# Passive Acoustic Location Information System with Spatial Placement of Sensors in the Vertices of Platonic Polyhedrons

Anastasiia Vynar, Anton Sorovetskyi, Inessa Kulakovska, Mykhailo Dvoretskyi

***Abstract —*** The process of the determining the sound source direction and based on the method of passive acoustic location are considered. A small-sized device based on the Orange Pi Zero single-board minicomputer and sound sensors based on the LM393 amplifier has been developed. This device can be built into existing lighting systems with the design of regular Platonic polyhedra. Options for the sound sensors placement on the plane and in 3D space which decrease the computational complexity of the problem due to the spatial placement of the microcontroller system based on Platonic solids are proposed. The software application for the offered information system of passive acoustic location (ISPAL) is developed on the basis of classical three-link architecture, contains backend and frontend components. The user interface (UI) for web and mobile versions of software are developed. The possibility of military-civilian use of the developed information system is considered.

***Keywords —*** information system, passive acoustic location, single-board minicomputer, Platonic polyhedrons

## I. Introduction

Determining the exact or approximate location of any object on the basis of sound vibrations created by itself can be used in various fields: during searching and rescuing operations, in security systems to notify of perimeter violations or intrusion into the object, for bioacoustic research of animals and processing of acoustic signals in underwater environments, etc. [1]. Some of the components can be used in military affairs, for example, to determine the location of a sniper or artillery system [2].

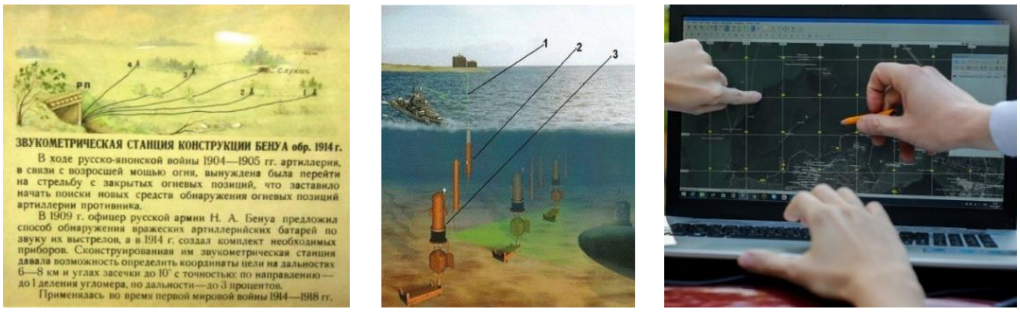
## II. Literature Analysis

Widespread use of acoustic location began in the early 20th century (Fig. 1, a). Its use at that time was almost military: counter-air defence, sonar for tracking submarines, etc. (Fig. 1, b). At present, the use of acoustic systems in the search of victims is very important – up to 600 people are lost in the forest in a week in the summer [3]. To use such systems in emergencies, it is necessary to urgently deploy such acoustic systems to determine the sound source, dividing the map into squares (Fig. 1, c) with simultaneous processing of the data using a specialized information system. The functions of such passive acoustic location information systems (ISPAL) include both the generation of sound vibrations to attract attention and the determination of the direction vector and/or location of the sound source. ISPAL can also be useful in residential and catering establishments to save on lighting costs, as well as to deploy security systems.

Thus, today acoustic location is used in the civilian sphere (acoustic and sonar during research and emergencies), and in the military (anti-sniper systems) and can be attributed to dual-use technologies. Acoustic location is divided into active (with the generation of sound oscillations for further monitoring of the "echo") acoustic location, and passive, which consists of a network of recording devices (microphones or sound sensors). Such devices determine the exact or approximate location of the sound source based on the waves or time difference.

Anastasiia Vynar, Petro Mohyla Black Sea National University, Ukraine.
Anton Sorovetskyi, Petro Mohyla Black Sea National University, Ukraine.
Inessa Kulakovska (advisor), Petro Mohyla Black Sea National University, Ukraine.
Mykhailo Dvoretskyi (advisor), Petro Mohyla Black Sea National University, Ukraine.




a b c

Fig. 1. Acoustic location systems: a – anti-aircraft warfare in 1914 [4],
b – modern submarine detection station [5],
c – ISPAL for search the people lost in the woods [3]

The main aim is to investigate the spatial arrangement of the components of the ISPAL for the fastest calculation of the vector of orientation to the source of sound oscillations while minimizing the number of calculations.

To achieve this goal the following tasks must be performed:

– analysis of existing methods and systems of signal source direction finding;
– development of a device capable of locating the object based on data from sound sensors processed on the microcontroller system;
– researching ways to reduce the computational complexity of the problem due to the proposed spatial arrangement of the components developed by ISPAL;
– development of ISPAL software application with backend and frontend components, as well as web and mobile versions of ISPAL user interface (UI).

## III. Object, Subject, And Methods Of Research

### A. Schematic solutions of the considered tasks

The solution can be based on passive acoustic location for short distances. The number of used sound sensors is determined from 3 to 20. The question arises at what distance and at what coordinate position in relation to the ISPAL central unit should be sound sensors.

Let's analyze the distance at which:

1) sound sensors can be developed from the central unit ISPAL [6];
2) it is possible to determine the sound source using sensors for connection to such ISPAL [7].

