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Air pollution monitoring system in semi enclosed building for agricultural sector

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Air pollution monitoring system in semi enclosed building for agricultural sector

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Abstract: This article explains about the development of an optical sensor system to detect and measure ammonia emission in the agricultural field. At initial stage, an open path optical technique where a cylindrical chamber is used to detect low concentration of ammonia in the UV region. The methodology describing the working principle of the sensor and the wavelengths combination technique to enhance the Lower Detection Limit of the measurement. The result demonstrates that the developed optical sensor is able to measure ammonia concentration at around 212 nm. It also shows that by combining intensities at 2 adjacent wavelengths, the Lower Detection Limit has been improved to 2.25 ppm and 1 s response time is retained. Then the system is tested to monitor ammonia pollution in the cattle barn in Tipperary, Ireland. It shows that the developed system is able to detect and measure very low ammonia concentration which is below 2 ppm.

Keywords: optical sensor; ammonia measurement; emission monitoring

1. Introduction

There are numerous sorts of ammonia (NH_3) sensors which have their own favorable circumstances and problems and have been reported in details in another journal [1]. Nevertheless, only a few sensors can distinguish extremely low concentration of NH_3 (under 10 ppm) within a short time which is under 3 s. This is factual especially sensors that is dependent on solid state material, for example, semiconductors or chemi_absorbtion sensors. Moreover, an optical fiber-based gas sensor has a lot of advantages as far as low weight and little size [2], robust from high temperature [2-3], no interference electromagnetically, and able to do distributed measurement instead of a point sensing [4].

Exposure to high concentration of NH_3 can cause aggravation and serious burns on the human body and organs. Brief contact of NH_3 with concentration level from 2500 to 6500 ppm can even bring fatal to human[5]. As indicated by the Toxicological Profile for Ammonia gave by the U.S. Branch of Health and Human Services, NH_3 reacts promptly upon contact with accessible moisture on the human body, for example, skin, nose, eyes, throat, respiratory parcel, and especially mucous surfaces, to develop the acidic ammonium hydroxide [6]. Ammonium hydroxide causes the corruption of tissues through interruption of cell film lipids (saponification) prompting cell annihilation. As cell proteins separate, water is extricated, bringing about an incendiary reaction that creates additional harm.

In an encased structure, for example, in an animal shelter that is utilized to house animals, ammonia is created by the anaerobic procedure of manure decay. The level of concentration may approach or surpass the limit (greatest safe degree) of 25 ppm in an enormous swarmed unit particularly for pig cultivating [7-8]. The impacts of NH_3 for human health such as inward breath in encased structures are very much reported by Donham [9]. It is discovered that NH_3 concentration as low as 7 ppm in encased structures can cause respiratory side effects towards agricultural workers essentially because of their extensive and repeated exposure to it. There have been expanded recorded occurrences of interminable hack, wheezing, windedness, chest snugness, hyper-responsive aviation routes infection, incessant weakness, bronchitis, asthma and irritation of the eyes, sinuses, pharynx and nose [10-12].

Other than agricultural workers, NH_3 can likewise influence the animals' health. Urbain et al [13] found that a receptive nasal cell reaction in pigs when expose to 25 ppm of NH_3 for five days. The exposed pigs were additionally seen as clinically depressed and the development paces of the youthful pigs were decreased by 12 percent [14]. The impact of this NH_3 exposure can increase expenses of cultivating and degeneration of the ranchers' profitability. Hence, Dewey et al [15] recommended that continuous checking of NH_3 concentration in an encased structure is important to guarantee the soundness of the ranchers just as the animals.

2. Theory

Various gas species absorb light at various trademark frequencies and for NH_3 gas, it has its own particular gas absorption spectrum as detailed by Chen et al [16]. It shows that NH_3 gas has a couple of retention tops in the UV area. So as to accomplish NH_3 absorption cross section value, the Beer-Lambert Law has been used. The Beer-Lambert law portrayed the linear connection among absorbance and concentration of an absorbing species and its overall structure is appeared in equation (1)

$$\frac{I}{I_o} = e^{(-\sigma.N.l)} \tag{1}$$

Where I_o is the incident intensity, $l(cm)$ is the distance that light travels through the gas, I is the transmitted intensity, N (*Molecules/cm*^{3}) is the gas concentration and σ (*cm*^{2}*/Molecule*) is the absorption cross section. So as to mention the gas concentration in *ppm* unit, equation (1) is rewritten. Hence the derivation of the Beer-Lambert Law is shown by equation (2). The derivation details have been previously reported in journal paper [17].

$$ppm = \frac{-[\ln \frac{I}{I_o}][24.4]}{\sigma \times N_A \times l \times 10^{-9}} \tag{2}$$

Using equation (2), the NH_3 gas concentration can be precisely calculated if σ is known. This σ value changes based on the wavelength measured. This technique to get the NH_3 gas concentration was similarly reported in many journals [18-20].

