SMALL-SCALE INFRARED FOG DETECTOR

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Abstract: *In the recent years, large improvement is being achieved in the area of decontamination by fog of environmental pollution caused by natural and industrial disasters or attacks with biological, chemical, nuclear weapons of mass destruction. Basic to this technique is the performance of sensors for the existence of pollution and fog in the environment. This article is going to present a small-size and relatively inexpensive instrument, developed by us, which purpose will be to alert the occurrence of visible pollution in air or mist. In that way, it can be controlled, too, whether the cleaning mist has reached all areas. It is possible, that this equipment would assess the density of fog. It works in the infrared spectral region.*

Keywords: OPTICAL SENSORS, FOG DETECTION,

1. Introduction

Environmental contaminations by biological, chemical, nuclear agents or toxic compounds due to industrial accidents, disasters, terrorist attacks, wars, etc. are usually spread by atmospheric dispersion. These harmful substances are usually dispersed as aerosols in liquid phase [1]. Recently the technique for effective decontamination of the pollution in the affected environment (indoors and/or outdoors) through spraying of fog is significantly improved in the framework of EU FP7 Security project COUNTERFOG [2]. Fog is an aggregation of microscopic water droplets spread in the air. The fog is able to sweep along different impurities – small particles, dust, different chemical compounds, etc. and to bring them to the ground thus decontaminating the area. The application of this technique requires sensors for continuous monitoring of fog. The ideal sensors should provide easy operation and the possibility for online control of both small and large areas.

Due to the presence of fog, composed of water droplets with a diameter only a few hundred microns, light scattering and reflection take place, resulting in signal degradation or complete prevention of light transmission through the environment [3]. Thus, the most widespread sensors for control of the presence of fog operate by measuring the medium permittivity. This is done in a number of ways: (a) by cameras that estimate the change in visibility as a result of the presence of fog or pollutants in the air [4], [5], [6]; (b) by light source (UV-IR) and a detector where the light intensity reaching the detector is less than the emitted intensity due to the light scattering by particles or droplets present in the optical path in the air; (c) by the use of LIDARs for surveying the environment [7]. The use of these sensors can be sometimes limited by relatively long sampling time, high price and high energy consumption.

To address these limitations, our team developed a simple and low-cost linear measuring system with high precision for quantitative assessment of disturbance effects on the quality of an optical signal transfer through optical line, called Fog Detector 1. It can be used to obtain results in relative values. Future calibration of the device can be performed.

2. Experimental setup.

The principle implemented in Fog Detector 1 is called “Transmission method”. The method measures how much light, emitted from a light source, is detected by a receiver located at a distance. In fog conditions, less light (compared to the clear optical path) will reach the receiver because of the scattering along the ray path. The reduction is used as raw data for straightforward calculation of the visibility. The attenuation of a light ray that is propagating through a homogeneous absorbing or scattering atmosphere can be described using an exponential function as:

$$I = I_0 \,.\, exp(-x.a) \quad (1)$$

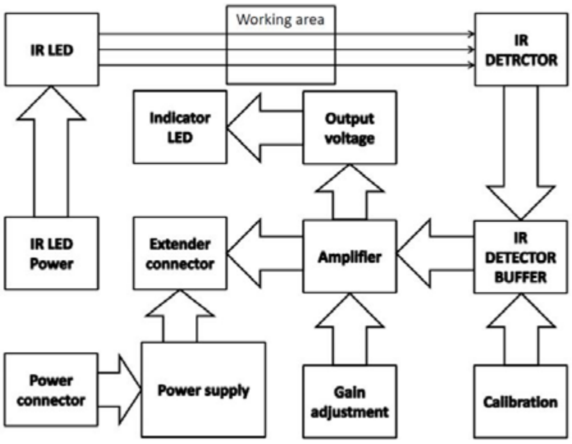


Fig. 1 *Block diagram of Fog Detector 1.*

where I_0 - is the intensity at a certain plane, x [m] - is the distance from that plane along the ray, a - is a constant [m^{-1}] that determines the attenuation.

