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The Study of the Effectiveness of Energy and Information Transfer Through a Large Reflector Using Its Conductive Materials

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Abstract

The article discusses various methods for transmitting energy and information using the electrical conductivity of tungsten components within a large, transformable structure. It explores the principles of data transmission and examines the most common standards in this field. Additionally, it evaluates the feasibility of creating a new information transmission protocol that could be used in outer space applications. Due to the fact that these energy systems consider not only the shape and material composition of a structure, but also its ability to accurately transmit energy and signals, developing algorithms for both energy and data transmission presents a complex scientific and technical challenge. Technical solutions have been developed that allow for more efficient use of the design of large-sized space-based reflectors. The results of field tests have confirmed the benefits of the developed methods for transmitting energy and information using tungsten components in grid design.

Keywords: Large-sized reflector; Transformable structure; Electrical conductivity; Tungsten; Energy transfer; Information transfer.

1. Introduction

Currently, the development and advancement of technology for the production and operation of large-sized transformable structures represents an innovative solution to several challenges within space-based technologies. Antennas with large effective areas enable remote sensing of the Earth's surface and provide high-quality, noise-resistant communication. However, such structures present significant challenges in terms of their manufacturing and operational processes, particularly when it comes to deploying them into a functional position in outer space and adjusting the shape of the radio-reflecting mesh [1], [2], [3], [4].

As a prototype, let us consider a reflector with a controllable reflector shape (Fig. 1) [5] and [6].

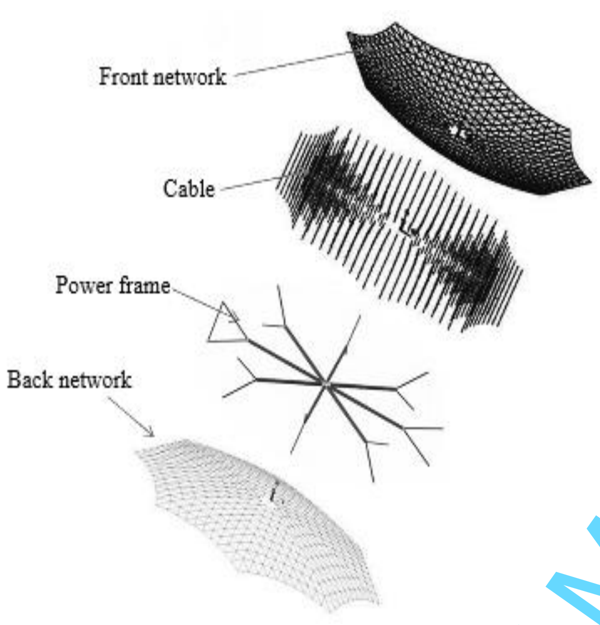

Fig. 1. Structure of a large-sized transformable reflector

The challenge in operating reflectors with a precisely controlled shape lies in the difficulty of launching large-scale structures into orbit from the ground in a functional state. This requires their deployment in outer space. A significant challenge in this regard is ensuring the accurate reproduction of the reflector's geometry in space, precisely as designed. Any deviation from the intended shape can result in a change to the radiation pattern, affecting the antenna's efficiency [7]. It is essential to deploy and subsequently adjust the specified reflector shape, as the structure may undergo changes due to external influences.

To determine the current configuration of the antenna, a geometric scan using a total station (or laser tracker) is performed. Actuators are used to adjust the shape, which are located throughout the entire area of the reflector, by altering the lengths of the cables stretched between the front and back networks [8].

Actuation devices are operated via wired connections, which, in addition to adding significant additional mass to the system, also pose risks of entanglement and cable failure during deployment. Therefore, it is essential to develop alternative methods for transferring information and power to actuators [9], [10].

2. Analysis and selection of the energy transfer method

In order to operate the shape control system for a large-sized transformable structure, power must be supplied to the actuators. A major challenge in this regard is the use of redundant wired connections [11].

