Development of a portable, multi-channel olfactory display transducer

J.A. Covington, *Member, IEEE*, S. Agbroko, *Student Member, IEEE*, and A. Tiele, *Student Member, IEEE*

***Abstract*—In this paper we report on the development of a simple, yet innovative multi-channel olfactory display. Unlike other sensory stimuli (specifically sight and sound), digital olfactory technology has yet to have wide-spread commercial success. Our proposed system will release up to 8 different liquid phase aromas (essential oils) using a thermal mechanism. The unit contains a speed controlled fan, temperature control of the heating element and a gas sensor to provide feedback to inform the release rate. It can be connected (via Bluetooth LE) to a tablet/computer to control the timing and intensity of the aroma. External measurements show that aromas can be detected within a few seconds of release and produce a broad range of intensities from low ppm to 10's of ppm.**

***Index Terms*—Aroma generator, digital olfaction, olfactory display.**

I. Introduction

THE field of olfaction has remained one of the most underdeveloped technological areas in our modern digital world. Though there have been significant advances in the way that information is presented to us as digital users – be it through visual or audio means, olfaction still appears to be a technology of the future. The reasons for this are complex and potentially associated with a mixture of factors, including the dominance of our other senses, poor training of the population in olfaction and a feeling that it is not an important sense. However, olfaction has the ability to enrich visuals and provide easier access to parts of our brain associated with, for example, long term memory [1].

The potential applications for olfactory technology are significant and range from medical applications to virtual reality (VR). This could include helping with anxiety/stress or in the diagnosis of degenerative disorders such as Parkinson's disease. In tourism/museum environments, smells can be used to compliment sound and vision effects of historical sites to re-live the past. Other applications include VR and multimedia to enhance gaming, television entertainment and beyond. There have even been attempts to create communication protocols based on gas phase chemical transmission instead of electrical [2]. Considering these applications, it is surprising that olfactory displays are not common throughout society and found in every home. There are a number of potential reasons for this, but one major gap is the lack of a simple, robust digital olfactory technology. These technologies should not be confused with most existing aroma approaches, such as air fresheners, perfumes (with paper smelling strips) or even candles, but are distinct in being able to provide a range of olfactory experiences controlled in a digital way. Unsurprisingly, there have been a number of attempts to produce such digital olfactory displays. The first works were associated with the addition of aromas in cinemas (so-called AromaRama) in the 1960s, which sprayed perfume from seats in an auditorium. At the same time, Morton Heilig brought out the Sensorama – the first full VR system [3]. Neither of these products were a success and olfactory displays were limited to scratch cards till the late 1990s. Here, the iSmell system by Digisense was proposed, with 128 key odorant markers. The company folded a few years later without bringing a product to market. Since this period, there have been a plethora of aroma based products, such as the Aromajet Pikolo, NTT Com Aroma Geur (for sending aroma emails), TriSenx Smell Dome (which became the Ozmoose personal diffuser) and ScentSciences Scentscape, to name a few. Aroma has even been integrated into mobile phones, with Samsung, Motorola and Hyundai integrating aromas into phones to allow sending of "smell messages". However, only Sony ever released a smell phone, SO70i, which used scratch and sniff approaches to release aromas [4]. More recently, there have been devices produced by Dale Air (Vortex USB), Scentee (plugs into the speaker socket on your mobile phone) and oNotes (Cyrano). These devices are commercially available (though not worldwide) and have partial digital control, but low integration with digital technologies. Finally, there have been VR aroma generators proposed that integrate into headsets, examples include the "Nosulus Rift" plug-in (Oculus Rift parody for South Park game) and Feelreal. However, these are not currently commercially available and have been in development for a number of years. Finally, (and unsurprisingly), the sex industry has utilised this technology to create "OhRoma", a face mask based system that replicates various "sex" smells. However, again, this product is not commercially available at this time and is unlikely to achieve widespread use [5].

Paper submitted 23rd October 2017. We would like to thank the Royal Academy of Engineering for supporting this project.

J. A. Covington is with the School of Engineering, University of Warwick, Coventry, CV4 7AL UK (e-mail: J.A.Covington@warwick.ac.uk).

S. Agbroko. is with the School of Engineering, University of Warwick, Coventry, CV4 7AL UK (e-mail: O.S.Agbroko@warwick.ac.uk).

A. Tiele. is with the School of Engineering, University of Warwick, Coventry, CV4 7AL UK (e-mail: F-A.Tiele@warwick.ac.uk).

Though it seems that there have been a huge range of developed products, this is the collective commercial activity of the past 70 years and the total number of available devices is still surprisingly small. To this end, due to the lack of commercially available technologies, our group has attempted to develop a simple olfactory display that other groups could construct and use for their own needs. This paper reports on our efforts to construct such a system.