In Fog Detector 1 we need relative results between different densities of the fog. In the laboratory experiments, the distance x is a constant. For relative results, it is enough to compare the difference between the results of the exponent part. It will not be a problem to transition from relative to real values when we have the results from Fog Detector 1.

A detailed block diagram of Fog Detector 1 is shown in Fig. 1. From the power connector, the device is supplied with stable +5V, which are used for powering the transmitter IR LED. The light from the IR LED is detected by a photo-transistor (IR detector) and the measured signal is transmitted to the buffer circuit. The buffer circuit is a high impedance operational amplifier with a gain equal to 1. The signal at the input of the buffer can be regulated through the calibration potentiometer. The purpose of that block is to reduce ambient factors such as light, temperature, humidity and etc.

After the buffer amplifier, the signal is sent to the main amplifier circuit. This circuit is a simple differential amplifier with the gain set by the switches of the 'gain adjustment' block. The reference input of the amplifier is connected to a stable reference voltage which is independent of the fog density. The output of the amplifier is connected to the extended connector and to the output for measuring. The indicator LED block contains a window comparator which is tuned for 1V to 1.1V output voltage. The LED will switch on only in that window. That guarantees that the amplifier works in its linear region. Fog Detector 1 has an analogue front end, which can be used with an external voltmeter or digital oscilloscope. The extender connector gives the ability of Fog Detector 1 to be connected to a microcontroller (MCU) module for displaying the information and/or calibrating LED transmitter. The MCU module is not a part of the current design.

Electrical schematic, which is an original design, is shown in Fig. 2.

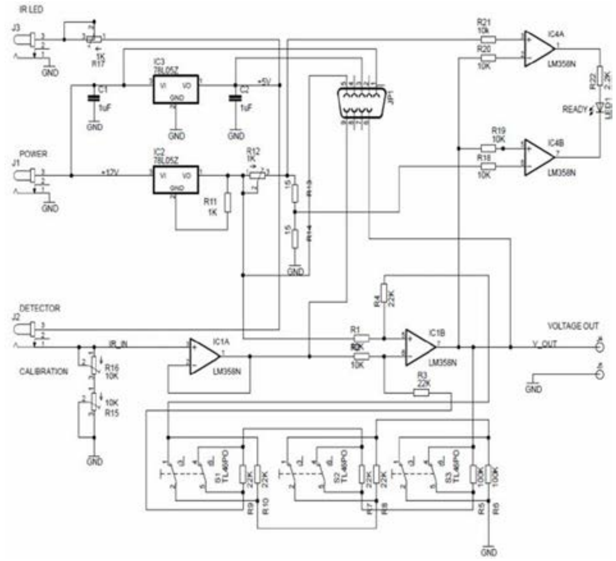


Fig. 2 – Electrical schematic of Fog Detector 1.

The main supply of the circuit (stable +5V) is contributed by the regulator circuit C1, C2, IC3. The operation amplifiers are powered directly from the power connector (+12V). The stable +5V is used for powering the IR LED through a current limiter resistor and also the photo-transistor (the +5V goes directly to the collector of the NPN photo-transistor, which is not shown on the schematic). The photo-transistor emitter (the second pin of the detector) is connected to the calibration circuit made by R15 and R16.

The photo-transistor emitter is connected to the buffer amplifier made by IC1A. The output of that amplifier is connected to the inverting input of the main amplifier circuit (IC1B), whose gain is adjustable through S1÷S3 and the corresponding resistors R5÷R10. The initial gain of the main amplifier is set to 2.2. When switching on the S1÷S3, we add gain to that initial gain. The non-inverting input of the main amplifier is connected to the reference voltage made by IC2, R11÷R14. That reference source is used also for reference by the window comparator consisting of IC4, R18÷R21. The window comparator is used to control the indicator LED. It turns on when the output voltage of the main amplifier is between 1V and 1.1V. Additionally, the circuit has extender connector for linking the device to a processor module. On that standard DB9 connector there are +12V, +5V, the reference voltage, the output voltage of the detector and the output voltage of the main amplifier.