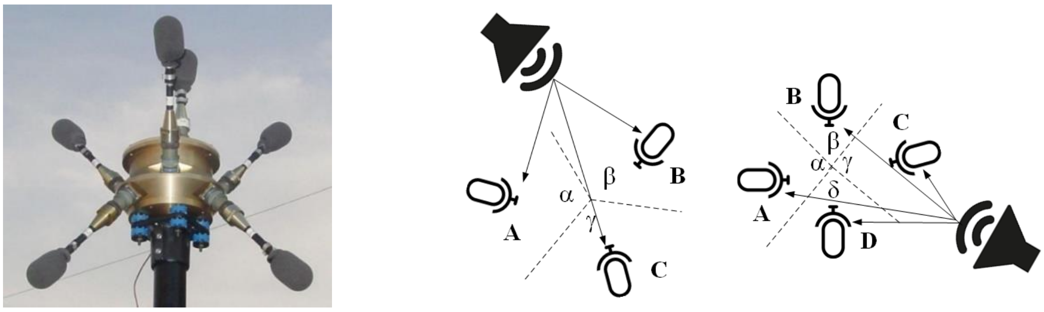
The issues of spatial placement of ISPAL sound sensors should be solved for two-dimensional (2D) and three-dimensional (3D) space.

At present, mathematical apparatus for calculating the coordinates of the sound source for three or four microphones has been created [8]. Modern research is aimed at simplifying the calculation algorithm for the location of the sound source [2] and to determine the number of sensors needed to calculate the distance to the sound source [9]. To increase the accuracy of the bearing and/or to determine the direction vector for a moving source of acoustic oscillations (UAVs) build structures of acoustic gratings from 4–12 microphones at distances of 10–30 cm [10–12]. A significant disadvantage of this design is that the sound sensor is used to determine the direction of arrival of the sound wave from the "front", such as at the filling stations 7 [13]; at the same time, the "rear" of such an installation – with the microphones lined up – is a "dead zone" (Fig. 2).


a b c

Fig. 2. Examples of possible location of the source and sound sensors on a plane with a coverage angle of 180° and linear (a, b) or spatial (c) placement of sensors [14, 15]

If it is necessary to increase the area of the location and/or increase the accuracy of the direction of the sound signal source, then it is necessary to increase the number of sound sensors and consider not the linear but the spatial deployment of the microphones. One of the effective implemented designs is the system "Boomerang" (Fig. 3), in which the grille of 7 microphones is mounted on the vehicle [16].

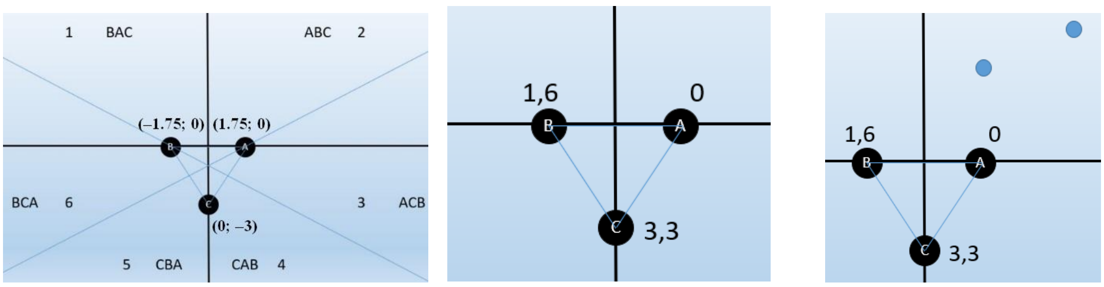



a b

Fig. 3. 3D placement of the 7-sensor system of passive acoustic location "Boomerang" [16]: a – photo, b – schematic image

Cardioid microphones with a coverage angle of 80–131° are the most common for PAL systems [17–19]. Minimum of 3 microphones is required for spatial construction on the plane. Each of the sensors will have its own name, for example, A – B – C.

Now, since the sensors are positioned in the shape of a right triangle, it is possible to divide the entire outer space into 6 equal sectors with 60° angle (Fig. 4, a). Each of them will receive its own number and each corresponds to a certain order of operation of the sensors. Therefore, only with the order of operation of the sensors, it is possible to set the sector of 60 degrees, in which the sound source is located. Some calculations are needed to determine the location more accurately. First, we give each of the sensors coordinates on the plane, making them corresponding to the actual distance between the sensors (Fig. 4, a).




a b c

Fig. 4. Placement of sensors on a plane in a right triangle
with defined coordinates (a), time (b) and two points of the sound sources (c)

Now it`s needed to take the time of operation of each of these sensors, which is memorized. The shortest time (the operation time of sensor A) must be subtracted from the other two. Then the difference of signal receipt will be received. The difference for the sensor A is established in “0” (Fig. 4, b). It will be a starting point.

The distance between point A and the point of the signal source is calculated for the specified coordinates by the following formula:

$$(1{,}75 - x)^2 + (0 - y)^2 = t^2.$$

The same situation for the other two points.

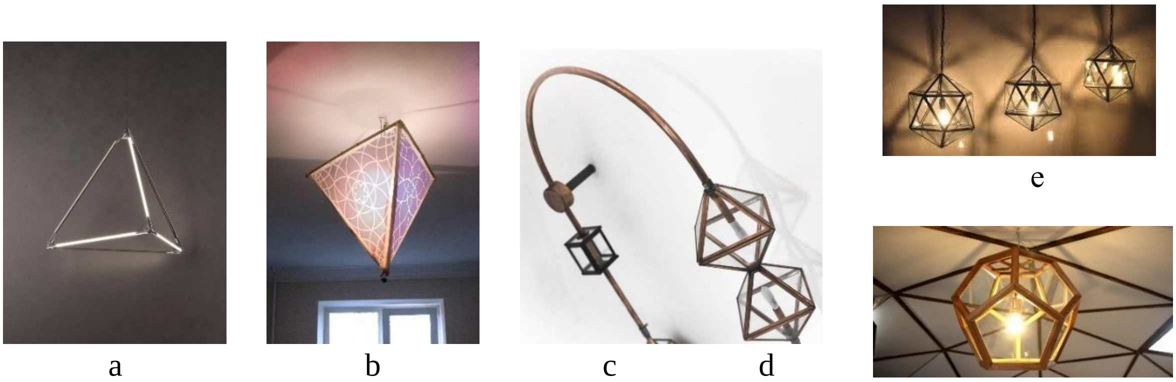
$$(-1{,}75 - x)^2 + (0 - y)^2 = (t + 1{,}6)^2,$$
$$(0 - x)^2 + (3 - y)^2 = (t + 3{,}3)^2.$$

If no rounding was performed, there was no data loss, and the quadratic equation will always have only 1 solution. After substituting *t* in *x* and *y*, the coordinates of the point of the sound source will be obtained, or two points, if there were losses in accuracy (Fig. 4, c).

