at the surface of wooden structures over the content of carbon dioxide inside the room of the architectural monument is calculated by the expression:

$$\Delta CO_2 = (CO_2^{WS} - CO_2^{AIR}) / CO_2^{AIR};$$

If $\Delta CO_2 > \Delta CO_2^{CRIT}$, then it is concluded that there is a high probability of damage to the area of wooden structures by wood-destroying fungi;

DM_2 is the method by which the DO_2 calculation data are obtained: comparison of the initial data of absolute moisture content of wooden structures W_{ABS} with the critical value of absolute moisture content W_{ABS}^{CRIT} = 22%, at which the process of mycological destruction of wooden structures is identified. If $W_{ABS} > W_{ABS}^{CRIT}$, the conclusion is made about high probability of wood destruction by wood-destroying fungi;

DV is the ways of presenting the results to the user: text message.

The relationships between the components of the model can be described by a set:

$$F = \{f_1, f_2, f_3, f_4, f_5\},$$

where $DI_1 = f_1 (ID_1)$ is the input data DI_1 comes from sensor ID_1: carbon dioxide content at the surface of wooden structures;

$DI_2 = f_2$ (ID_2) is the input data DI_2 comes from sensor ID_2: absolute humidity of wooden structures;

$DI_3 = f_3$ (ID_3) is the the initial data DI_3 comes from the sensor ID_3: the content of carbon dioxide inside the room of the monument;

$DO_1 = f_4$ (DI_1, DI_2, DM_1) is the calculation data DO_1, are formed from the initial data DI_1 and DI_2 using the method DM_1;

$DO_2 = f_5$ (DI_3, DM_2) is the calculated data DO_2, formed on the basis of the initial data DI_3 using the method DM_2.

The scheme of the monitoring algorithm is presented in Figure 1.

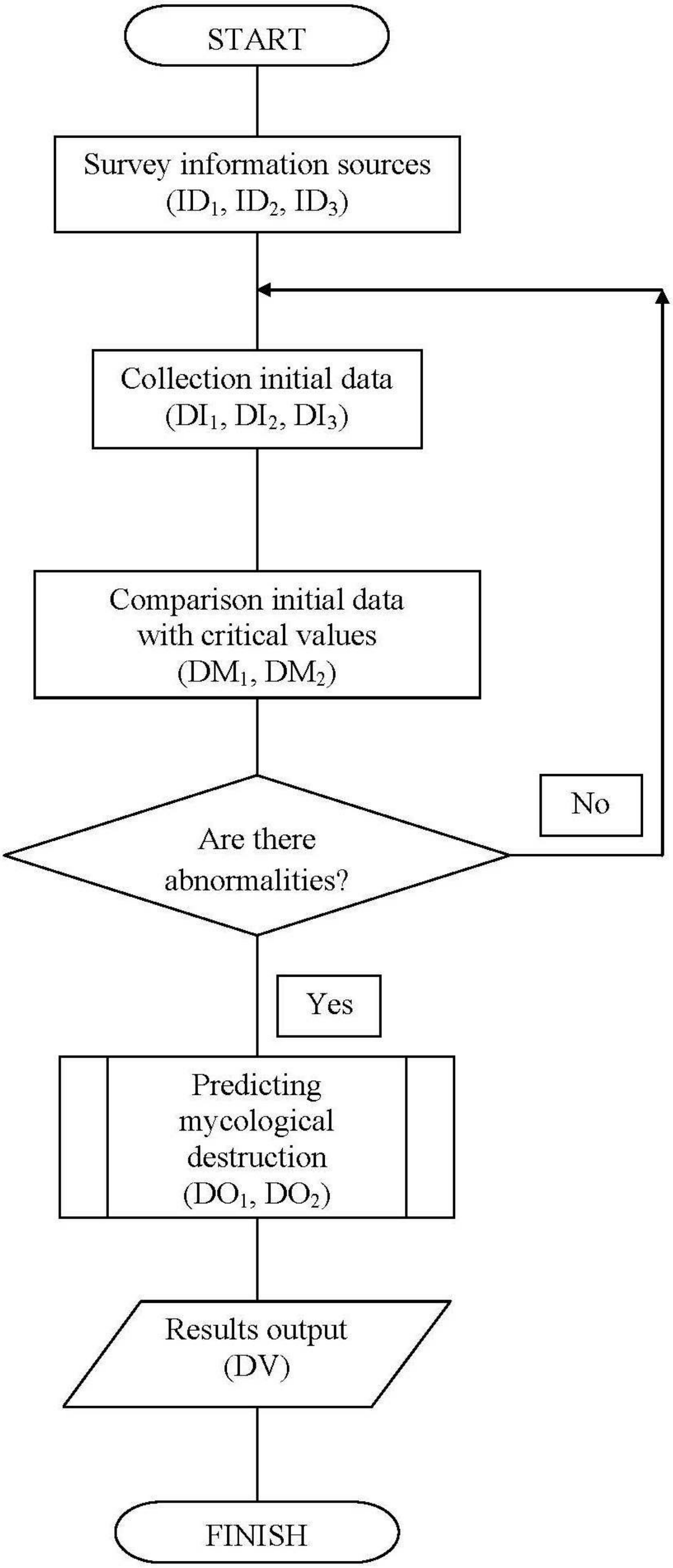

Figure 1 - Monitoring algorithm scheme

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Conclusion

Within the framework of the conducted modeling, a mathematical model of the automated system for monitoring mycolysis of architectural monuments wooden structures has been built, which describes the components of the monitoring system and their relations quite completely. The model allows to develop an effective and reliable system for monitoring the condition of architectural monuments wooden structures, allowing to detect the process of mycological destruction at the earliest stage. The modeling results are consistent with the results of experimental studies of architectural monuments wooden structures using multisensor systems of automated remote monitoring performed by the author [6], [12], as well as with the results of other authors [13], [14].

Конфликт интересов

Не указан.

Рецензия

Все статьи проходят рецензирование. Но рецензент или автор статьи предпочли не публиковать рецензию к этой статье в открытом доступе. Рецензия может быть предоставлена компетентным органам по запросу.

Conflict of Interest

None declared.

Review

All articles are peer-reviewed. But the reviewer or the author of the article chose not to publish a review of this article in the public domain. The review can be provided to the competent authorities upon request.

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