There have been studies in the field of energy transmission using an open optical channel. This approach has a relatively low efficiency, as optical receivers are not very efficient. In addition, while it offers the potential to eliminate wired connections, it requires the use of complex laser positioning systems for receivers and design of energy storage solutions, as it is not feasible to transmit energy continuously. This approach is challenging to implement in terrestrial environments due to atmospheric dispersion, which further reduces efficiency. Several countries are pursuing research in this area, but no commercialized space-based solution has yet been developed [12], [13].

Another potential method of energy transfer could be the use of microwaves. In this scenario, a significant amount of energy would be distributed through space past receiving devices.

In this paper, a system for transmitting energy using structural conductive elements in a grid is proposed. The radio-reflective net consists of tungsten, a good conductor, which allows it to be used entirely as a conductor. Because of the need to maintain almost the entire active area of the reflector energized, the efficiency of this circuit is lower than that of directly wired connections, although it is many times higher than that of an open optical channel.

This approach allows for the transmission of not only energy but also information over a network, which necessitates a number of modifications to the energy transmission structure, as it becomes necessary to transmit at different voltage levels. In this context, it is important to note that on larger structures, there will be a significant voltage drop due to tungsten resistance. This requires the use of multiple synchronized on-board power supplies or step-down devices for elements located closer to sources.

Due to the need for different logic levels to be transferred, it is not possible to maintain a constant voltage. This issue is addressed by incorporating an energy storage system, based on either a battery or supercapacitor, into the actuator [13], [14]. In this scenario, information transmission is possible through simple presence/absence of voltage. However, this results in short-term disruptions to the power supply. Therefore, it is necessary to store energy in order to maintain operation during information transmission events. Another option is to utilize the conventional supply voltage of the control circuit as a reference zero. Alternatively, a higher voltage level, such as 1.5 times the standard voltage, can be used as a unit. In this instance, only overload protection would be required, allowing for a reduction in system weight and size.

3. Analysis and selection of the method of information transmission

To select an information transfer protocol, it is essential to consider the design characteristics of the network protocol. The reflector comprises two main components – the front and back network (Fig. 1). The rear side is used for grounding, hence only one line is available. This significantly reduces the number of potential methods for transmitting information. Under these circumstances, the UART interface appears to be the most suitable option. A common ground is provided by the backside of the reflector. Although two lines are typically required according to the UART specification, one can be omitted, as data transmission is only required in one direction.

The circuit includes a master microcontroller, which processes control signals and transmits them to a network of slave microcontrollers. Communication between the master and slave devices is established using the UART (Universal Asynchronous Receiver/Transmitter) protocol, with the TX (transmit) output of the master connected to the RX (receive) input of the slaves. This arrangement is dictated by the lack of a dedicated second channel for communication and the requirement to transmit data from the slaves to the master device.

To verify the functionality of this design, an experiment was carried out using tungsten as the data bus. Two microcontrollers were used in the experiment (Fig. 2). The research was conducted on models with significant size limitations. While this does not fully conform to the definition of a large-sized structure, it does allow for low-cost, in-kind validation of the viability of the proposed algorithms. At present, the practical implementation of the suggested methods on large-scale structures is achievable, although it has been little explored, which could potentially lead to additional challenges in their application to real-world scenarios.