3. Experimental Setup

The initial experimental setup is shown in Figure 1. The absorption gas cell, the spectrometer and the UV light source were linked using optical fibre cables equipped with standard SMA connector. SMA is a fibre optic coupling device and it also known as for Sub-Miniature version A. SMA connector is threaded to ensure the connection is intact. It is also small in size and it is mechanically tough. PVC piping tube is used to convey the gas from the gas tank to the absorption cell. The commercial metal connectors and fittings from Swagelok were chosen to join all pipelines. A laptop installed with the related software is function as a screen to display the measurement reading by the spectrometer. It is also used to control the Mass Flow Controller (MFCs).

The light is transmitted from Deutrium-Halogen light source and interact with ammonia in the gas chamber. Then the transmitted light is pickup by the spectrometer which served as a detector. The spectrometer is connected to a computer which has a spectrum software reading installed. Two optical cables are used in the setup to transmit the light between the light source and the detector. Mass flow controllers (MFCs) are used to dilute the ammonia concentration. A commercial ammonia sensor called Tetra is used in this experiment to validate the reading.

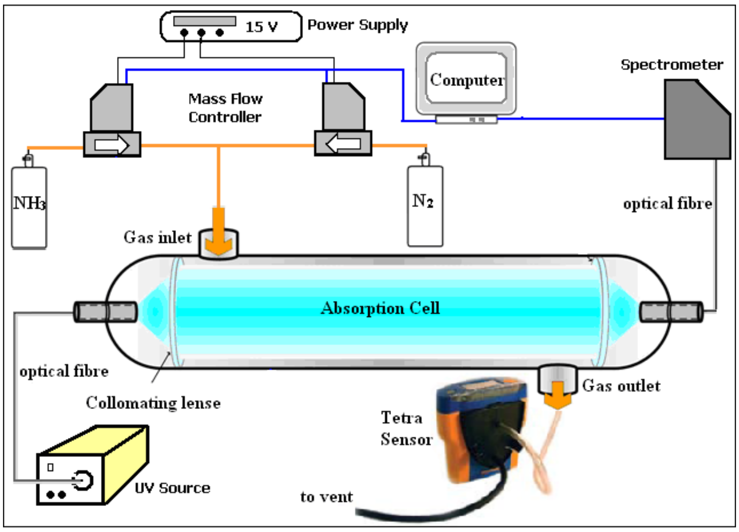

Figure 1. Laboratory experimental setup.

4. Results

In the initial experiment to quantify the NH_3 concentration, the developed sensor system has demonstrated that it is able to measure the NH_3 gas at various concentration and has been reported before in journal [21]. However, this sensor system reached only 9 ppm Lower Detection Limit (LDL). Therefore, it is still unconvincing to spot NH_3 gas in an open space especially at a farm where NH_3 gas may be exist at a very low concentration. Webber et al [22] stated that the maximum NH_3 concentration spotted in the naturally controlled compartment at a ranch for a two-day period was 8 ppm. Moreover, the NH_3 concentration sensed on day one by Webber et al was only at 3 ppm. On top of that, the detection is presumed to be conducted in summer season where the atmosphere is rich with NH_3 due to the raised temperature e.g. 22 ºC.

As stated by Yamamoto et al [23], the NH_3 concentration rises exponentially with increasing temperature. During summer, it has higher concentration and become lower during winter. Hence, an upgrading detection system with a better LDL is required. This is an initiative to provide a sensor that is capable to sense NH_3 in extreme climate conditions especially during winter. However, the improvement of LDL must hold the current sensor characteristic for example good response and recovery time. The trade-off between these two characteristics (response time and LDL) is difficult to be achieved. However, it is important step to enhance the performance of the developed optical sensor system.

4.1 Wavelength Combination

Combining the intensity measured at two nearby wavelengths is the early idea to improve the LDL. The method is to capture intensities at two wavelengths (212.5 nm and 212.7 nm) simultaneously. Before the two captured intensities are plugged into concentration equation (2), they are averaged in the first place. By averaging the intensities, the noise is getting lower. Hence, the standard deviation, σ are supposed to be lower which enhance the LDL. By the way, capturing intensities at two wavelengths concurrently will not deteriorate the response time of the optical sensor system.

