Use of Unmanned Aerial Vehicles for Monitoring of Air Pollution Generated by Stationary Sources

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Abstract: This paper is focused on the use of unmanned aerial vehicles for the monitoring of air pollution by stationary sources. A quadrocope with digital image capture was used for experiments. The data thus obtained was processed and the Ringelmann scale method for determining the darkness of the smoke plume was applied.. The values obtained are relevant and can be used to determine the rate of air pollution by a stationary source. The advantage of this proposed procedure are the low costs of realization and reduction of the influence of the human factor on determining the darkness of the smoke and finally no need for direct access to the stationary source of air pollution.

1 INTRODUCTION

The aim of the paper is to explore selected possibilities offered by unmanned aerial vehicle in the field of monitoring of small stationary sources of air pollution. It is a combination of two areas, namely the protection of the environment and unmanned aerial vehicles (UAV). Both areas evolve over time and it is only a matter of a relatively short period of time before they begin to mutually interfere and support each other. UAVs are multifunctional devices offering a wide range of uses, including in this area. In the experimental part, the possibility of using the UAV for data collection has been verified. For this purpose, several test flights were carried out, during which videos for subsequent analysis were made.

Based on legislation in the Czech Republic, the method of determining the darkness of the smoke is described. Ringelmann scale is used to evaluate data (Uekoetter, 2005). This is applied to recorded data using computer software. This is essentially a digital determination of the darkness of the smoke plume of a stationary source of air pollution.

Already today, using the UAV in the field of emissions monitoring is often considered. This specialized field is developing very fast. For example, the European Maritime Safety Agency deals with "Remote Pilot Aircraft System (RPAS) services in the maritime environment. RPAS has an on-board gas analyzer draws samples of air and monitors of SOx, NOx and CO_2 levels. However, this is a relatively expensive technology (EMSA, 2017). Another example is UAV based smoke plume detection system controlled via the short message service through the GSM network, proposed system consist of two parts: flying hardware and embedded kit for finding smoke plume. This system is dependent on the operation of GPS networks (Ramanatha, 2016). The aim of this paper is, among other things mentioned above, to show a very simple and inexpensive way to use the UAV for the detection and evaluation of air pollution. A micro UAV with standard camera and optics was used. We used the free software to process the data. The total cost of experiments (including UAV, insurance, pilot registration fees, flight fee, free SW) did not exceed EUR 1000. The economic aspect and the cost of UAV use is a very important factor in its wider expansion.

2 UNMANNED AERIAL VEHICLES

An UAV, sometimes referred to as a drone, is generally perceived as an unmanned aircraft. It can be controlled remotely at the pilot's eye or outside

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the pilot's reach. In some cases, the distance between the pilot and the drones may be several thousand kilometers, as is the case for military UAV. Another option is the autonomous movement on a previously planned route. Nowadays computer technology is at such a level that it allows a completely independent movement, which is, however, limited by the legislative conditions of operation. (Karas, 2016)

One of the biggest advantages over piloted machines is the lower cost of operation and acquisition of the machine. It cannot be said that this applies to all UAVs. Some are more expensive than ordinary planes. But with commercially available drones, it's a fact. If you need to scan a small area, deploying these resources is much more economical than conventional methods (Saadatseresht, 2015).

They are also a suitable solution if you need to scan or explore only a small area or area where the classic procedure cannot be used. Their further advantage is therefore the reach and permeability of the unfavorable terrain. If allowed constructively, they can start or land perpendicular, which can be used in places where such operations are not necessary for ordinary aircraft. (Rehak, 2012)

Another great advantage is maneuverability and safety. They can be used in natural disasters and other situations where rescuers, firefighters, etc. would otherwise endanger life. (Karas, 2016)

This contribution is also based on some articles on air quality monitoring. This is mainly research on the use of quadcopter for monitoring air pollution (Zhaoyan et al., 2017), and methodology for smoke detection and monitoring (Gómez-Rodríguez, 2002; Gómez-Rodríguez, 2003)

The disadvantage of drones can be flight time, low load capacity. This does not have to be the case for special army UAVs, which are able to use the combustion engines to travel to one tank for thousands of kilometers and can last for several tens of hours in the air. Commercially available drones are not capable of so long flights. There are dozens or hundreds of possibilities and ways to use the drones. Each field or profession brings another (d'Oleire-Oltmanns et al., 2012).