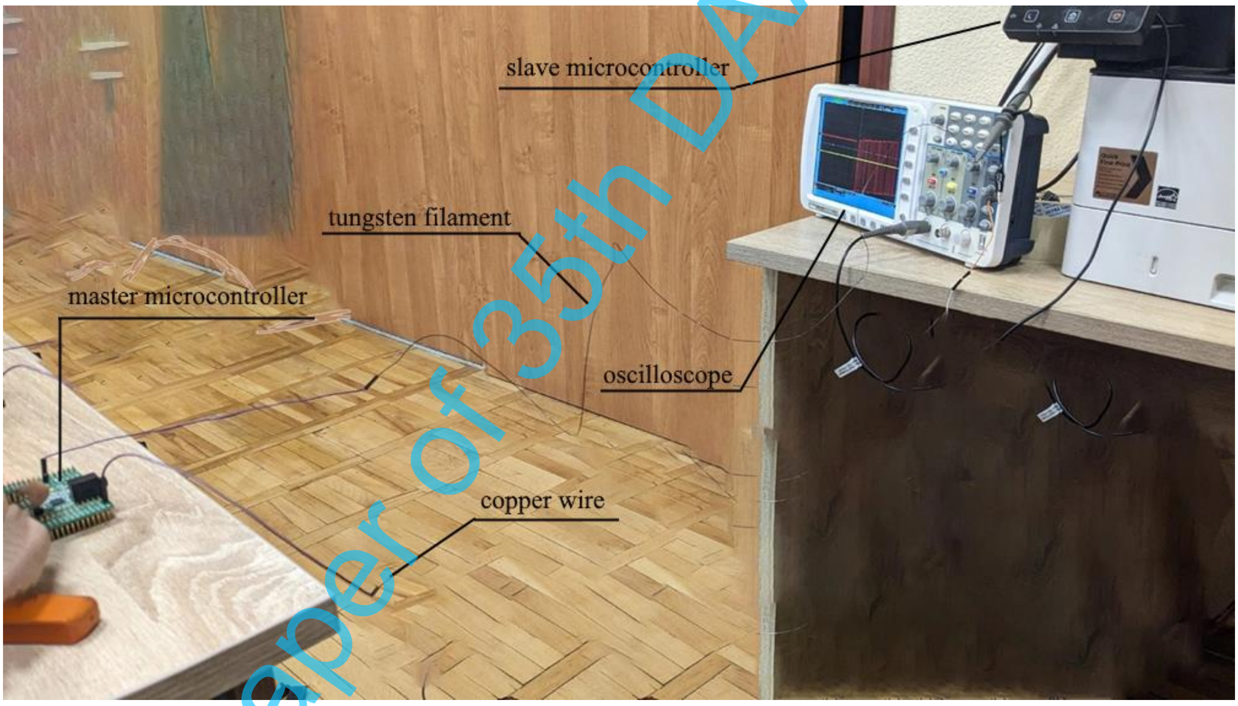

Fig. 2. Experimental setup

In the developed data transfer algorithm, each character is assigned a separate byte. This is an efficient approach that ensures stable data transmission, even if the packet needs to be expanded, and not just in extreme cases. The first two bytes indicate the slave device's number, for example 01, and the next byte indicates the direction of the device's rotation (0 for clockwise and 1 for counterclockwise). The next three bytes specify the time for the executing device to work. While this message does not provide all the information necessary for a real device's operation, it simulates the operation well enough.

Initially, the experiment was performed on a 1-meter-long tungsten wire using two STM32F407 microcontrollers. A communication channel was established using tungsten and the ground was provided by a regular copper wire. The phrase "01 0 200" was transmitted between microcontrollers at a rate of once per second. The accuracy of the transmission was verified when sending a message from a subordinate microcontroller to a personal computer. Initially, the rate was set at

9,600 kilobits per second (kbit/s). There were no transmission errors for an hour. Next, the rate was increased to 14,400 bits per second (baud) and then adjusted according to specifications. Transmission errors started to occur at 56,000 baud. This indicates the possibility of increasing data transfer speed, but this can also lead to errors and reduced compatibility. A rate of 9,600 kbit/s is sufficient to transfer the necessary amount of data (one byte per millisecond). After replacing the tungsten wire with weave, general grounding was also performed using tungsten. The experiment was repeated and the results were consistent. Therefore, the UART protocol ensures reliable signal transmission [14].