3. Experimental testing and results.

Electrical simulations of the schematic itself were performed and the result can be seen in the graphs below. In Fig. 3 you can see the transfer function of the device without additional gain applied (S1÷S3 are OFF). On the ‘x’ axis you can see the input voltage from the photodetector. On the ‘y’ axis you can see the output voltage of Fog detector 1. The photodetector is powered by 5V, so the absolute maximum input voltage will be less than 5V, because of the voltage drop of the photo-transistor. The input voltage is inversely proportional to the amount of detected light. As you can see in Fig. 3, the output voltage is a linear function of the input voltage. (The input voltage is a linear function of the amount of light). This mode gives the ability to measure from 0% to 100% reduced visibility.

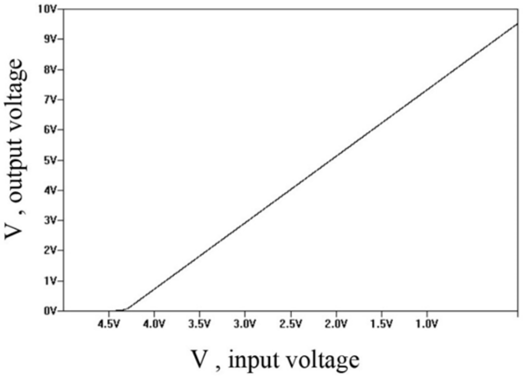


Fig. 3 – Electrical simulation without gain

For the purposes of the fog density measurements, additional gain should be applied to the circuit. The results are shown in Fig. 4. On the 'x' axis you can see the input voltage from the photodetector. On the ‘y’ axis you can see the output voltage of the device. A small change of the input voltage (amount of the light detected by the photodetector) results in a big linear change of the output voltage. This gain gives the ability of Fog Detector 1 to measure small differences in the optical ambiance of the working area, thus measuring the fog density.

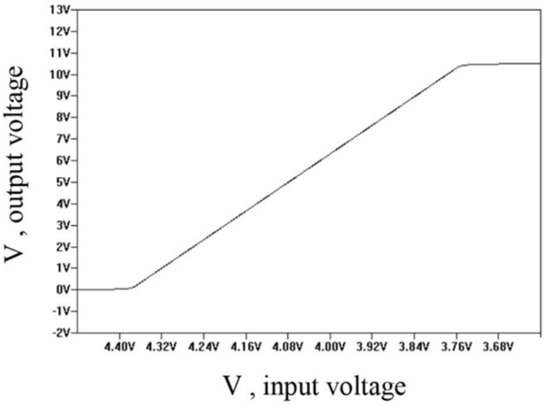


Fig. 4 – Electrical simulation with maximum gain

The mechanical description and connection diagram are presented in Fig. 5.

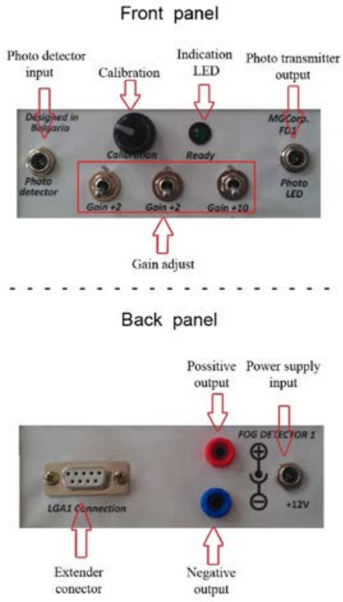


Fig. 5 – Mechanical description and connection diagram

4. Experimental procedure

For detection of particles in the air and qualitative evaluation of their diameter/density, Fog Detector 1 is connected to an optical system, Fig. 6. The system comprises of a rail with two optical stands and the emitter and detector placed in these stands. The distance between the emitter and the detector can be changed by sliding the moving stands.

Fig. 6 *– Measuring setup for Fog Detector 1.*

The light detector and the light emitter are both connected to the Fog Detector 1 front panel. The device has three gains to the measured signal and a calibration potentiometer. All of those are used to adjust the device in accordance with the environment under study. All possible variations of the gain switches can be used as needed. After each change in gain, calibration is needed. The optical stands are at a working distance between 35 and 100 cm. The measurement of fog can be performed in the range of 0 -100%.