II. Olfactory Aroma Generation

A. *Aroma Dispensers*

A key consideration is how to contain and then release the aroma (which we describe as the “aroma dispenser”). At present, most easily accessible/available aromas are in a liquid phase – be it perfumes or more likely essential oils. The latter is particularly appealing as there are a broad range of oils with different aroma properties. These can be purchased from a range of retailers and are generally regarded as safe for the public. Within the research community, there have been a number of different aroma dispenser approaches that have been proposed. These have mainly focused on five different methods, covering:

- Inkjet printing technologies [6]
- Piezoeelectric/surface acoustic wave [7]
- Air cannon [8]
- Pumps and valves [9]
- Thermal/heating [10]

In our drive to create a technological solution that is easily accessible to others, the first two options were discarded due to difficulties in design and manufacture. In fact, those working in this space have often collaborated with a commercial printer manufacturer; however, they have yet to realize a commercial solution. The air cannon option is a very interesting solution, but only deploys a single aroma and would be complex for multi-aroma applications. Valves/pumps work well and are widely available, but are generally expensive. For this reason, our aroma dispenser was based on a thermal/heating approach. This is the simplest and lowest cost option to construct an aroma generator, with the additional merit of being soundless (due to a minimal set of mechanically-moving parts). The disadvantage of this approach is that some chemical compounds are destroyed in the heating process, which can limit the range of odour materials [8]. However, it still remains a good solution in using essential oils.

The aroma dispenser used in this project was based on a combination of capillary action and a thermal heating element. 5 ml vials were sourced from Supelco Analytical and fitted with a screw top lid with a PTFE septa seal. Two 2 mm holes were machined through the seal, into which two glass capillaries were inserted. One capillary was cut at around 4 cm and the other around 1 cm. Nichrome (NiCr) wire was fed through the capillaries and coiled inside the longer capillary and then fed back through the short capillary. This process gave a total heater resistance of typically 9 Ohms. The arrangement is shown in Figure 1.

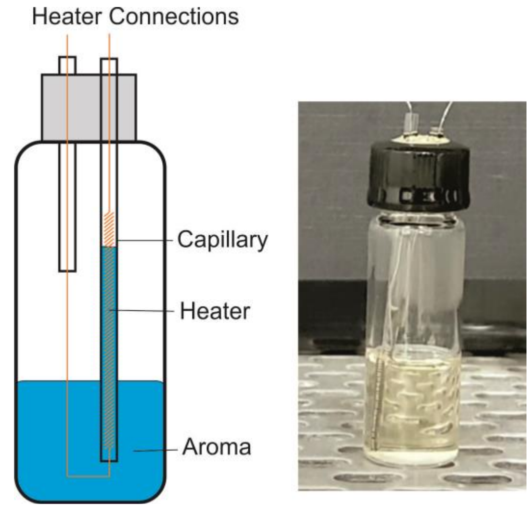

Fig. 1. Capillary arrangement for the aroma dispenser.

B. *Aroma Unit*

The aroma dispensing units were fitted into a custom PCB and operated from a 9V supply. The unit was designed to hold 8 aroma dispenser units, which kept the size of the final unit manageable. The heating element was controlled using a simple bang-bang controller (using a high-sided switch, a VN7040 with an on-state resistance of no more than 40 mOhms). This IC is driven through a I2C I/O expander (MCP23008), which controls all 8 aroma dispensers. The temperature was monitored by measuring the resistance change of the heating element. A small value load resistor (1Ohm) was added to the circuit to measure the current through the heating element, from which the resistance was calculated. This voltage was measured using a 16 bit ADC (an ADS1115). Figure 2 shows the aroma dispending drive circuit.

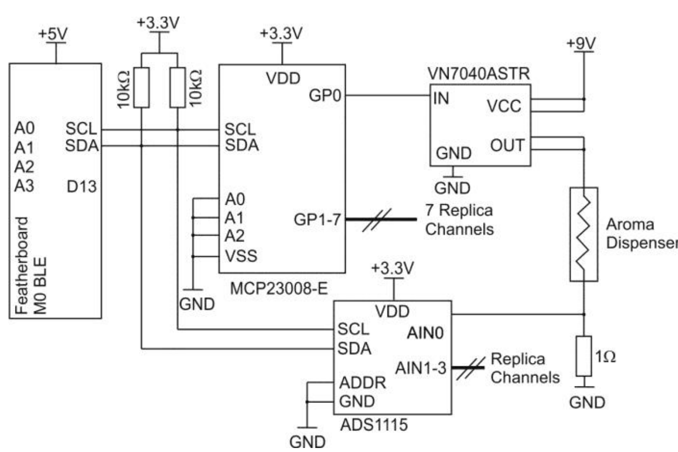

Fig 2. Aroma dispenser drive circuit.

