Multifunctional SMART Air Cleaner

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Abstract. Environmental air quality often affects human health. Allergens, viruses, bacteria often float in the air and settle on surfaces. This situation prompts various world organizations to address this problem by means of disinfection and cleaning of premises where a person is most often. Pathogenic bacteria are often spread by airborne droplets and can persist on surfaces for a long time. The proposed study was aimed at proposing a device for a disinfecting room without harm to human health. The multifunctional SMART cleaner is based on the existing and proven properties of UV light to ensure disinfection of not only air but also surfaces. The multifunctionality of the device is represented by different modes of operation and functionality, and the intelligent control unit provides wireless communication with the detection sensor and adjustment of operating modes and cleaning intensity. The properties and parameters of individual components of the device, as well as market research made it possible to assert that the device is effective and also meets modern requirements.

Keywords: UV · UV-C · IoT · SMART · Disinfection · Sensor

1 Introduction

Disinfection has become especially important in the current situation in the world. Despite the growth in demand on disinfection devices and antiseptic due to the pandemic in recent years, air purification becomes also needed. Air cleaning is actual not only in pandemic situation but also in ordinary life. Allergens, viruses are constantly present in the air and in order to limit the spread of opposing pathogens, it is worth preemptively using air purifying devices.

Every day, employees of any enterprise spend about 7 h a day indoors. Caring for employees and visitors of the enterprise is the primary task of not only the entrepreneur but also of the state.

In connection with the development of the pandemic situation in the world, the European Committee took measures, namely the creation of an Emergency Support Instrument (ESI) [1]. In general, the ESI represents a financial lever to curb the spread of coronavirus in the EU countries. The main assistance is provided in areas such as:

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– providing a vaccine,
– treatment,
– testing of patients,
– assistance in the transportation of essential items, medical teams and patients,
– provision of personal protective equipment,
– training of medical personnel and exchange of experience,
– UV robots for disinfection of hospitals throughout Europe [2].

Robots have long been used in many economic fields and therefore arose the idea to use them for disinfection. It did not arise by chance, since it is very important in a difficult pandemic situation to provide fast and high-quality disinfection of surfaces, and most importantly, in hospital wards. On the European Committee's website writes that "The Commission has allocated 12 million Euros from the Emergency Support Tool for the procurement of 200 UV disinfection robots that will be delivered to hospitals across Europe. The robots can disinfect standard patient rooms with UV light in just 15 min and represent an important an asset that can help hospitals reduce the risk of infection and contain the spread of the coronavirus [2]". This type of disinfection is very effective and not new at all. For the first time, the fact that ultraviolet radiation can be used in medicine became known in 1892. Then the practice was introduced to destroy bacteria and microbes using ultraviolet light. And in 1906, the first quartz lamp for medical use was created [3]. The process of using the lamp in some countries was called "Quartzization", which meant the process of processing (disinfecting) rooms, objects, the human body with ultraviolet radiation from a quartz or bactericidal lamp. As a result, infectious microorganisms [4]. Based on the above, it can be argued that the European Commission went through the use of time-tested technologies. Robots of this type began to be used not only in healthcare, but also in warehouses and even some banks [5]. As example, one of the banks, equipped robot with 100 W ultraviolet lamps, which, according to representatives of the Sberbank Robotics Laboratory, can effectively disinfect a room with an area of 20 m^2 in 5 min. And the robot can process 2500 m^2 overnight. The disinfector operates autonomously. When entering an unknown room, he first examines it, after which he can independently navigate and move around it. When a person is detected nearby, the robot immediately turns off the ultraviolet lamps. Sberbank notes that the new robot will be useful even after the COVID-19 pandemic - in particular, during seasonal outbreaks of influenza and SARS [5, 6]. The warehouse robot was equipped with four ultraviolet lamps that shine 360°. According to the creators, the robot manages to clean a 380 m^2 warehouse in half an hour and will destroy 90% of the particles of coronavirus on surfaces [5].