The developed algorithm for the system's operation, considering data transmission, involves the following steps:

- Determination of the current state of the network using a laser tracker.
- Calculation of the necessary offsets for actuation points.
- Transmission of these offsets to the master microcontroller.
- Generation of information packets by the master microcontroller.
- Transfer of these generated packets through the tungsten network elements using the UART (Universal Asynchronous Receiver/Transmitter) protocol.
- Reception and processing of the packets by slave microcontrollers.
- Execution of the corresponding control actions by executive devices.

One of the challenges associated with the use of the UART protocol lies in its application to reflectors with a larger radius. While reducing the data transmission speed can help increase the range, the use of tungsten has limitations that restrict the feasibility of this approach.

To ensure the successful transmission of a signal over long distances, a method of separating receivers at the logical level is employed. This is because voltage drops over extended distances, and packet lengths must be reduced to account for this phenomenon. Additionally, addresses are not necessary, as there is no address system in place. Addresses are used to determine which device a command is directed towards, and this increases packet length.

When using this protocol, losses can become significant, so it is important to reduce message lengths to minimize the risk of errors. Because it is not feasible for the slave microcontroller to report on the status of received packets, any error could disrupt device operation. Using accurate ADCs allows for more precise tracking of voltage changes.

To confirm this, a current propagation model has been developed using the Matlab software package. This model shows voltage drops at specific points, with coordinates indicated in millimeters from the lower left corner of the antenna structure. The algorithm used is illustrated in Fig 3, and the simulation results are presented in Table 1.

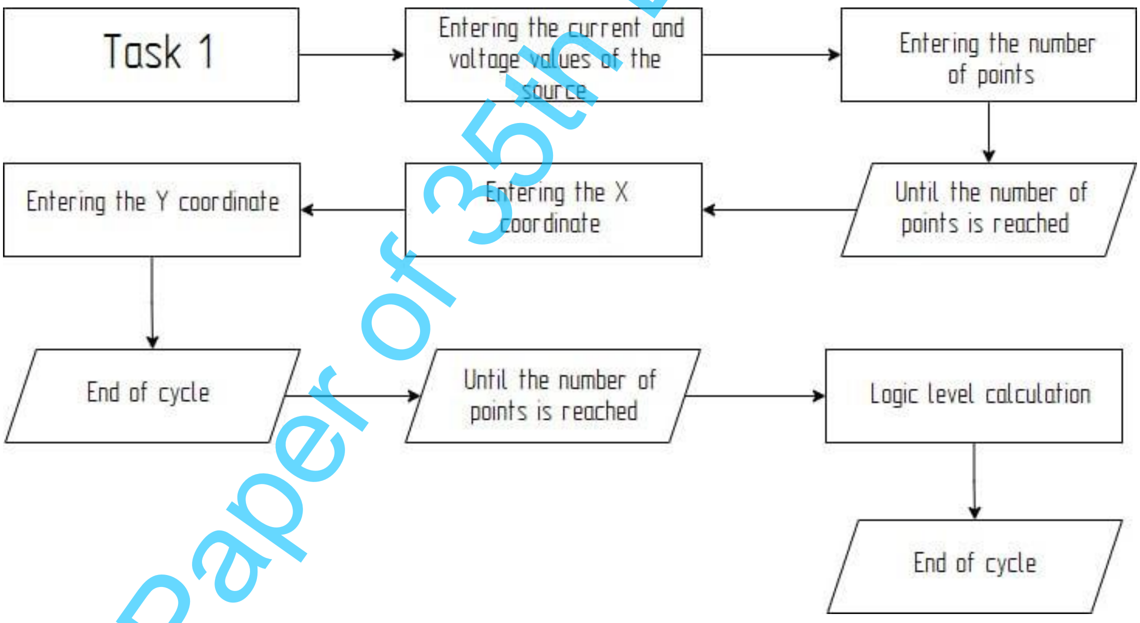

Fig. 3. The structure of the algorithm for modeling the distribution of stresses across network points

The address can only contain one bit, which is necessary if the network nodes are located at equal distances from a reference point. For instance, in the given table, this is the case for points 2 and 4, or 3 and 7. Due to the short distances in the layout, the voltage differences in the table are relatively small.