The UAV can be seen as a dynamic system that can be modeled and analyzed using various tools (Ibl, 2016). No unified international legislation exists for the operation of UAV. Therefore, it is necessary to read the laws for the airspace in which the flight is to be conducted before flight (Cracknell, 2017).

From the historical point of view, there has been and still remains the greatest benefit of an UAV for military and military purposes, whether used for protection, search and rescue of missing persons, monitoring, communications, exploration or as a weapon.

In recent years, UAV have become available to civilians as well. Due to their variability and features, the most common purpose of the job is to simplify work and cost effectiveness. They also provide the ability to represent a person in potentially dangerous situations, thereby contributing to increased safety. A wide range of applications also stems from the use of various special sensors.

All drones usage can be broken down according to the following division:

- Aerial photography
- Aerial video
- Aerial monitoring
- Space and terrain mapping
- Special applications in conjunction with special sensors
- Transport and logistics
- Entertainment (Rodríguez-Canosa et al, 2012.; Towler et al., 2012; Karas, 2016)

3 AIR POLLUTION

In each developed country, air pollution is regulated by the applicable law. This paper is based on the Czech Air Protection Act 201/2012 Sb.

The sources of air pollution by origin are divided into natural and anthropogenic. We mean natural sources that are not of human origin. This may be, for example, volcanic activity or dust storms. The other group is anthropogenic sources related to human activity, namely industrial and agricultural production, electricity and heat generation, transport and waste disposal. We have focused here on anthropogenic stationary sources.

Depending on location, we can divide our sources into ground, elevated and elevated. We also divide the sources of pollution according to their layout, point, line and bulk order. The point source can be, for example, a chimney.

A stationary source is, according to the Act on Air Protection, a stationary technical unit which is further indivisible and in which the fuels are oxidised in order to use the released heat.

The list of polluting sources and their categorization together with the requirements for individual categories can be found in Appendix 2 to the Act on Air Protection (The Act No. 201/2012, 2012). We place stationary sources in the following categories:

- Energetics - Combustion of fuels
- Heat treatment of waste, waste management and sewage
- Energy - others
- Production and processing of metals and plastics
- Processing of minerals
- Chemical industry
- Food, woodworking and other industries
- Livestock farming
- Use of organic solvents
- Petrol handling

In order to protect human health and the environment, limitations on the quantity of airborne substances discharged by stationary sources are established. These are emission limits, immission limits and emission ceilings (Jirava et al , 2010) . The degree of air pollution by smoke from a stationary source can be evaluated by means of a Ringelmann scale. This is a visual method where the observer visually assesses the darkness of the smoke plume at the outlet of the chimney. Ringelmann scale, which consists of six rectangular arrays (see Figure 1), each representing a given degree of darkness of smoke.

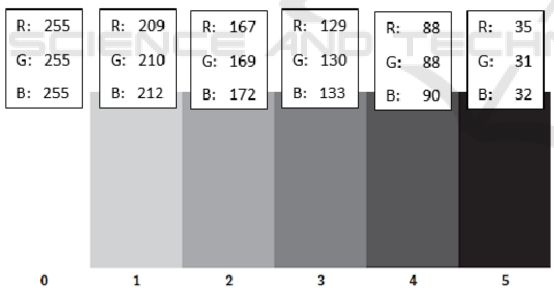

Figure 1: Ringelmann's scale with RGB values.

