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The multilayer distributed intelligence system model for emergency area scanning

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ABSTRACT

Emergency situations have a huge impact on various important areas of human life. Every year there are many situations, the elimination of which requires a lot of financial and human resources. Therefore, the ability to reduce the impact of the consequences and increase the speed of their elimination is extremely important. In this article, a multi-level model of a system was proposed that provides support for performing operational tasks in emergency situations in open areas. The most important elements, areas of their responsibility, and interconnection were identified and described in architectural style. The idea of the work is to design a system that should use Swarm intelligence under the hood to provide continuous support in emergency situations. The system consists of 4 main parts: Cloud, Swarm, Swarm operator, and Swarm Node. The Cloud (Swarm Wamb) is the main decision-maker that provides ETL data pipelines and operates under strategically tasks. In accordance with the idea, Swarm womb should be a cloud service-like system with the ability to scale over the world. The Swarm is a combined set of multiple Swarm Nodes and only one Swarm Operator. The main task of the Swarm is to provide support in local operational tasks where SN is responsible for the execution and SO is for control. Rescue and search operation after any natural disaster is a target to show the system's purpose. In practice, the cloud system (Swarm Wamb) receives requests to perform an operation, calculates resources effort first, and delegates a task to the Swarm. When the swarm reaches the location, it starts executing. Operator with nodes tries to find survivors and collect as much important information as they can. Video, images, recognized objects are continuously sending to the Cloud for additional analysis in real-time. Any information in an emergency situation can help save more humans lives and reduce risks. In this article, the multilayer distributed intelligence system architecture for emergency area scanning was designed and described. The set of terminology was proposed as well. This architecture covers different levels of tactical and operational tasks.

Keywords: Expert systems; system architecture; system model; emergency situations; swarm; cloud computing

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INTRODUCTION

Every year many natural emergencies happen in the world with unpredictable consequences. According to statistics, in 2019 only, 361 cases of natural origin on a global scale were recorded (Fig. 1), and it is impossible to calculate local incidents of technogenic and biological-social origin.

The result of such incidents always leads to large-scale, costly material and physical operations aimed at eliminating the consequences and developing means of preventive action.

At the moment, the level of technology development provides many opportunities for the delegation of complex and dangerous work to mechanical means, such as manipulators, robots, and drones. Auto factories have long used industrial manipulators for welding and painting, robots are used to distribute goods in warehouses, and technology using AI approaches has flooded stores. Collaboration between man and machine is no longer new and has established itself as a successful combination in many spheres of life [1].

Due to technological progress, robotics is already becoming available for widespread use. Toy robots and aerial photography drones have already become mainstream commodities and are powerful and cheap to manufacture. Companies such as Amazon have already paid attention to the prospects of using this tool for solving problems in the delivery of goods [2]. Also, many developments are underway in the following directions: remote observation, research of objects and territories, drawing up maps of the area [3].

Cloud technologies and solutions are another powerful and widely used tool now. Many projects and large corporations are using a cloud computing and scaling approach to improve reliability and performance and reduce costs. Due to the distribution and fault tolerance, cloud solutions, for example, Amazon, can guarantee the SLA of their services up to 99.99 % [4] and using combined approaches, that allows creating a system in afault-tolerancemanner.