It is impossible to deny that this is a great idea, but still, it is a known fact that ultraviolet dysentery lamps have a detrimental effect on people's skin. The proposed studies are aimed at finding a similar solution but under different conditions, namely disinfection in the presence of people.

2 Literature Review

The World Health Organization (WHO) claims that air pollution has become the biggest environmental health threat, with about 7 million deaths in 2012 [7]. Indoor and outdoor

pollution affects health. Recent statistics on household indoor pollutants (HAP) exposure are alarming. The WHO HAP and Health Fact Sheet states that 3.8 million people die prematurely each year, including stroke, coronary heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer associated with exposure to indoor air pollution [8]. The use of air cleaners and filters is one proposed strategy for improving indoor air quality [9].

There are several types of air purification that have long been known and popular:

- recuperator [10],
- conditioners with cleaning function,
- stationary air purifiers.

The main cleaning components of such devices:

- carbon filter,
- dust filter,
- ionizer,
- UV lamp.

The main purpose of all these devices is to purify and circulate the air indoors. Sublett and James, in their article "Effectiveness of Air Filters and Air Cleaners in Allergic Respiratory Diseases: A Review of the Recent Literature" write that air filtration is often recommended as a component of environmental management techniques for patients with allergic respiratory diseases [11]. It follows from this that air filtration in residential premises can be provided by WHF through a home HVAC system, PRAC, or a combination [11]. But what to do in work areas, where filter replacement will be much more frequent than in residential areas and the flow of people is much larger. Sublett and James point out that currently popular ionic devices produce ozone, irritating to breath, and in one study caused an increase in submicron particles [11], which in turn proves that ionization is not an appropriate technology for high traffic.

Due to the difficult epidemic situation, the question arises: what type of filtration or cleaning helps in the fight against SARS-CoV-2. Many scientists claim that the virus is spread by airborne droplets and that there are people who carry the virus who do not have signs of the disease, but are its distributors [12]. It is difficult for employers to provide constant testing of employees, and even more so for clients. Constant testing would bring a lot of inconvenience and frustration on both sides.

In this case, the solution is to clean surfaces and air. Cleaning of surfaces is important, as microparticles breathed out by a person and those that are spread by touch remain on surfaces in the room. Air purification will help trap airborne particles and reduce the amount of bacteria deposited on the surface, thereby reducing the likelihood of inhalation of these particles or bacteria by a person in the room.

Christiane Silke Heilingloh and a team of scientists conducted a study involving SARS-CoV-2. Scientists have investigated the susceptibility of high titer SARS-CoV-2 virus stocks to combined or separate exposure to UVA and UVC [13]. Laboratory studies have shown that SARS-CoV-2 can be inactivated by UV radiation [13].

Song Tang and a group of scientists in their studies of the covid-19 and other groups of doctors and scientists have come to the conclusion that during a pandemic it is very important to use:

– masks,
– gloves,
– disinfectors and sanitizers [14].

Such precautions have long been used by doctors, even in peacetime. Wearing masks and fear of spreading bacteria is a lot of inconvenience. It is especially difficult to provide comfortable conditions for enterprises that continue to work in the same mode. Viruses, bacteria, allergens are always present in our life, and one method of air or surface cleaning is not enough. A well-known example is the ubiquitous pathogens of intestinal gram-negative bacteria such as Salmonella, Escherichia and Shigella, especially in summer, which continue to cause severe diarrhea infections worldwide. The food pathogen Listeria monocyogenes also has a significant impact on statistics, as it tends to develop serious diseases in people with weakened immune systems. Actinobacteria of the genus Mycobacterium are also a major cause of morbidity and mortality. Despite the development of medicine, the pathogens of the Mycobacterium tuberculosis complex remain one of the most serious causes of infectious diseases worldwide.

3 Methodology

The traditional methods of disinfection currently used have their limitations. Practical problems are known associated with damage to cleaning devices or cleaning filters, finally, the development of microbial resistance due to the long-term use of chemical disinfectants such as sodium hypochlorite, ozone and H_2O_2. Mycobacteria are inherently resistant to chemical decontamination because they have an unusual cell membrane containing peptidoglycan, arabinoglycan and mycolic acid, which restricts the passage of many chemicals and drugs through the cell membrane, which contributes to the resistance of this microorganism [15, 16].