**B. Platonic solid**

A reduction in the computational complexity of this task can be achieved if the sensors will be placed on the vertices of the Platonic solids (PSs) – regular polyhedras. There are a total of five three-dimensional PSs: tetrahedron, hexahedron (cube), octahedron, icosahedron, and dodecahedron. In this case, the number of sound sensors in ISPAL will be 4, 6, 8, 12 or 20 sensors respectively according to Euler's theorem [20–22]. This arrangement gives the same distance (the length of the edge of a regular polyhedron) between adjacent sensors (positioned at the vertices of the PSs), which greatly simplifies the calculation.

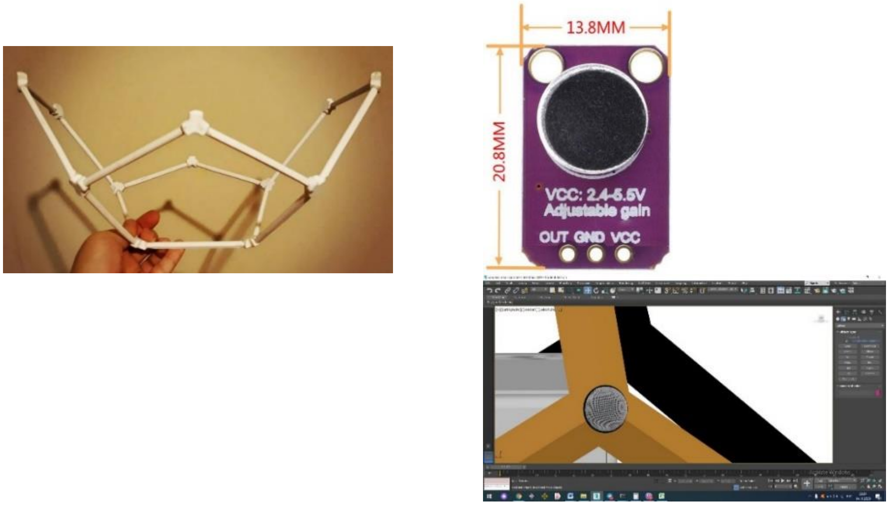
The most interesting option is the design in the form factor "lamp" (Fig. 5). It allows to combine several functions: direct lighting, lighting control system, perimeter penetration control system (during non-working hours and/or in the absence of people).



a b c d e f

Fig. 5. Lamps in the form of Platonic solids: a, b – tetrahedron [23, 24], c – hexahedron (cube), d – octahedron [25], e – icosahedron [26], f – dodecahedron [27]

A sound sensor (GY-MAX4466 (Fig. 6, b), KY-037(038), or any sound sensor on the audio amplifier LM386 or LM393 [7]) is mounted on vertex of the lamp (Fig. 6, c). It can be wooden, made of brass profile or printed on a 3D printer made of ABS plastic (Fig. 6, a). The thickness of the frame should not exceed 10 mm (the height of the microphone above the sensor board).




a b c

Fig. 6. Frame of a dodecahedron lamp (a) with the sound sensor (b) built in the vertex (c)

The ISPAL hardware kit is built into the construction. The wires from each sensor converge in the center of the sphere described around the PS, where the microcontroller module is physically positioned (Fig. 7, b). The length of all wires is considered to be the same. Their capacity has the same effect on the result of signal processing from each sensor.

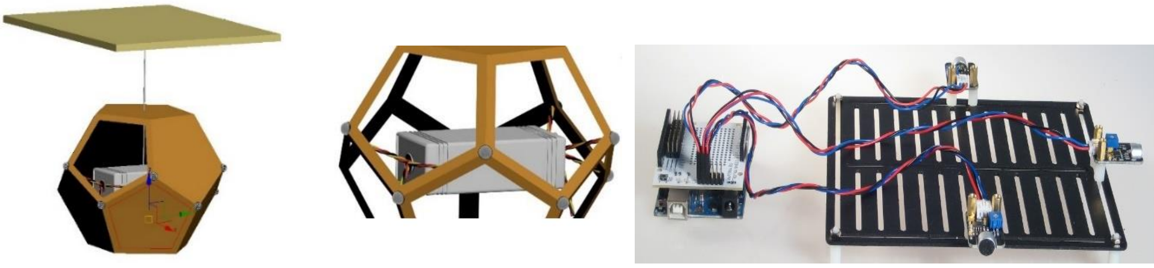


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Fig. 7. "Enclosed structure" of dodecahedron lamp (a) and opened with sound sensors mounted in the vertices (b) and connected to the microcontroller board (c) [28]

For lighting the power cord of the light bulb, which is positioned under the body of the kit, passes together with the power cord, then through the body of the ISPAL central unit (Fig. 8).