The result for wavelength combination is shown in Figure 2. It is demonstrated that by combining two measured intensities at 2 adjacent wavelengths, the graph fluctuation can be lowered down. Before wavelength combination, the peak to peak (P2P) value is 12.8 ppm as shown in Figure 2 (a). This value is 3.45 times higher than the P2P in Figure 2(b) where wavelength combination technique was applied. The standard deviation of the zero-concentration state is reduced due to lower noise demonstrated in Figure 2(b). Therefore, the LDL of the sensor is improved to 2.25 ppm. This achievement is 75 percent better than the earlier LDL.

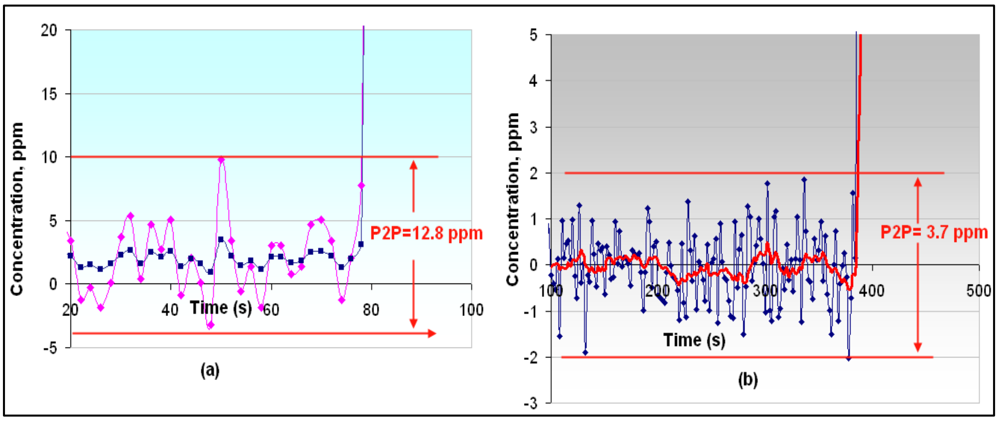

Figure 2. (a) Previous peak to peak (b) after combination of wavelength.

The improvement for the LDL is because the noise produced by the combined wavelengths is lowered down. The lowered noise is attained due to the peaks of the first wavelength, λ_1 intensities are combined with the troughs of the second wavelength, λ_2 intensities. This combination can yield the averaged intensities line which have lower fluctuation as shown in Figure 3. It shows that the averaged intensities for the combined wavelength produce a line with a lower fluctuation.

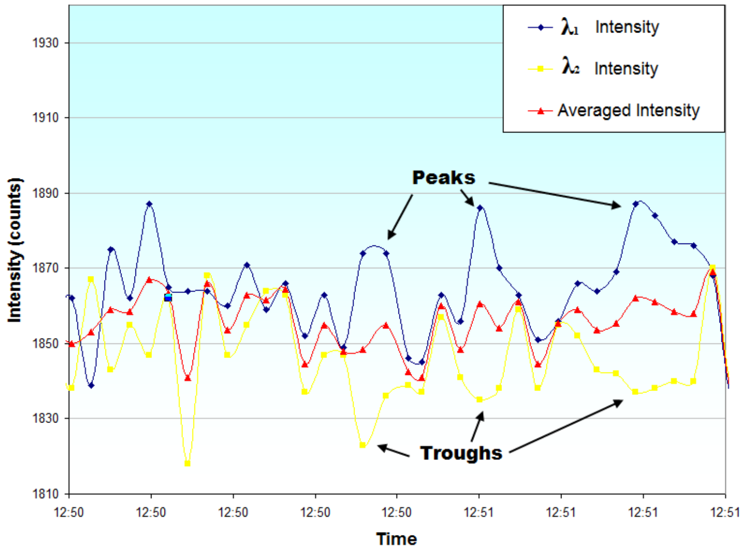

Figure 3. Peaks and Troughs combination.

4.2 Field Testing

Once satisfied with the sensor system on the LDL characteristic, on-site monitoring was carried out. The purpose for on-site monitoring is to justify the performance of the developed sensor system. On-site testing was conducted at a cattle farm located in the north of County Tipperary. Figure 4 shows the location on the map for experimental setup in the farm labeled with an 'A' balloon.