In response to the persistent challenges posed by established and emerging pathogens and to provide complementary or alternative approaches to microbiological control, there has been considerable interest in new, alternative methods of disinfection and decontamination.

The problem of disinfection and cleaning from bacteria and viruses remains relevant, since each of the previously associated methods has its own disadvantages (Table 1).

Household stationary cleaners can help the spread of some particles, but alas, with a large flow of people, they are not very effective and they also lack a mechanism for adjusting the strength of air purification. The proposed studies are aimed at offering a universal smart device for continuous air disinfection not only in hospitals and medical institutions, but also in schools, canteens, restaurants, cinemas, theaters, etc.

Table 1. The main disadvantages of existing cleaning methods [10, 11].

Cleaning element	Disadvantage
HVAC system	Main task is climate control
PRAC	Requires constant cleaning
UV-A& UV-B	Causes oxidation of proteins and lipids resulting in cell death
UV-C	Adversely affects the skin Photochemical reactions in DNA&RNA resulting in inactivation of microbes and failure to reproduce
HEPA (High Efficiency Particulate Air) Filtration	efficient only to trap particles 0.3 microns and larger

This decision was made in connection with the difficult economic situation in all economic sectors.

The main problems of all of the above facilities are:

– continuous and uneven flow of people,
– the need for disinfection even in the presence of people in the room,
– adjustment of the intensity of cleaning depending on the number of people in the room.

If to turn to real devices on the market, can be distinguished four basic principles of interior air purification (see Table 2).

Table 2. Four main principles of interior air purificators [10, 11].

Cleaning element	Parameters
HEPA filtration	- efficient to trap particles 0.3 microns and larger, - can be incorporated into central HVAC systems, - energy-intensive technology, - is not effective on many mold spores, bacteria and viruses, - requires repairing of filters
UV purification	- Disinfects by passing air through ultra-violet light - can be incorporated into central HVAC systems - cleans only those surfaces and air that is directly exposed to UV light, - do not restrict airflow, - requires replacing worn bulbs

(*continued*)

Table 2. (*continued*)

Cleaning element	Parameters
Ionization	- Creates single polarity ionization to attract particles, - the single polarity will use any nearby surface as the needed opposite polarity and dust will be settle on it, - effective workable distance 8–9 inch radius, - energy-intensive technology, - mostly ineffective against bacteria, spores and volatile organic compounds, - can interfere with radio equipment
Dust collectors/filters	- Collect particles on a metal surface contained in the unit and produces single polarity ions, - ineffective against bacteria, spores and VOC compounds, - not integrable into other systems

According to the above properties (see Table 2) of cleaning elements, it can be argued that the most suitable are UV lamps, which not only disinfect surfaces but also the air, what is especially important in conditions of raging acute respiratory diseases and pandemic. It is a well-known fact that bacteria are transmitted tactilely, by air, and also have the ability to settle on surfaces and stay there for several months, and in such cases, UV lamps are used in hospital rooms [17]. This technology is widely used not only in laboratories, but also in operating rooms where the number of bacteria is reduced by 85%, and the number of infections by 73% thanks to UV lamps [17].

4 Proposed Solution

The control of purifier filter contamination is very important in premises with a large flow of people, especially if the enterprise works in three shifts. Deactivation of pathogenic microbes by UV light is the cheapest and fastest method of the so-called surface disinfection.

For example, standard disinfectant can be diluted at a 48:1 ratio. The cost for a gallon (3,78 L) of bleach is about US dollars 2,67 (Euros 2,22). That equates to US dollars 2,67 for 48 gallons (143,846 L) of solution (3,78 L). Typical retail disinfectants cover approximately 150–250 square feet (14–23 square meters) per gallon (3,8 L). Manufacturing facilities typically occupy about 15000 square feet (1393,5 m^2), which is 1393,5 L (3093,57 Euros). This significantly affects the overall cost of disinfection [18].