Another possible solution could be to consider transferring the grounding to the spoke along which the actuator moves. This would allow for the rear part of the network to be freed, making it possible to utilize two transmission lines and providing access to several other protocols that require two lines, such as RS-485.

The choice of this particular protocol avoids issues related to long-distance transmission of information. However, the physical implementation of this protocol is typically in the form of twisted pair, and it can be difficult to predict proper operation in scenarios involving lines spaced over a significant distance using rather unusual materials such as tungsten. As a result, testing of such a configuration is required.

This approach has been identified as a key direction for further research in this field.

Capacities in the circuit elements arise when the weave is designed in such a manner that gaps occur. If air or vacuum appears in the interweaving, a planar capacitor may form. Its capacitance depends on the thickness of the resulting air or vacuum layer. Let us assume that this thickness is 1 millimeter. Then, $C = 0.058 * 10^{-12}$ F. This capacitance is quite small and therefore does not significantly affect the design. Therefore, it is impractical to calculate the capacitance taking into account the wire's geometry [15].

Point number	The X coordinate	The Y coordinate	Voltage value
1	0	0	10.0000
2	100	0	9.9900
3	200	0	9.9800
4	0	100	9.9900
5	100	100	9.9859
6	200	100	9.9776
7	0	200	9.9800
8	100	200	9.9776
9	200	200	9.9717

Table 1. The results of modeling the stress distribution at points in the tungsten network

4. Physical features of tungsten energy transfer

In the Ansys software, a mathematical representation of the grid system was created to verify voltage drops from the starting point. This model takes into account heating and current intensity. The findings are presented in Fig. 4 and Fig. 5.