Grade 0 corresponds to 0% of black on a white background with definition. Reflectivity 80%.
Grade 1 corresponds to 20% of black on a white background.
Grade 2 corresponds to 40% of black on a white background.
Grade 3 corresponds to 60% of black on a white background.
Grade 4 corresponds to 80% of the black on a white background.
Grade 5 corresponds to 100% black on a white background.

4 EXPERIMENTS

The experiments and calculations performed were as follows. Firstly, UAV flights were conducted and data capture was performed using a digital camera. With the UAV, one stationary source of pollution was repeatedly scanned under different meteorological conditions. The obtained data was preprocessed and digitally processed (Panus and Simonova, 2005). The outcome was the determination of smoke darkness according to the Ringelmann scale.

4.1 Flights and Data Collection

For the experiments, conventional commercially available UAVs were used (Parrot AR Drone, 2017). This is a quadrocope controlled by smartphone or tablet (Benson, 2017). Communication of the control device (mobile phone) with the machine takes place via Wi-Fi, which limits the operating range to 50 meters. The UAV has the following features:

720p 30fps HD camera (4)
Photo format: JPEG
Connection: Wi-Fi
With internal frame: 380 g
With external frame: 420 g
Processor: ARM Cortex A8 1 GHz
RAM: DDR2 1 GB at 200 MHz
USB: High-speed USB 2.0 for extensions
Gyroscope: 3 axles, accuracy of 2,000°/second
Accelerometer: 3 axles, accuracy of +/- 50 mg
Magnetometer: 3 axles, accuracy of 6°

The take-off of an UAV was carried out on a private property with the permission of the owner and did not leave it for the duration of the flight. Also, safe horizontal distance from surrounding buildings and persons not directly involved in the flight was maintained. As a stationary source of air pollution a combustion boiler with a manual solid fuel supply was used, where the chimney mouth was on the same land from which the UAV was started.

The Figure 2 below shows a graph with the important flight data. The y axis on the left refers to the altitude of the flight. The second axis on the left shows the values related to the flight velocity in meters per second. The top speed that the UAV reached was 3.7 m / s, 13.3 km / h. The vertical axis on the right shows the percentage of battery charge. At the beginning of the flight, the battery was charged almost 80%. After five minutes, this value dropped by half. The time is captured on the x axis. According to the chart, the flight lasted for just over five minutes

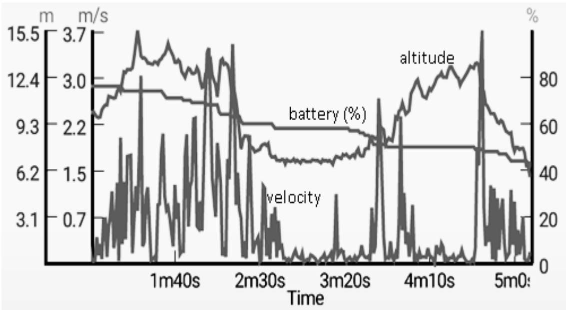

Figure 2: Flight data.

4.2 Data Processing

During the flight, a digital record of smoke plume was taken (Aber et al., 2010). Appropriate images were separated from it, as shown in Figure 3 (with free SW Avidemux 2.6). Subsequently, only the smoke plumes were separated (using free graphical SW GIMP v. 2.8.22). In order to determine the average values of the RGB components of smoke plume, it is necessary to place the smoke plume on a transparent background that does not affect the mean values of the individual component (realized with free graphical SW GIMP v. 2.8.22).

Figure 3: Digital image of smoke plume.

In the following figure 4, the smoke plume is excluded from five different pictures taken from one video. The interval between the slides is five seconds. For each of the smoke plume, the RGB values are determined by the procedure described above in this paper. In the table 1 are summarized outputs from one flight. In the first column is computed RGB value. In the second column is the closest grayscale from left (based on the Ringelmann scale). In the third column is the closest grayscale from right (based on the Ringelmann scale). In the last column is computed value for pictures a,b,c,d,e. The last row of the table is the total result.

a

b

c

d

e

Figure 4: Preprocessed smoke plumes.