Under normal conditions, the working premises should be cleaned 3 times per shift. The enterprises have about 20 working days per month. Basis on this, the company will spend 3938,4 Euros per year on a 15 m^2 room of per year.

The proposed device serves a room with the same square, but at the same time its cost and maintenance are much cheaper and clean not only surfaces but also air. The cleaner needs to replace the lamps, where price of replacing such a lamp will be about 40

Euros. This manipulation can be made by any employee. The most sensitive component of the purifier is the UV lamp, where its working life is 8000 h, which is more than 1000 working days (over 2.8 years). Even assuming that all three lamps should be replacing at once, it will cost about 120 Euros.

Proposed device is not able completely exclude the need in cleaning surfaces by standard methods, but it able to reduce number of usual cleaning procedures, especially in room with a high level of pollution.

Construction of dust collectors, often represented by several filters (for different sized particles) embedded in the housing. This method of cleaning is not bad, but replacing filters directly depends on the amount of pollution in the air and the operating time of the device. The main problem is the lack of a filter clogging indicator (Fig. 1).

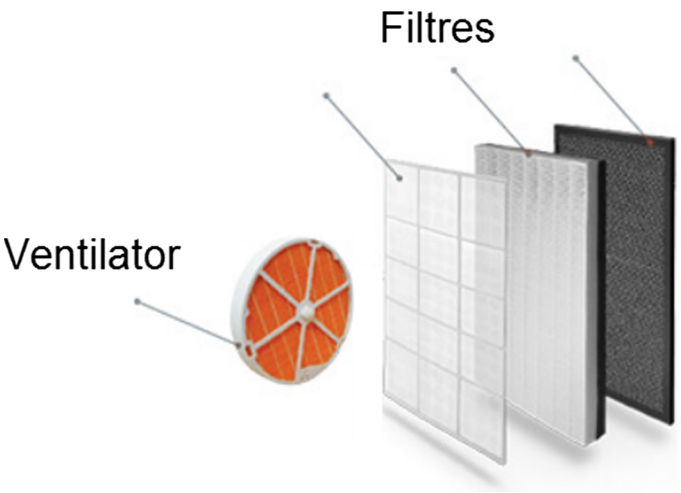

Fig. 1. General components of the HEPA air cleaner [19].

The design of filter air purifiers is represented by several filter plates and two fans or so-called "turbines" that move the air inside the air purifier structure. This design is very simple but effective.

Based on the specifics of the presented cleaners, the main requirements for cleaners that should be met:

– continuous disinfection;
– processing of the visible environment of the room and the invisible (air and surfaces);
– safety of use in the presence of people;
– effectiveness against a wide range of pathogens;
– Low operational requirements;
– The presence of a wear sensor of the working elements of the device.

To meet all the requirements, a device design was proposed (see Fig. 2).

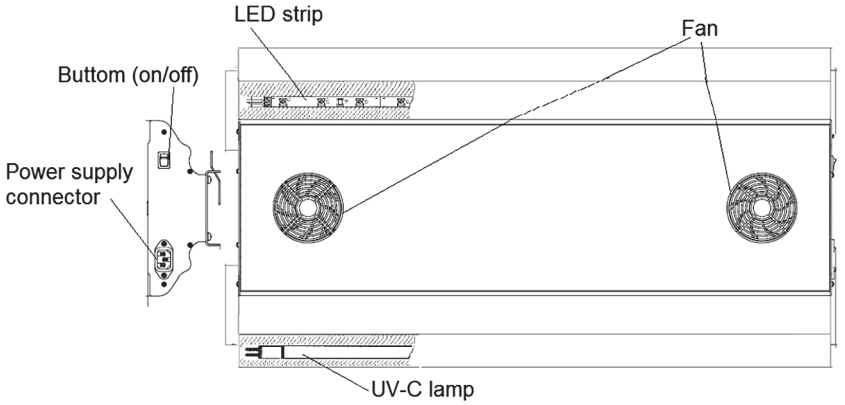

Fig. 2. Multifunctional SMART air cleaner

The main components of SMART air cleaner are: 2 fans, 3 UV-C lamps, cooling tubes, a central control unit for the device, 2 LED lighting strips and a separately mounted motion sensor (Fig. 3).