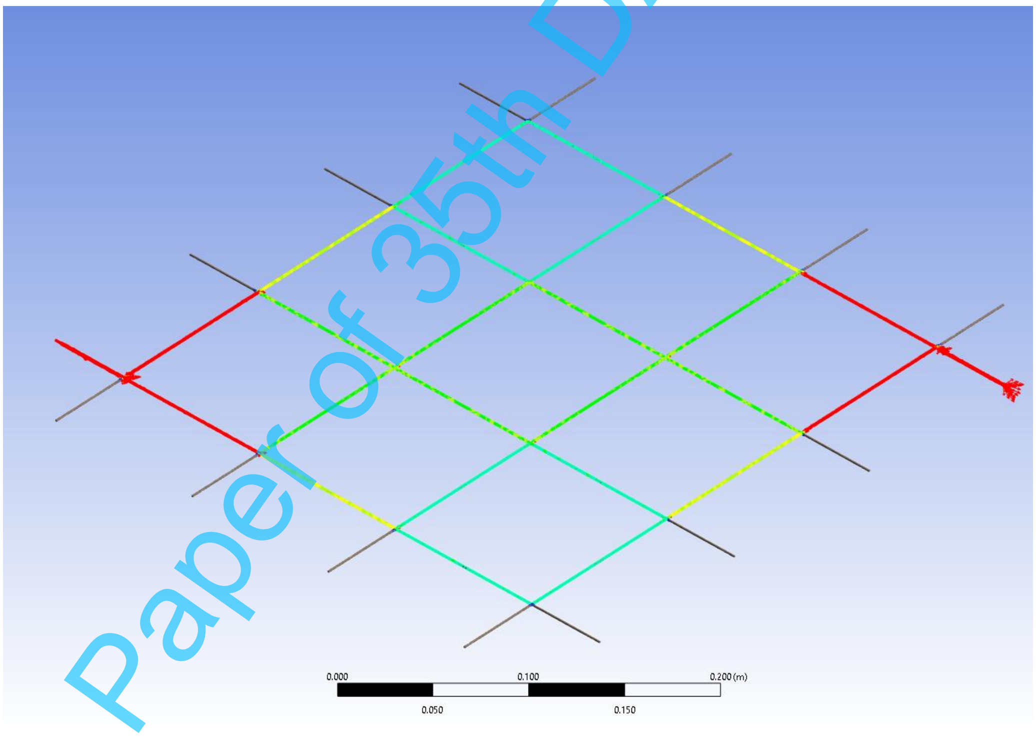

Fig. 4. Simulation of the current distribution in the ANSYS program

When moving from a grid node to its center, the number of nodes in the network increases, resulting in a decrease in the current strength within the segments between nodes. In the center of the network, current strength is at its minimum. As the current flows through the middle of the network, however, the number of nodes begins to decrease and the current strength begins to increase. This indicates that there are additional network parameters, in addition to resistance, that affect voltage and current strength. For instance, the shape of the network and the location of voltage application play a role. According to the Joule-Lenz Law, heating will occur unevenly due to high amperages, which can affect the geometry of the grid. These factors must be taken into consideration when designing a power supply system [16].

When transferring the developed techniques to a full-scale product, it is suggested to conduct additional testing that may reveal new opportunities to enhance the methods discussed in this paper [17].

5. The design of the layout facets of the reflector

To investigate the principles described, it is proposed to construct a mock-up simulation of a reflector array with a side length of 1 meter. The triangular frame will be constructed from aluminum tubes and the connections will be made from ABS plastic. The mesh will be completely composed of tungsten filaments, which will bring the scale of the model closer to that of the actual product. The small scale also allows for access to various testing chambers that can replicate space conditions. An example of a potential layout for investigating the processes under consideration is shown in Fig. 6.