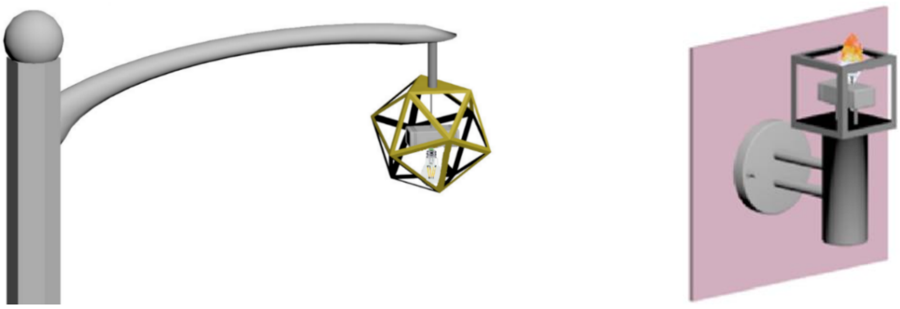

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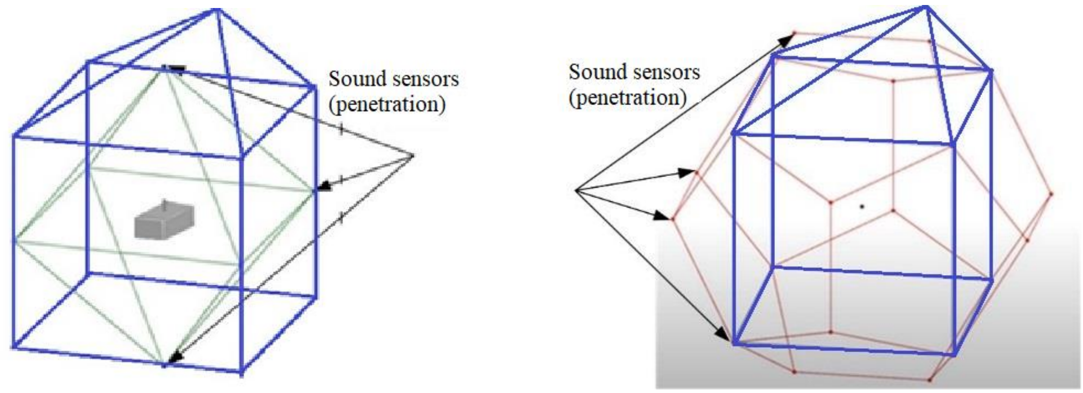
Fig. 8. Pendant lamp-icosahedron (a) and wall lamp-cube (b) with built-in ISPAL hardware kits and light bulbs behind the ISPAL central unit [28]

Table 1. Overall dimensions of the microcontroller system of passive acoustic location on the basis of Platonic solids [28]

| **Distance between sound sensors, m** | **Number of sensors** | **The form of the ISPAL hardware set (Platonic solid type)** | **The radius of the sphere circumscribed about the hardware set ISPAL R, m** | **Volume of the ISPAL V hardware set, m³** |
|---|---|---|---|---|
| **0,5** | 4 | tetrahedron | 0,30 | 0,015 |
| | 8 | hexahedron (cube) | 0,43 | 0,125 |
| | 6 | octahedron | 0,35 | 0,059 |
| | 12 | icosahedron | 0,47 | 0,273 |
| | 20 | dodecahedron | 0,70 | 0,958 |
| **…** | … | … | … | … |
| **4** | 4 | tetrahedron | 2,45 | 7,542 |
| | 8 | hexahedron (cube) | 3,46 | 64,000 |
| | 6 | octahedron | 2,83 | 30,170 |
| | 12 | icosahedron | 3,80 | 139,628 |
| | 20 | dodecahedron | 5,60 | 490,440 |
| **5** | 4 | tetrahedron | 3,06 | 14,731 |
| | 8 | hexahedron (cube) | 4,33 | 125,000 |
| | 6 | octahedron | 3,53 | 58,926 |
| | 12 | icosahedron | 4,75 | 272,712 |
| | 20 | dodecahedron | 7,00 | 957,890 |

Luminaires with a radius of about 30 cm are mainly used in residential premises and in public catering establishments. ISPAL hardware kits with similar dimensions can be built into their construction (see line 1 in Table 1). The length of the wires from the sound sensor to the central unit of the ISPAL hardware kit can be reduced according to the size of the luminaire. In the calculations, the analytical formulas for the distances from all sensors are the same and can be replaced by a constant for each type and number of luminaires. This significantly reduces the computational complexity of calculating the direction and/or location of the sound source using the method of passive acoustic location [29].

The large size (several meters) of the radius of the circumscribed sphere about the ISPAL sensor system corresponds to the spatial systems of access control to the premises. They can be activated during non-working hours for organizations and in the absence of homeowners for residential premises. In this case, sound sensors are installed around the perimeter of such a room (Fig. 9). For such purposes, it is advisable to use wireless sensors with data transmission according to the BLE standard and a battery for 10 hours, for example, from Pasco Group [30].




a b

Fig. 9. Access control system to the premises of the house in the octahedron (a) and to the adjacent territory in the dodecahedron (b)

It should be noted that the sensitivity threshold of sound sensors should be set depending on the purpose of ISPAL, considering that the range of ambient noise intensity varies from 30 dB to 90 dB [31].

Generating a sound that is louder than the set threshold, each of the sensors positioned at a known equal distance from the neighboring sensors, through the communication line (CL) will notify ISPAL about the receive of the sound signal (Fig. 10).