The result giving the density of the fog is expressed as the difference in the output voltage (ΔU). The bigger the difference in voltage, the greater the visibility is reduced. The maximum output voltage depends on the gain. If for example, the instrument works without gains (0-100%) and after calibration the normalized voltage is 1V. Applying fog we get a reading of 3V. This means that the fog is: (((3V-1V)/(4.3-1))/1Gain)*100 = 61% (reduced visibility).

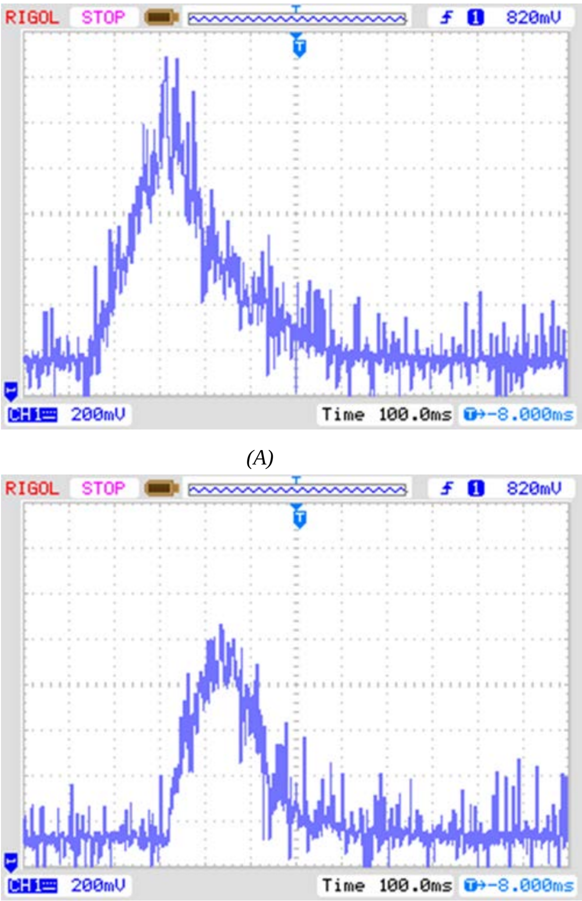
When working in mode „Fog detection“ the device lights up the alarm LED in the case that the input signal is bigger than a certain threshold for the range. After this even if the fog disappears, the LED blinks until the function is reset from the red button on the top of the module.

During measurements, the ambient illumination is of no difference to the measurements unless there are sudden changes or fluctuations. This is so because the instrument can be calibrated in accordance with the input signal, which makes such conditions correctable. It is also very important to note that under direct sunlight exposure, the receiver oversaturates and the device cannot be calibrated into a working range of values.

The speed of the measurement instrument is important. No matter the method of fog application, sometimes the voltmeter cannot react as fast as needed in monitoring the signal changes if the duration of presence of fog is less than 2 seconds. This can be avoided if an oscilloscope is used.

5. Experimental results

Fog Detector 1 has been applied to studying the diameter and density distributions of laboratory-made fogs. Here are presented results from the study of lab-made fogs with different average sizes of the droplets – Fig. 7. In Fig 7 the signal in the graphs is inverted, i.e. the stronger the signal, the greater the decrease in visibility. The generated signal is displayed versus time. It is seen in Fig. 7 that the fog with smaller average particle size generates a stronger reduction in visibility. This is explained by the higher number of particles present in the same control volume.



(A)

(B)

Fig. 7 *– Visibility measurement during spraying of lab-made fogs with different average size of droplets: (A) droplet size 65-70 µm; (B) droplet size 150-170 µm.*

6. Conclusions

A device capable of generating an electrical signal proportional to the fog density was developed. The mechanism of detection and the principles on which the device Fog Detector 1 is built are described in this report. It relies on light attenuation for detection of the reduced visibility. The circuit operation is based on a differential amplifier which amplifies the difference between the reference source and the measured light beam. It is an original circuit solution.

Acknowledgement

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