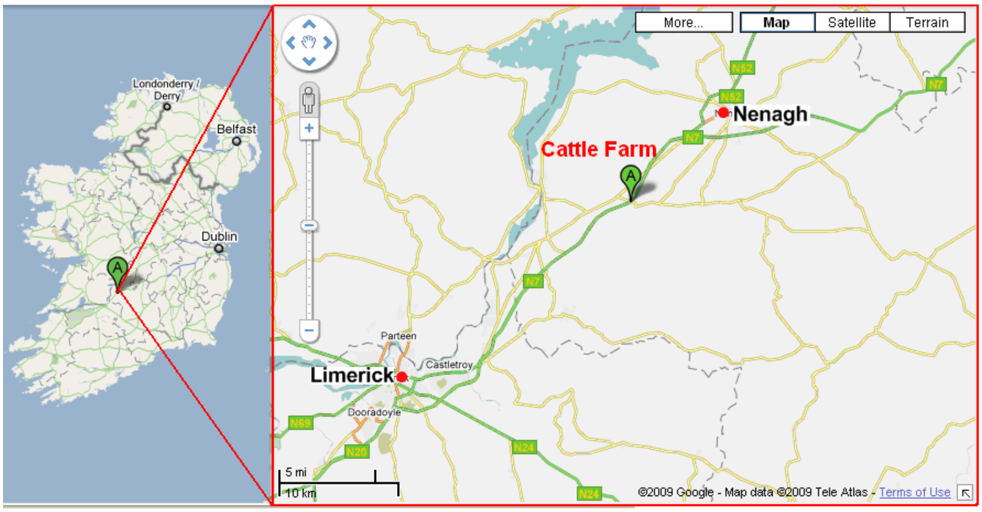

Figure 4. Location of the cattle farm.

There are four fenced sections that accommodate 22 cattle in a barn as shown in Figure 5. This site is suitable for field testing due to manure is everywhere on the floor. The barn size is estimated (20 x 30) m^2 with 5-6 *m* roof top height. Since the wall and roof are not properly sealed and there are many gaps, so the ventilation inside this barn is considered as good. Hence, the experiment performed is considered to be semi open-air environment because it is not a completely enclosed area. The cow dung, which is the primary source of NH_3, is well spread on the ground in the area where the cattle are sheltered.

Figure 5. Cattle barn.

The experimental setup for field testing is displayed in Figure 6. Yamamoto et al [23] reported that NH_3 is believed to be absent during winter or maybe exist but at a very low concentration. The experiment was conducted in a cattle barn for two days at the peak of winter. It is a good situation to carry out a very rigid test of the optical sensor system's ability to justify its performance. The first day was a bright day and the temperature was 3 ºC. The pressure was assumed to be at 1 *atm* as the farm is not at a high ground.

At the initial stage, the commercial sensor and the UV light source were switched on and it was left for 300 s to warm up. In the meantime, the LabVIEW program was turned on to display all the reading. Then, N_2 gas was released into the gas cell to clear the air in the absorption cell. Concentration of NH_3 will equal to zero after purging pure N_2 into the gas chamber and the averaged initial intensity, I_0 was recorded. Once I_o appeared on the screen, the developed sensor system is ready to detect NH_3 in the surrounding area.

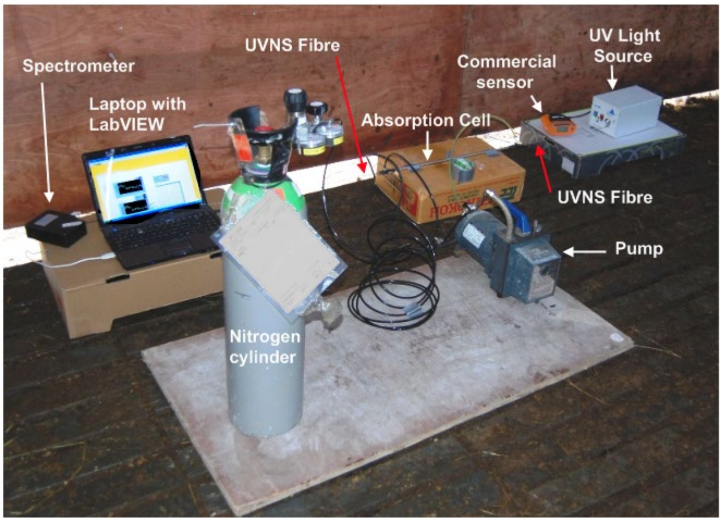

Figure 6. Experimental setup at the farm.

The concentration meter panel was viewed on the final page of LabVIEW program. The concentration meter on that panel showed zero concentration when N_2 gas was being purged. Once the pure N_2 gas is stopped, the vacuum pump is switched on. This step is to draw the surrounding air into the absorption cell. The concentration meter for NH_3 reading is immediately increased when the pump started to operate. It is hard to read the concentration amount because of the fluctuation of the meter needle in every 1 *s*. Nevertheless, the real time graph shows the fluctuating data with 10 points of moving average and in can be clearly seen the graph located next to concentration meter. It can be determined that approximately 2 *ppm* NH_3 present by looking at the 10 points moving average line.