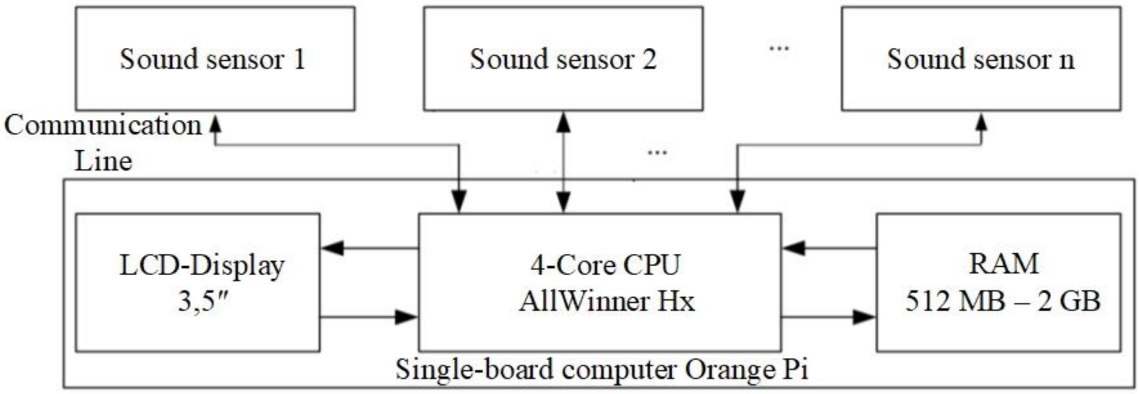



Fig. 10. Block diagram of a multi-sensor system of passive acoustic location

The RAM (512MB–2GB DDR3, shared with the GPU) of the specified minicomputer will store the time of receiving the audio signal for each of the sensors. Then the PAL algorithm will be processed. The data on the vector of orientation to the source of sound oscillations will be displayed on the LCD display, PC and/or mobile device using the developed software application.

## C. Description of the software application

The software application of the described ISPAL is developed on the basis of classical three-link architecture. The alarm signal is transmitted from the sensors (using the http protocol) to the web server and recorded in the database (DB). The developed UI connects to the web server and receives from the database data on the occurrence of alarm (Fig. 11). The user, in turn, accesses the application and receives information about the alarms.

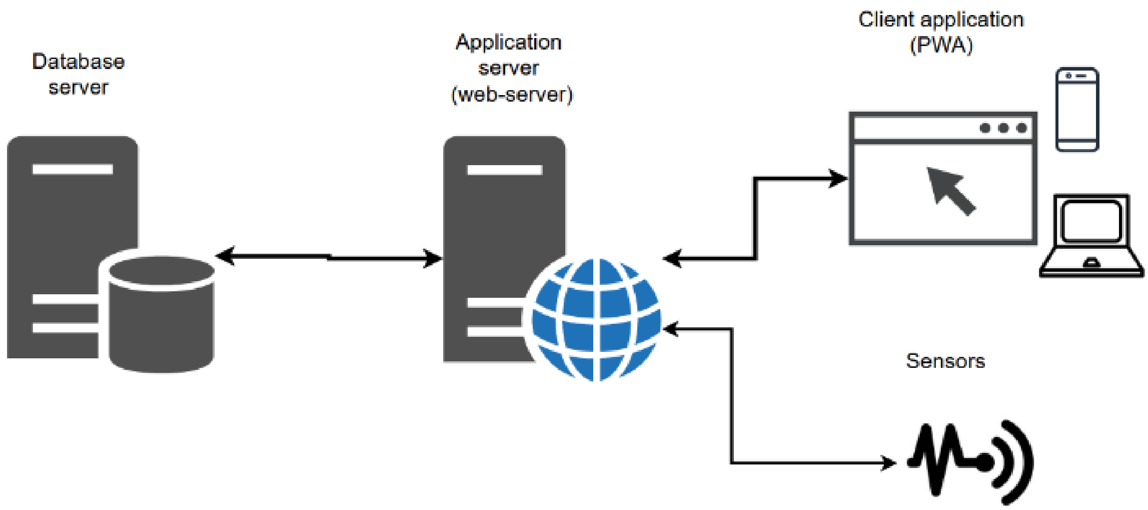



Fig. 11. Three-link architecture of the ISPAL web application

MySQL Server was used as a database server in the developed software application ISPAL. The backend component of the application is implemented on the basis of the Laravel framework, which is designed for development using MVC (Model View Controller) technology. Migration and Object-relational mapping (ORM) model classes are used to interact with the database, which is a built-in ORM of the Laravel framework and allows you to execute SQL queries on the database using entity object methods.

Alarm signals from the luminaire sensors are sent to the integrating device, which sends an *http*-rest request to the appropriate controller of the backend component to store data about the occurrence of the alarm in the database (Fig. 12). In turn, this information is displayed immediately and also available later.

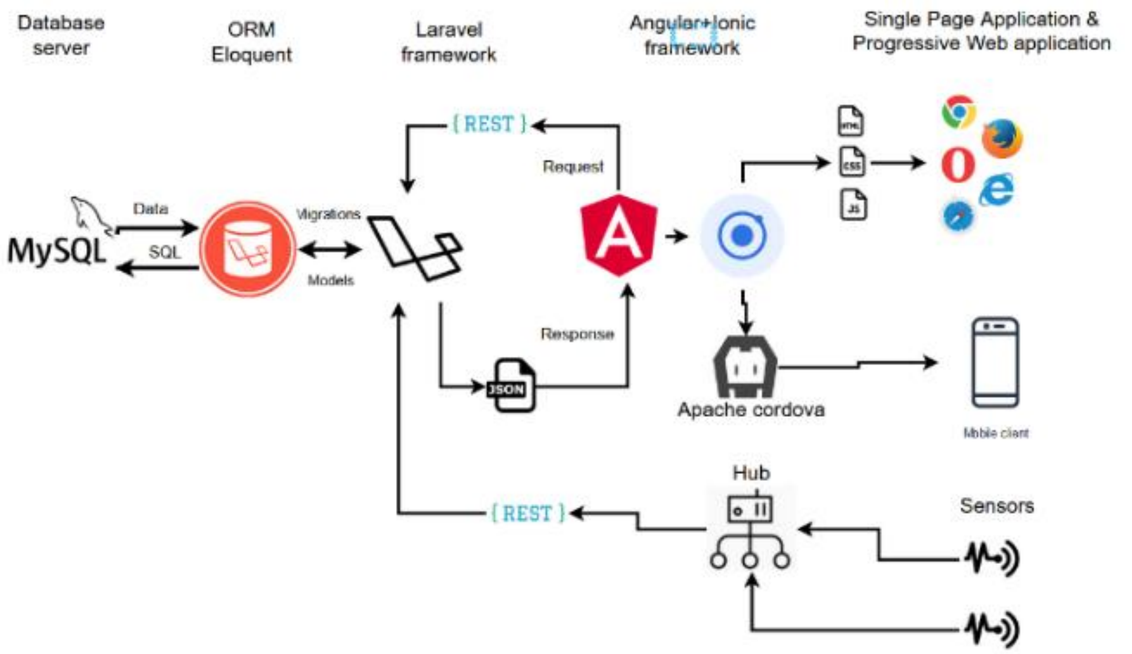



Fig. 12. Scheme of interaction of application components

The Ionic framework is used to implement the frontend component, which in most cases is used as an add-on to JavaScript (JS) single-page application development (SPA) frameworks.