Table 1: Computed values.

RGB values	Ringel. L	Ringel. R	Final value
a	0	1	
210,8 202,2 205,4	255 255 255	209 210 212	1
b	0	1	
229,0 221,2 212,9	255 255 255	209 210 212	1
c	1	2	
193,2 187,3 197,6	209 210 212	167 169 172	1
d	0	1	
239,8 232,6 228,8	255 255 255	209 210 212	0
e	1	2	
201,3 193,1 192,9	209 210 212	167 169 172	1
Final Ringelmann value			1

4.3 Discussion

The proposed procedure (see Fig. 5) appears to be applicable according to the obtained results. Digitization and computer processing minimize the impact of human factor on final results. These could, of course, be supported by other methods such as Gas chromatography, Dynamic Optochemistry, Gravimetric analysis, or Spectroscopy. These methods, however, require more complex and expensive devices (Wolf and Witt, 2000; SenseFly, 2011). Meteorological conditions also affect measurement. For example, strong wind gusts can not only affect the smoke plume but also endanger the UAV.

We believe that the measurements must be carried out by an authorized person. The question remains whether it is necessary for this person to be the pilot of an UAV or only to be present when carrying out the measurements. An operator could be another person who has all the permits needed to make a flight (licence). The officers of the competent authorities would not have to have the necessary pilot licenses at all. They would only perform their own measurements.

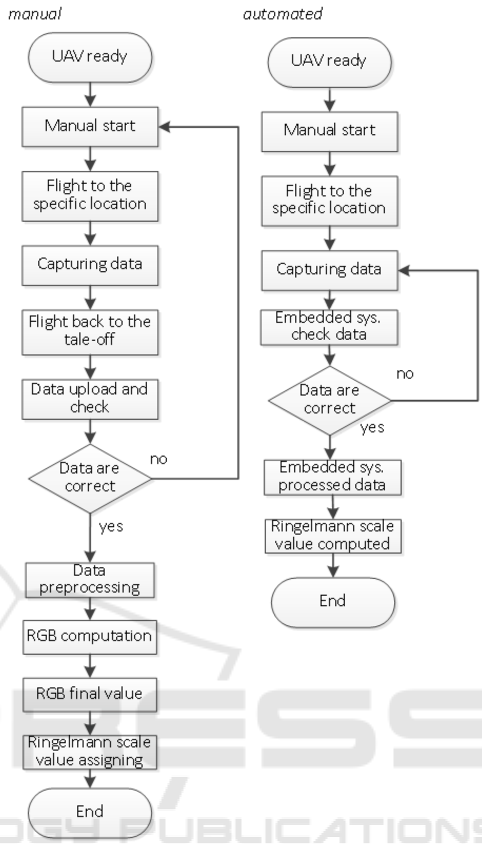

Figure 5: Experiments - block diagram.

5 CONCLUSIONS

In this work we dealt with the problem of determining the darkness of smoke plume from a stationary source of air pollution using the UAV. The smoke darkness can be determined using the Ringelmann scale. This process is usually realized manually and the measurement is thus largely affected by human error. The proposed procedure should eliminate this human error. The experiment was as follows (figure 5 - left side block diagram). First we collected data using UAV. The obtained digital records were pre-processed and modified for the RGB component decomposition. These were then compared with the Ringelmann scale using the software and finally the resulting value was assigned. In addition, this procedure does not require direct access to a source of pollution because it uses the UAV.

The whole process can be done by an embedded system on board of the UAV (see figure 5 – right side diagram). The results may be sent via GPS to the ground stations. But that is only the aim of future research.

A disadvantage may be the varying legal regulation of UAV issues in individual countries. The application of the method would thus have to be considered from the point of view of the country's legislation.

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