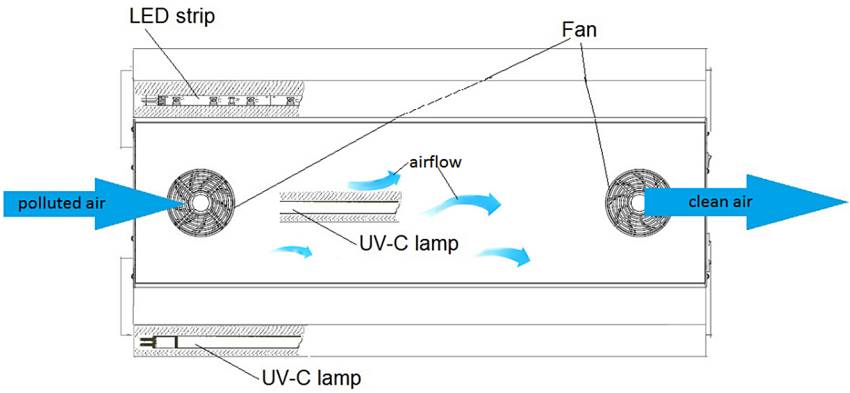

Fig. 3. Scheme of airflow in Multifunctional SMART air cleaner

One of the fans draws air into the device, the air inside the device flows near the UV lamp and is then expelled outside by the second fan. For the prototype, 16 V UVC lamps (G5) and a life cycle of 8000 working hours were chosen. This shelf life is quite competitive, since with a typical working day of 8 h/day and an average number of working days in a month of 22 days, it can be argued that the enterprise will not need to replace lamps for more than 3 years. But this is on condition that there are no drops in electricity. The fans are capable of handling 50 m^3/h at an average normal load. In order to correctly calculate the required power as well as the operating mode of the device, it was proposed to use the Smart control unit, which communicates with the detection (motion) sensor and determines the required power and frequency of switching on the device and transferring it to the surface disinfection mode.

The design of the device provides for several modes of operation:

1. LED lamp and air purifier.
2. Disenfector of surfaces.
3. Disenfector of surfaces and air.

The first mode is needed for normal office work with and/or without neighbors, i.e. provided that the employee is in the working area. In such conditions, the room is illuminated with light, and an internal UVC lamp is turned on for air disinfection.

The second mode is activated when there are no people in the room for surface disinfection. The light is off at this moment to save energy.

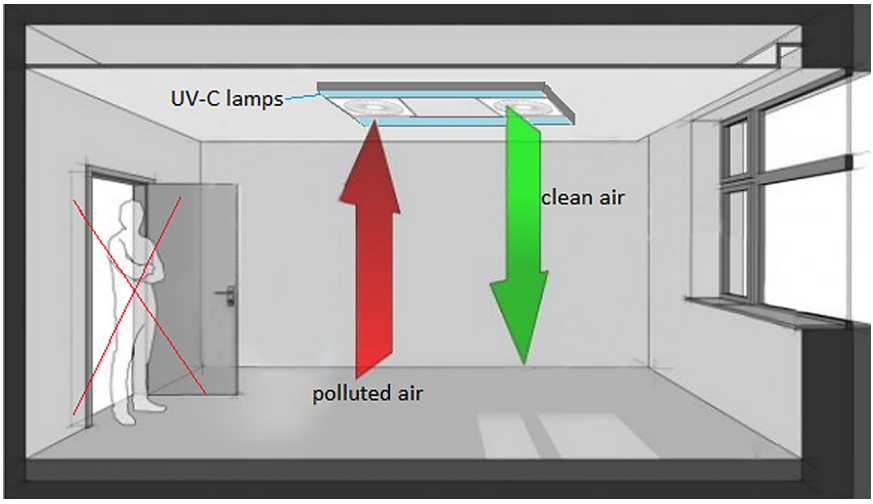

Fig. 4. Third mode illustration

The third mode (see Fig. 4.) appropriate when number of visitors was maximum and careful disinfection is needed. During third mode the LED light is turned off, but all UV-C lamps is in active mode to provide the best purification. Should be noticed, that when third mode is switched on, there should be no people in the room during disinfection.