Within the current project, the Angular framework was used, which implements basic and additional functionality as a set of TypeScript libraries that have been added to the project.

Using Apache Cordova (or Ionic Capacitor) technology allows you to build a project for the target platform of a mobile device (Android or iOS of the selected version) and get a progressive web application (PWA) that can be used on a mobile phone, tablet or any other device with the appropriate operating system installed.

## Database structure

The MySQL database management system (DBMS) was used to store reference data and alarms received from the respective sensors. The following entities were used in the implementation of the database structure: «User», «Building», «Premises», «Lamp type», «Alarm» and «Alarms behind sensors» (Fig. 13).

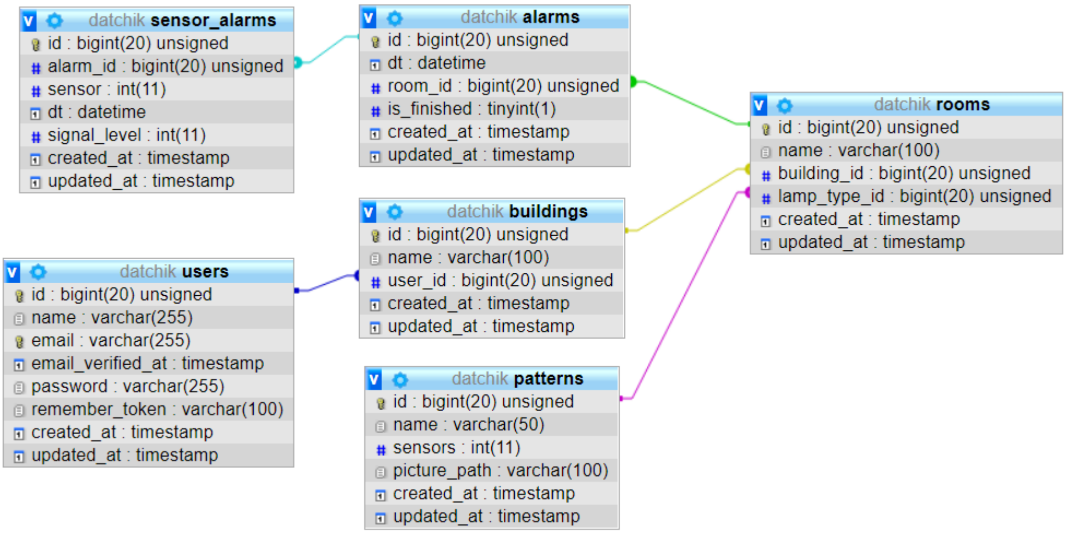



Fig. 13. Database structure

## Backend part

The backend is implemented in PHP based on the Laravel framework. To generate the database structure, a number of migration classes have been created to create the corresponding database tables, each of which implements two methods: *up ()* and *down ()* – to perform and roll back the migration, respectively. In Fig. 14 as an example, the code of the migration class "CreateRoomsTable", which is responsible for creating a database table "Rooms".

```
<?php

use Illuminate\Database\Migrations\Migration;
use Illuminate\Database\Schema\Blueprint;
use Illuminate\Support\Facades\Schema;

class CreateRoomsTable extends Migration
{
    /**
     * Run the migrations.
     *
     * @return void
     */
```

```
public function up()
{
    Schema::create( table: 'rooms', function (Blueprint $table) {
        $table->id();
        $table->string( column: 'name',  length: 100);
        $table->bigInteger( column: 'building_id')->unsigned();
        $table->foreign( columns: 'building_id')->references( columns: 'id')->on( table: 'buildings');
        $table->bigInteger( column: 'lamp_type_id')->unsigned()->nullable();
        $table->foreign( columns: 'lamp_type_id')->references( columns: 'id')->on( table: 'patterns');
        $table->timestamps();
    });
}

/**
 * Reverse the migrations.
 *
 * @return void
 */
public function down()
{
    Schema::dropIfExists( table: 'rooms');
}
}
```

Fig. 14. Code of migration class "CreateRoomsTable"

Seeder classes were used to fill the tables with test data.

After deploying the project and creating the database, using the above implementation of migration classes and seeders to generate the structure of the database and fill the tables with test data, you must perform in the command line "php artisan migrate" and "php artisan db: seed", respectively.

The following interaction with database tables is implemented through Eloquent ORM model classes. In general, the following model classes were implemented: "Alarm", "Building", "Pattern", "Room", "SensorAlarm" and "User".

The interaction between the routes accessed by the UI and the application logic is organized in a set of controller classes. In Fig. 15 shows a class diagram for the controllers implemented within the application.