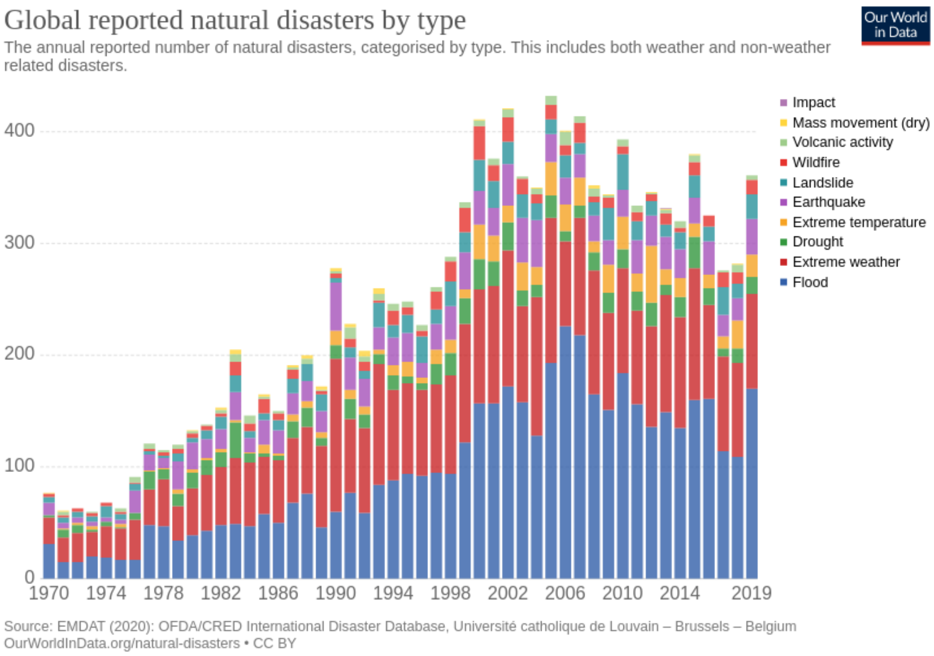

Fig. 1. **Global reported natural disasters by type, 1970 to 2019**
Source: Inc. [Public domain], via Our World in Data
(https://ourworldindata.org/grapher/natural-disasters-by-type)

This article describes the possibility of using drones, swarm intelligence, and cloud technologies as a service to provide support in the performance of rescue and search operations, as well as a preventive tool.

Drones as a solution

One of the ways to reduce the risks has been the use of various remote and automatic mechanisms.

Drones as a resource have long been used in various industries. However, drones that can be in flight for a long time and have sufficiently powerful sensors and processors are expensive and the loss of such a device may result in the inability to continue working.

Table 1 shows the dependence of flight duration on price.

In addition, the computing power of such a drone may not be enough to load it with a universal set of object recognition algorithms.

Therefore, the creation of a system in which, by increasing the number of cheap drones, a similar scanning quality can be achieved, may be a solution to the problem.

Such drone systems are called "swarms", and special algorithms have been developed by various researchers to ensure their interaction with each other. Cheap drones are more affordable and can be easily replaced. Even if their range is limited, they can return to recharge or the charging module can move with the swarm.

One of the features is the collaboration between humans and drones. In order to increase the stability of the system and increase the coverage of non-standard situations, a human is introduced as an additional element of control. In this case, the human plays the role of an element of verification and must be part of the swarm.

Table 1. **The mapping between drones costs and flight duration**

Model	Price ($)	Flight duration (min)
Tello edu	198	13
DJI mavic mini	500	30
DJI mavic pro	1785	31

Source: **compiled by the authors**

On the other hand, to perform operational tasks, drones need a high-bandwidth channel. Almost all modern drones are capable of transmitting high-quality video over long distances in real-time. For example, Mavic Pro can transmit 4K 4096 x 2160px over a distance of 5 km [5]. However, for example, for constructing object detection, this is even more than needed and in real implementation, it will be necessary to cut the video quality to 1024 × 760px or 1024x1024px [6] to reduce noise and increase the speed of the algorithm.

Table 2 presents the comparison of the drones' possible video quality and their price.

Table 2. **The mapping between drones costs and video quality**

Model	Price ($)	Video Quality (px)
Tello edu	198	1280 x 720
DJI mavic mini	500	2720 x 1530
DJI mavic pro	1785	4096 x 2160

Source: **compiled by the authors**

System architecture creation approach

In this article, the term system architecture will mean a set of conceptual views that define system behavior and structure. The chosen approach has 4 main views: logic, processual, development, and physical.

To create the system vision, a 4 + 1 approach was chosen, which will allow examining the system from different angles. This approach contains 4 views of the system and sets of scenarios [7], [8]. At the current stage, the logical and process views were considered.

This approach helps to present the system from different angles started from the high-level system tasks, modules, and responsibilities.