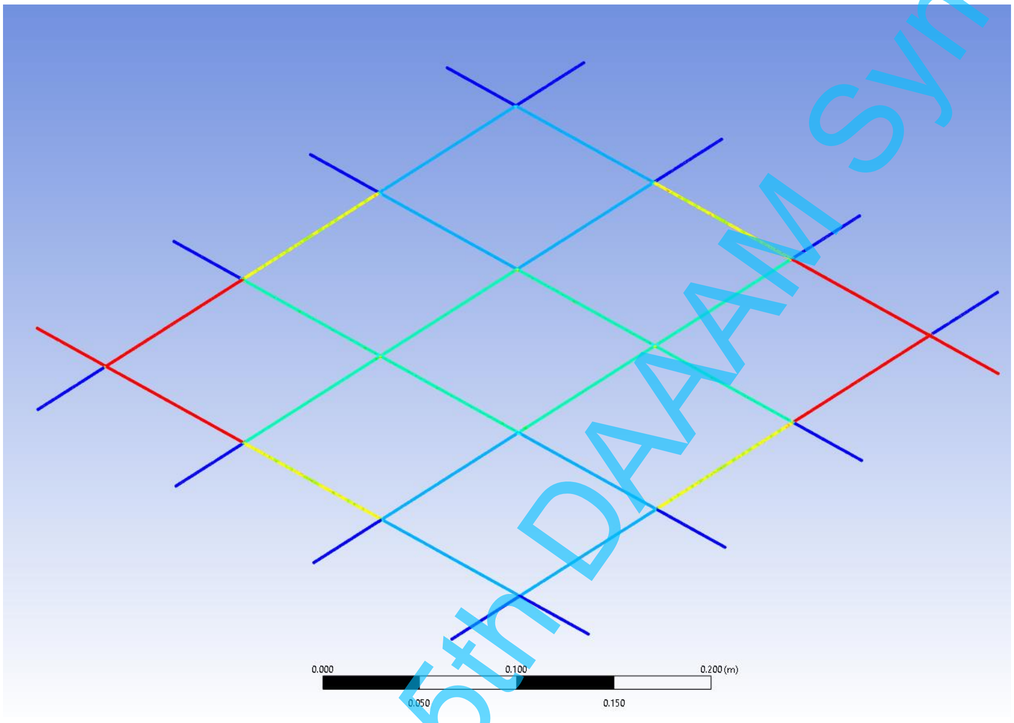

Fig. 5. Simulation of the heating of the grid in the ANSYS program

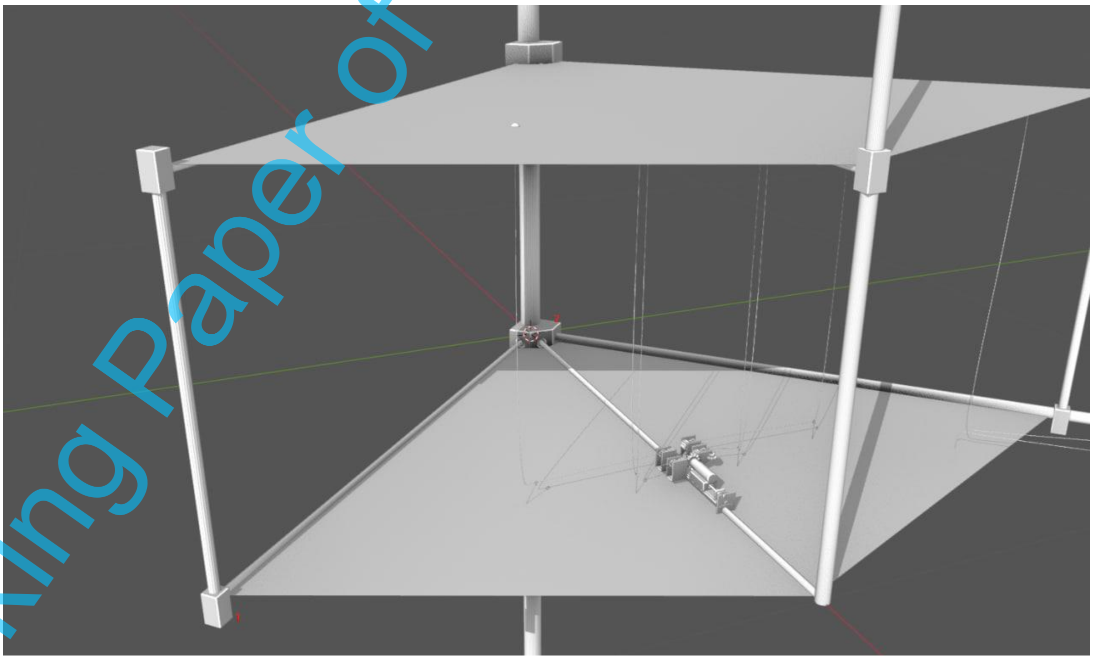

Fig. 6. The layout model in the Blender environment

6. Conclusion

The research presented in the article is designed to solve the problem of optimized energy information support in shape control systems of large-sized structures. The authors considered possible solutions to this problem and chose a method for transmitting energy and information through the elements of a tungsten network.

During the research, results have been obtained demonstrating the potential for developing a system to transfer energy and information utilizing network elements. Techniques for physically constructing such a system have been proposed, taking into consideration the specific requirements of power supply for actuation points as well as operational algorithms. Recommendations have been provided for selecting methods for constructing energy supply, contingent on the design characteristics of the reflector, facet utilized, and weight and size constraints. Techniques to reduce the length of a message have been developed, enabling the transmission of less information and, consequently, enhancing the accuracy of data transfer. Additionally, considering the physical structure of a conductor opens up novel research objectives in this area, such as addressing uneven heating of the structure and optimizing stress application points.

In the future, the authors propose to conduct research on a more complex layout, which has a more accurate repetition of the geometry of the large-sized structures used. In addition, it is planned to work out algorithms over long distances, which will allow us to obtain new data and improve algorithms for energy information exchange.

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