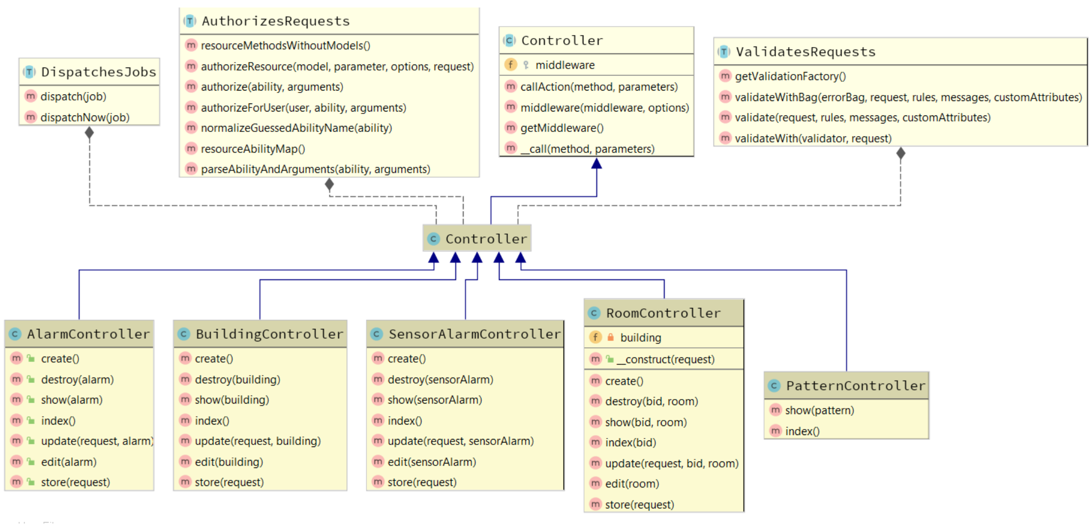



Fig. 15. Building model class

**Frontend part**

The frontend is implemented in the JS language based on the Ionic framework and Angular. To interact with the backend, the "ApiService" class service is implemented, which uses the built-in Angular "HttpClient" class. This service implements methods to execute all the necessary commands of the backend component and return the received data in response. As an example, in Fig. 16 shows the *getRooms ()* and *editRoom ()* methods for obtaining a list of rooms in a building and editing a room.

```
getRooms(buildingId) {
  return this.http.get( url: this.baseUrl + '/buildings/' + buildingId + '/room');
}

editRoom(buildingId, id, name, lightId) {
  return this.http.put( url: this.baseUrl + '/buildings/' + buildingId + '/room/' + id,  body: {
    name,
    lightId
  });
```

Fig. 16. *GetRooms ()* and *editRoom ()* methods of the “ApiService” class

During the implementation of the UI, four main pages were created. These are “Types of Lamps”, “Buildings”, “Premises” and “Alarms”. Each page consists of a “TypeScript” class that implements the logic of user interaction, and an html template that is responsible for the appearance of the UI.

**User interface for web and mobile versions**

All the above information is displayed on the UIs developed by ISPAL, respectively, for web and mobile versions. Thus, in Fig. 17, and Fig. 18, and accordingly the possibility of choosing the type of lamp and the type of room on the web interface ISPAL is given. In Fig. 17, b and Fig. 18, b shows the implementation of similar actions on the mobile version of the developed application. Similarly, the room is selected for the installation of lamps in the form of Platonic solids with sound sensors in the vertices.

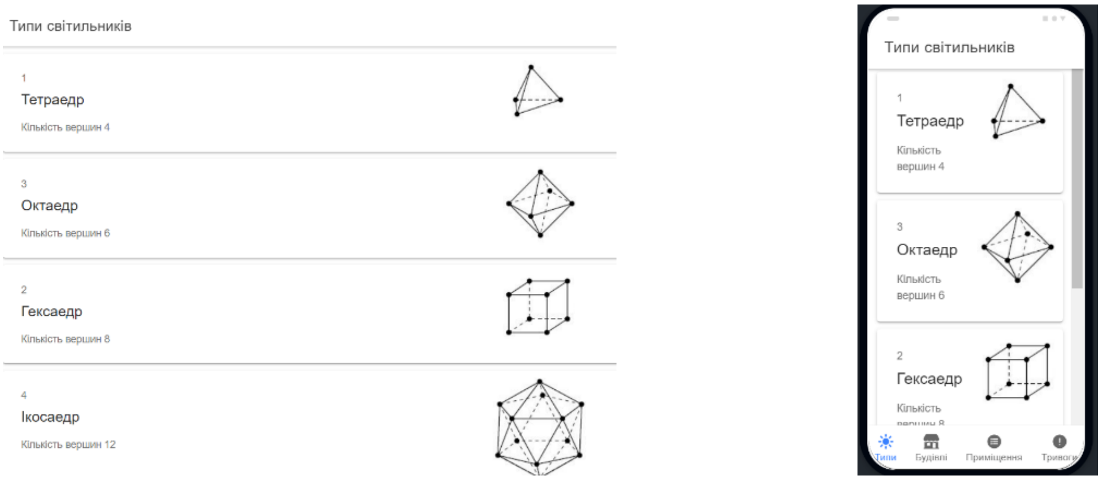



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Fig. 17. List of "lamp types" for web (a) and mobile (b) versions

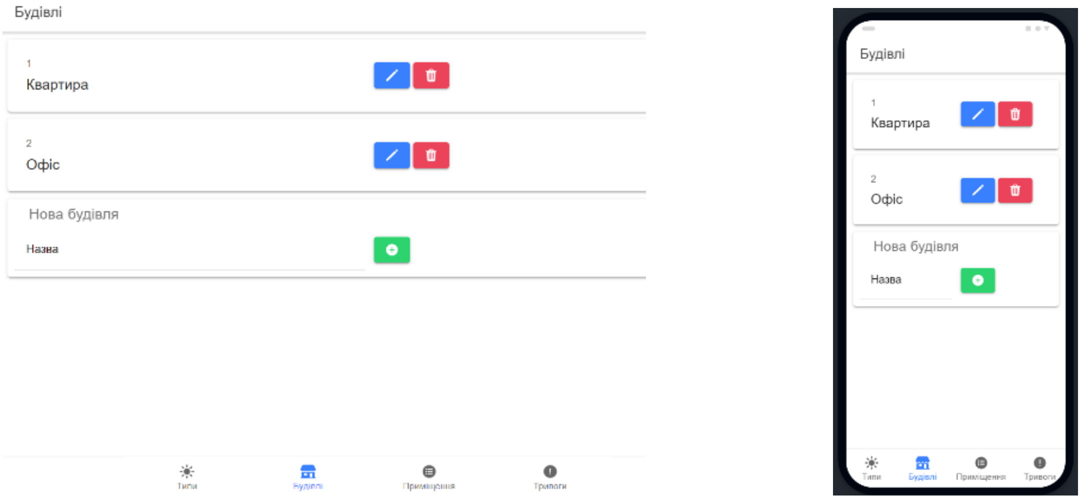


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Fig. 18. List of "buildings" for web (a) and mobile (b) versions

In the case of sound on any of the sensors on the described "chandeliers" in the room, the UI displays a list of alarms indicating the date and time for each room (Fig. 19). Also, for each case of alarm, it is possible to view detailed information on the direction of movement of the sound source (Fig. 20).