LITERATURE REVIEW

To date, the development and implementation of systems that use drones for various tasks, in particular for working in emergency situations, are already underway. For example, there are already search drones that are used by the army and the police. In this paper, it is proposed to use a swarm of drones and a combination of known approaches to solving such problems.

There are different ways to build a cloud-based or swarm control solution and are useful technical approaches, solutions, and design techniques that can be used for analysis to develop a complex vision of the system.

To perform this analysis the initial task was split into 2 main directions:

1) cloud system;
2) swarm

Cloud system

In emergency situations, it is important to have real-time access to data and the ability to perform ETL pipelines [9] in a fast and stable way. The clusterization approach [10] is a common way to enrich scalability and accessibility system quality attributes. Among the known solutions, this method has shown good performance across different system setups and environments [11], [12], [13].

From another point of view, the system should have a stable connection and a high bandwidth to make it possible to receive a huge amount of data [14]. From different sources, it's clear that the cloud provides such as AWS can grant stable data receiving channels [15]. Thus the system should be oriented to the cloud but with cloud-agnostic techniques to make the transition between cloud providers possible.

Swarm

Swarm intelligence has become a common practice to organize cluster and cluster processing [16]. A lot of problems in in-swarm communication and tasks distribution are already accomplished [17]. But in this article swarm and swarm nodes should be understood as a specific element of system architecture abstractions that is responsible for stable and fault-tolerance work. Thus, cloud solutions architecture can be applied as well.

The Docker swarm and Kubernetes is a good example of these solutions types [18], [19]. These solutions are orchestration tools that are used to manage massive and scale applications. Kubernetes provides the distributed internal structure for each node that can be reused in the task of this work [20].

THE PURPOSE OF THE ARTICLE

The aim of the work is to develop a system that can provide support for rescue operations using drones and swarm intelligence, thereby reducing the involvement of human resources in order to reduce traumatic risks for the participants of the operation, increase the coverage area and enable the operation managers to see the full picture.

The purpose of this article is to design system architecture, form a set of terminology relevant to this domain, and provide a high-level relationship between system layers by introducing a system logical view.

To achieve this goal it is proposed to solve the following tasks:

1) analyze system requirements and identify system quality attributes;

2) design system architecture using the best practices and common techniques from different areas and relevant tools of cloud management and maintenance solutions;

3) provide transparent and self-descriptive terminology to reuse it in future development.

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MAIN PART. SYSTEM VISION

This chapter describes the main components, their relations, and responsibilities in the system. This section introduces the set of terminology and the way of its understanding.

System tasks and requirements

A key feature of search and rescue operations is location distribution and duration over time. Therefore, one of the most important requirements will be to cover the maximum area and provide long-term support.

Also, in such operations, often a lot of human resources are used, which are subjective and, in many cases, cannot provide accurate data about what is happening. Therefore, in such situations, a hierarchical model [21] is used, which connects field teams and headquarters in order to filter data and divide areas of responsibility [22].

Therefore, it is necessary to ensure the impartiality of data processing and provide several ways to assess the situation.

1) Provide continuous support in emergency situations.

2) Allocate system resources to ensure maximum quality.

3) Work with data in a safe and fault-tolerant manner.

To provide a way of decisions comparison the next system quality attributes [23] can be highlighted in accordance with the system architecture design approach:

1) flexibility;
2) scalability;
3) survivability

System model concept

To reach distributed responsibilities and improve system fault-tolerance a multi-level model of the system was introduced where each level has different areas of usage, as well as a distribution of tasks and data. At actual state 3 layers have been highlighted [24].

1) Top-level. Cloud level.
2) Average level. Swarm level.
3) Bottom level. Swarm Node Level.

Cloud level is remote storage of data, information, and resources (such as specific object recognition algorithms). It provides an interface for strategic resource management and provides the tools to get things done.

The Swarm level is the level of tactical tasks. There are several controls at this level such as the Swarm Operator and the Swarm Node with Swarm Leader functions. These entities have different responsibilities and tasks.

Swarm Node Level is tactical units whose tasks directly include area scanning and object detection. All features of this level are aimed at the highest quality scanning.

Fig. 2 shows the layers arrange layers details and responsibility funnel.