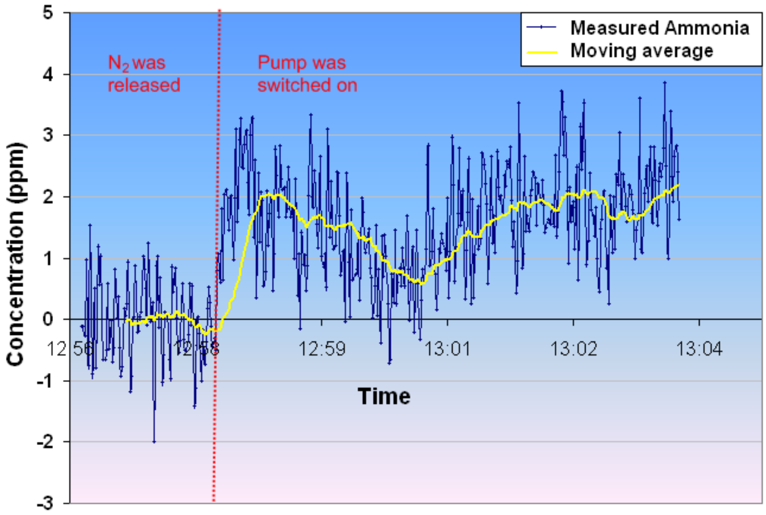

Figure 7. Farm result-Day 1.

The complete set of NH_3 concentration data were save based on the data that displayed while the experiment was carried out and the data was saved for subsequent analysis. Figure 7 shows the graph of NH_3 concentration versus time. Based on the graph, even at a very low NH_3 concentration the optical system can successfully detect the present of NH_3. The response time of this optical system when NH_3 was presented was 1 *s*.

On the next day, the experiment was repeated. The temperature on that day is around 0 *ºC* with the foggy air. It was snowing softly at the farm when the test was led and this compares to the most exceedingly awful climate condition situation for NH_3 measurement. But, this optical sensor system was able to detect 1 *ppm* NH_3. The result is shown in Figure 8. Simultaneously, the commercial sensor called Tetra unable to get any reading in a both experiments. Tetra failed to show any reading because of the very low concentration and not persistent of NH_3 existence in open air. It is found that, this commercial sensor requires a continuous exposure to NH_3 for more than a few minutes before it can detect low concentrations of NH_3.

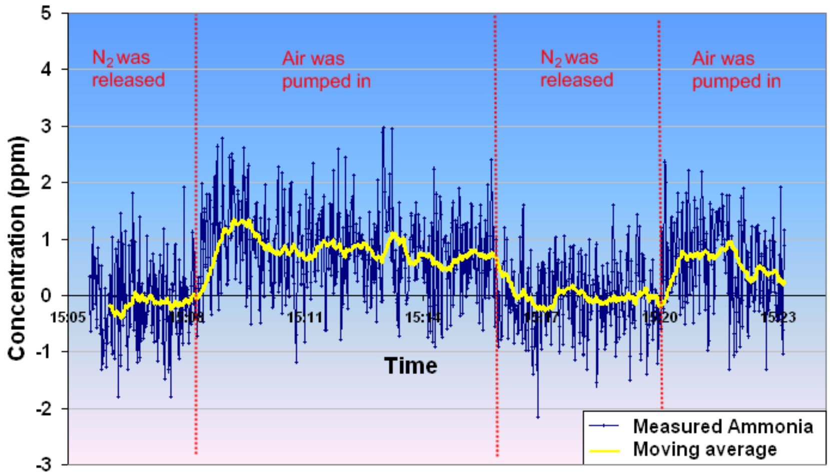

Figure 8. Farm result-Day 2

5. Conclusion

A sensor system for ammonia gas sensing and monitoring in the agricultural sector is presented. This system proves that, the optical system can monitor the concentration of NH_3 even at a very low concentration down to 2.25 *ppm* when measured at combined wavelength. This developed system also allows a real-time NH_3 gas detection at extreme weather condition. The system performed fast response time with immediate measurement which is 1 s and provides significant advantages over commercialize sensor especially for measurement of NH_3 in very low of gas concentration.

The sensor system was able to monitor NH_3 concentration of 2 *ppm* in real-time and it is proved by a monitoring test in cattle barn. The demonstration shows that this system has an ability to monitor low NH_3 concentration in a real environment. It is a vital step to provide a monitoring system particularly in semi confine space like a barn with a single NH_3 gas detection to reduce the air pollution from agricultural sector. Certain parameters on monitoring system can be improved for a future work in order to test this system in various type of environment.

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