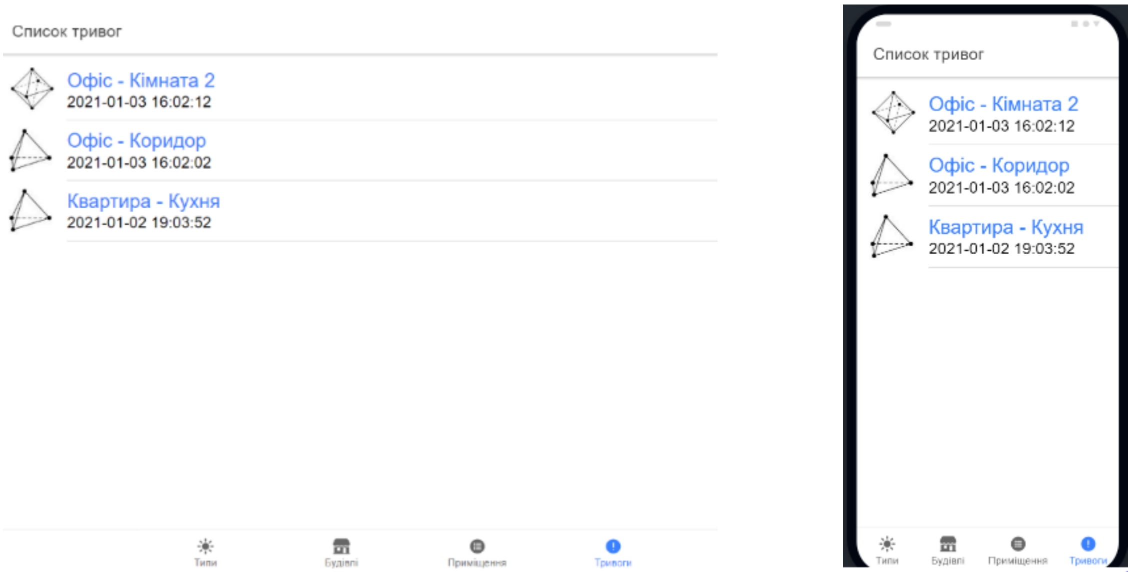


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Fig. 19. List of "alarms" for web (a) and mobile (b) versions

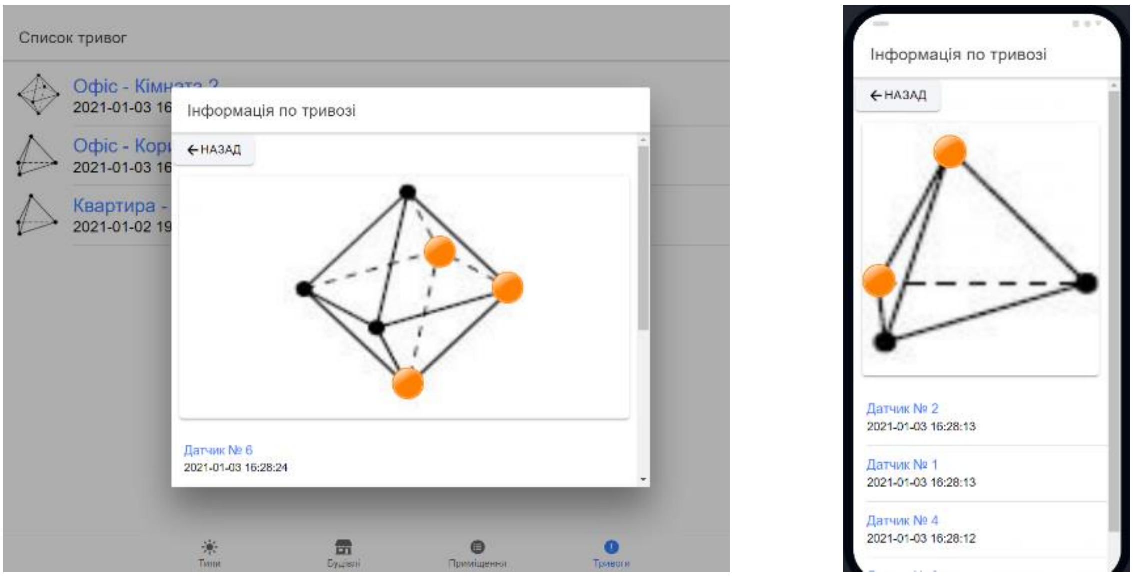


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Fig. 20. View detailed alarm information for web (a) and mobile (b) versions

In the future, it is advisable to pay attention to the chronometric visualization of such information, indicating the sequence of sensors that have registered the receipt of sound vibrations. In this case, it is necessary to develop an analytical definition and formation, for example, of a radar/spider chart in a polar coordinate system showing the chronology of alarms with its display on the user interface in real time. This solution to the problem will allow to determine as soon as possible not only the fact of violation of the perimeter of the organization or the receipt of sound from the victims, but also to determine the direction of their movement in space. This will significantly increase the speed of response and decision-making in search operations.

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