The next sections provide a detailed overview of each level structure, modules description, tasks, and responsibilities in accordance with the initial system requirements and goals.

Swarm Node

The Node is an electromechanical device equipped with sensors and certain software that can move in space. The Node contains 2 main built-in mechanisms:

1) Follower Node (SNF).
2) Leader Node (SNL).

The SNF is a node that receives commands from the Leader Node. Also, Swarm Operator can take control of this node at any time.

The SNL is a node that receives commands directly from the command post (it means Cloud) or from Swarm Operator.

Each node has these two potential roles to increase survivability [25], [26]. So, if the Leader Node fails, any Follower Node can take over its task.

This is done for survivability and is a common practice in distributed parallel computing systems [27], [28], [29].

Fig. 3 shows the internal module’s structure of each node and provides a logical view of it.

Swarm Operator

Swarm Operator (SO) is a human resource that is the controlling element in the work of a swarm.

Swarm Operator has all the statistical information about the Swarm, getting the most important information from the Leader node.

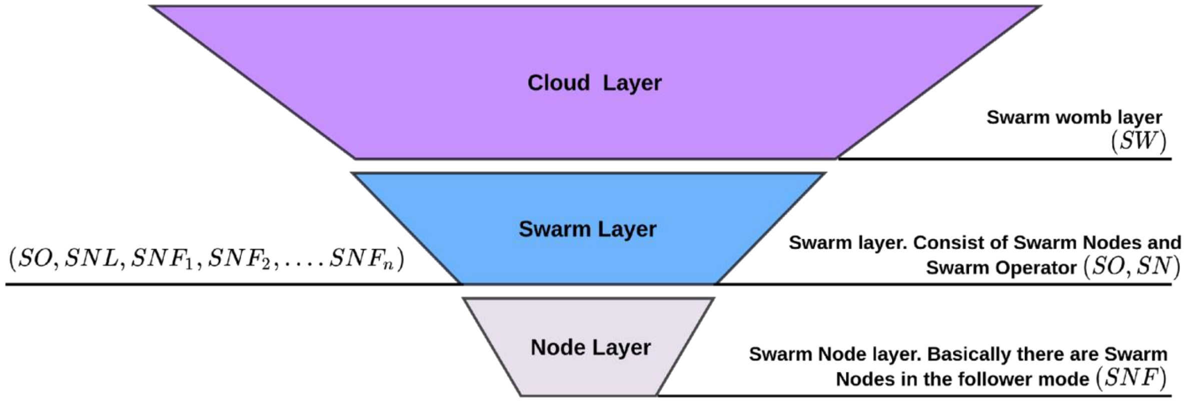

Fig. 2. **The multilayer system model.**
Shows the responsibility funnel of the components
Source: compiled by the authors