Optimal control or switching of individual wavelengths of white, blue and UV light is ensured by the IoT smart control unit with external biosensors, sensors for detecting movement, the presence of people and the current light intensity to outdoor lighting conditions.

Device management is planned through a mobile application. This decision was associated with the spread of SMART home technologies as well as the Internet of Things. The sensor responsible for controlling the device modes was selected based on several criteria:

– - counting the number of people in the room,
– - wireless connection to the gravel device,

– - identification of people without a chamber principle in connection with the protection of personal data.

A conventional motion sensor does not detect the number of people in the room, but only reacts to movement and is not always correct. Due to the fact that there is a category of employees working at a computer and their actions, the sensor will not always be able to recognize as movements - this can switch the device to the surface disinfection mode and thereby harm a person or simply turn off the lighting in the room. In connection with this principle of operation of the sensor, it was proposed to replace it with a people counting sensor. This decision was due to the new rules introduced in many EU countries. These rules state that in connection with the pandemic, the number of people in the room is limited based on the size of the room. This rule helps not to load the cleaning device, as well as to notify employees through notifications when the number of people is already close to the boundary value.

As Khaled Al Huraimel and a group of scientists write in their article "SARS-CoV-2 in the environment: Modes of transmission, early detection and potential role of pollutions", the virus disease SARS-CoV-2 is influenced not only by the initial state of a person, but also by the quality of air [20]. This statement is applicable not only to coronavirus but also to other types of infections.

For laboratory testing was used sensor Count Max [21], which provides automated counting with infrared beam, where its accuracy up to 95% with a passage width of up to 2 m. Works regardless of changes in temperature, humidity, ambient light [22].

The horizontal infrared (IR) counter is the basic model for automating counting serving for registering the number of visitors; they are counting in two directions (entry-exit). Attendance data is accumulated in the sensor's non-volatile memory [21]. The rules say that for one customer should be allocated per 15 m^2 of the sales area of all operations in the department store intended for customers [23, 24]. Since the normal operating capacity of the device is 50m^3, it can be argued that the device will provide a comfortable working environment for four people. Thus, it was configured that when there are 4 people, the device will signal that the limit value has been reached.

5 Conclusions and Future Research

The multifunctional SMART cleaner helps to disinfect not only the air in the room but also the surfaces, as well as illuminate the room. Three modes of operation will help to effectively manage the device but also save on electricity thanks to the person counting sensor in the room. In the basic mode, it controls the optimal mixing of white and blue light in the presence of people in the room and, based on the number of people, maximizes the performance of the disinfection. The connection of the sensor and the purifier is performed by connecting to a common Internet network according to the principle of Smart Home devices. In further research, it is planned to develop a full-fledged mobile application with many functions for convenient control of the purifier. Instantly the device was controlled via the Internet resource similar to MI Home [25], which in the future will acquire more functions. In the basic mode, multifunctional SMART cleaner controls the optimal mixing of white and UV-C light in the presence

of people in the room and, based on the number of people, maximizes the performance of the disinfection. At the same time, in future studies, it is planned that the device signals the status of disinfection and stores information about the power of operation in disinfection mode in a given room at time intervals in the cloud storage. Data from the control unit will be saved via the IoT communication network (Sigfox, LoraWan) on a cloud platform from multiple control units for comprehensive monitoring of the entire building and disinfection status, as well as monitoring the presence or absence of personnel.

Since the idea of smart integrated control systems is constantly evolving, it is assumed that the proposed device will provide comfortable working conditions not only during a pandemic but also in peacetime and will meet all the requirements of our time.

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