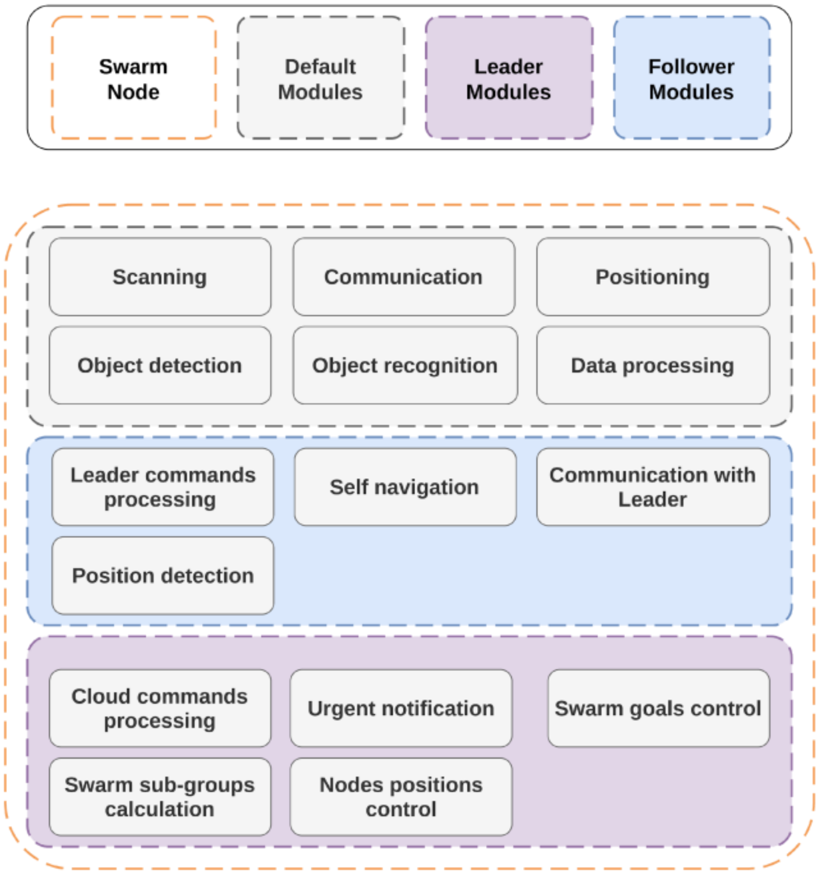

Fig. 3. **Swarm Node logical view**
Source: compiled by the authors

Also, it can access any of the swarm nodes at any time (Follower + Leader). Also, it can independently determine the Leader node at its discretion.

The task of SO is to control the work of the swarm, monitor the state of the nodes and the quality of the information received. Along with the Leader, a node can request additional resources being a priority.

Swarm

The Swarm is a set of Swarm Nodes and Swarm Leader with the specific proportion of elements and their responsibilities (1).

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$$\left(SO,\ SNL,\ SNF_1,\ SNF_2,\ ....\ SNF_n\right). \qquad (1)$$

This is because of the task nature for each component and there is no possibility to have more than one operator or leader. The argument is that would be difficult to separate responsibilities between more than one leader.

This level also refers to the level of tactical tasks. However, it already provides another aspect of working with data. The Swarm's main task is to provide maximum coverage with allocated resources to achieve the assigned goal.

Fig. 4 shows the Swarm structure and operational modules.

Swarm Womb

Swarm Womb is a set of cloud servers and services designed to manage, support the swarms, and process data from them.

The Cloud should provide distributed data access and should be stored for historical data and configurations. From another point, Swarm Womb provides the resources control module that should be focused on the swarm elements managing,

The Cloud task is to ensure an even resources distribution depending on the priority of the task, as well as provide tools for storing and managing data received from all swarms.

Fig. 5 shows the modules of the Swarm Womb and high-level system structure.

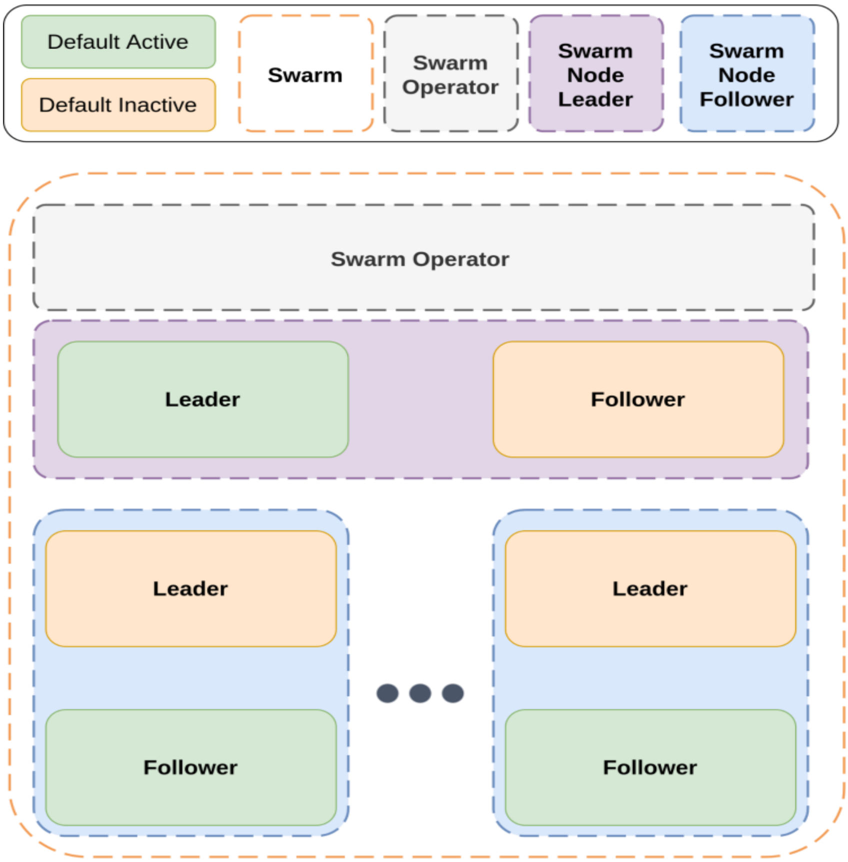

Fig. 4. **Swarm logical view**
Source: compiled by the authors

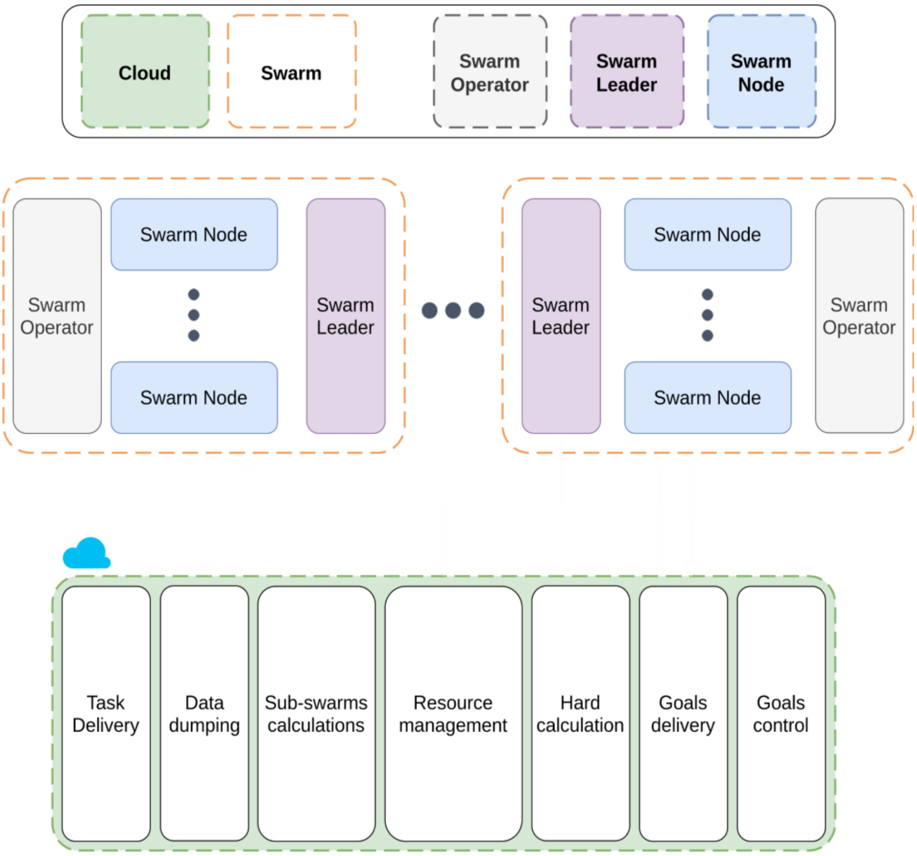

Fig. 5. **Swarm Womb logical view and high-level system structure**
Source: compiled by the authors

Summary

Swarm Operator, the most important system model points, their focus, and responsibilities are presented below.

Swarm Womb (SW) – should aspire to get a maximum average value of the swarm survivability and scanning ability and minimize the difference between swarms by these parameters

Swarm Leader (SNL) –should aspire to get the maximum area coverage with maxim quality of the scanning/detection

Swarm Operator (SO) – system quality control tool. Should be a mediator between Swarm Node and Swarm Womb.

In the following works, the implementation of this system will be considered in detail. But at this stage, it is already possible to deduce some recommendations for the technology stack.

As was mentioned above the AWS Cloud services is a highly available and common tool for building systems like that.

That’s why the next services can be recommended:

1) EC2 as the main service for computing and server hosting;

2) AWS Lambda function for images screening and processing

3) AWS SQS, SNS, and ActiveMQ for communication between microservices;

4) AWS Kinesis Streams as an input video and data streams handler;

5) AWS RDS and S3 as the main SQL and NoSQL storage.

All these services are polymorphic and can be used together with different programming languages and frameworks. E.g. for the image processing can be used a combination of AWS Lambda, Python, and OpenCV what allows to process each frame and do some kind of simple recognition. Also, this setup can be easily scaled to use ML algorithms e.g. in pair with AWS image processing services of TensorFlow.

By the next articles, detailed Process View and Physical Viewl diagrams will be introduced.

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CONCLUSIONS

By this article, the multilayer system model was provided with the 3 most important layers. Components logical structure presented on the diagrams and responsibilities defined. Because of separated responsibilities the system survivability can be improved. In case of any faults, the system can replace one module with another one without additional efforts from the support or development team. The flying duration was improved by introducing the swarm of cheap drones and replaceable charging dock stations. Each SN has the ability to switch between their responsibilities, in practice, the node will know about the actual status of each other and has the ability to make the right decisions based on the situation. A cost-saving model was introduced on each level and the initial configuration should be identified and deligated to each SN at the early stage of the mission by SW.

As described above the combination of architecture approaches can be used to provide the expected level of scalability, accessibility, and survivability. This information will be used to prepare the whole system architecture and development strategy.

Therefore, by the next milestone should be prepared the mathematical model and other levels of the system architecture.

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АНОТАЦІЯ

Надзвичайні ситуації мають величезний вплив на різні важливі сфери життя людини. Щороку виникає безліч ситуацій, усунення яких потребує значних фінансових та людських ресурсів. Тому здатність зменшити вплив наслідків та збільшити швидкість їх усунення надзвичайно важлива. У цій статті було запропоновано багаторівневу модель системи, яка забезпечує підтримку виконання оперативних завдань у надзвичайних ситуаціях на відкритих територіях. Найважливіші елементи, сфери їх відповідальності та взаємозв’язок були визначені та описані в архітектурному стилі. Ідея роботи полягає в тому, щоб розробити систему, яка повинна використовувати під капотом ройовий інтелект для забезпечення постійної підтримки в надзвичайних ситуаціях. Система складається з 4 основних частин: хмара, рой, оператор рою та вузол рою. Хмара (Swarm Wamb) є головним елементом, який приймає рішення, що забезпечує обробку даних ETL і працює в рамках стратегічних завдань. Відповідно до ідеї, матка Swarm повинна бути схожою на хмарні послуги системою з можливістю масштабування по всьому світу. Рой - це комбінований набір з декількох вузлів рою та лише одного оператора рою. Основним завданням Рою є надання підтримки у місцевих оперативних завданнях, де SN відповідає за виконання, а SO-за контроль. Рятувально - пошукова операція після будь-якого стихійного лиха - це мета, яка показує призначення системи. На практиці хмарна система (Swarm Wamb) отримує запити на виконання операції, спочатку розраховує зусилля ресурсів і делегує завдання Swarm. Коли рій досягає місця розташування, він починає виконуватись. Оператор з вузлами намагається знайти тих, хто вижив, і зібрати якомога більше важливої інформації. Відео, зображення, розпізнані об’єкти безперервно надсилаються в хмару для додаткового аналізу в режимі реального часу. Будь-яка інформація у надзвичайній ситуації може допомогти врятувати більше людських життів та зменшити ризики. У цій статті було розроблено та описано архітектуру багатошарової розподіленої розвідувальної системи для сканування надзвичайних ситуацій. Також було запропоновано набір термінології. Ця архітектура охоплює різні рівні тактичних та оперативних завдань.

Ключові слова: Експертні системи; архітектура системи; модель системи; надзвичайні ситуації; рій; хмарні обчислення

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