The unit also contained a speed controlled fan (SanAce40, Sanyo Denki, Japan) and a metal-oxide gas sensor (AS-MLV-P2, AMS, Germany). The fan speed was controlled using a pulse width modulation (PWM) approach, with a fixed oscillation frequency of 25 kHz (using an LTC6992, which uses a voltage input to set the mark/space ratio). This voltage is provided by the analogue out on the microcontroller. The fan also produced a PWM output of the read speed which was monitored to ensure the functionality of the unit. This was achieved by simply using a low pass filter and then using the microcontroller to measure the resultant voltage. Figure 3 shows the circuit for the fan.

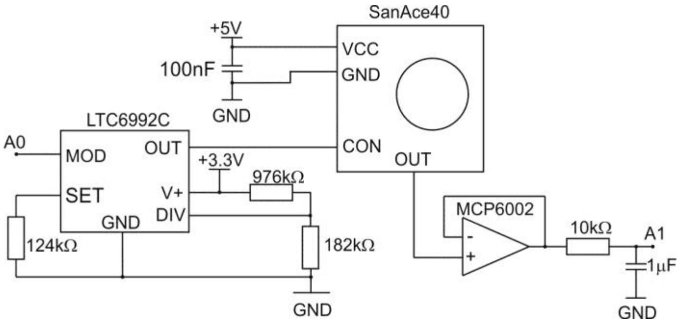

Fig 3. Fan control and measurement circuit.

The gas sensor is driven/controlled using the general configuration supplied by the manufacture (PWM heater drive with a potential divider for the sensing element) and has a clean air resistance of around 200 kOhms, using the microcontroller directly to control the PWM speed and the marks/space ratio. The VN7040 was used again as a high-sided switch to control power to the heating element. Figure 4 shows the circuit used.

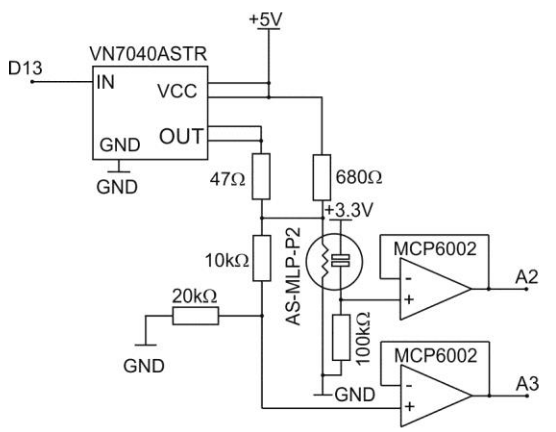

Fig.4 Gas sensors drive circuit

The unit is driven by an Atmel AMDSAM18G M0 microcontroller, which has a 14-channel 12-bit ADC (analogue to digital converter) to monitor the output from the gas sensor and the fan speed. The microcontroller was purchased as a development board produced by Adafruit (Featherboard M0 BLE, US). As the change in resistance will be small from the heating element (NiCr has a low temperature coefficient of resistance), a high resolution ADC is required. Figure 5 shows the internal configuration of the unit.

Fig. 5. Internal PCB of aroma generator.

The unit has also been fitted with a Bluetooth LE module for communication. Therefore, it can be controlled wirelessly using Bluetooth or through a wired USB connection. By being able to accurately set the temperature of the heating element and the flow rate through the aroma generator, we are able to have some control over the aroma concentration provided to the user. The unit itself is fitted into a tube, which is 75 mm in diameter and 250 mm in length, with plastic end caps. Figure 6 shows the final aroma generator.

Fig. 6. Final aroma generator.

C. *Aroma Control Software*

To control the unit, a custom software interface was created, as shown in Figure 7. This was written in C# using Visual Studio (2017) to create a Universal Windows Platform (UWP) app that can be installed on any Windows 10 device. The interface can communicate with the aroma generator via Bluetooth LE. The low energy Bluetooth allows continuous high bitrate communication with less power consumption. The current version of the software allows the user to select one or more aromas to be dispensed, adjust the fan speed and change the aroma intensity. This is shown in Figure 8. Information on the state of the unit is streamed back to the interface for the user to monitor.

Fig. 7. Aroma Generator with control software on Acer Tablet.

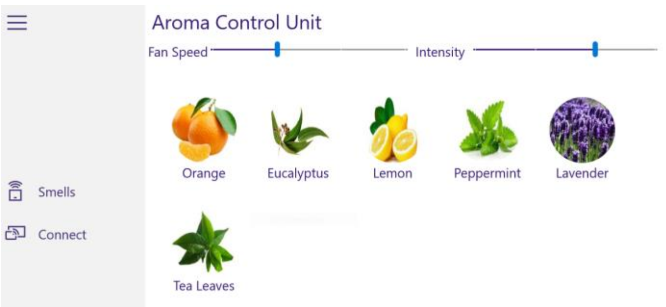

Fig. 8. Aroma control software interface.

This version of the software uses six aroma channels. The intention is to keep one or two free channels for dedicated cleaning cycles. The clean is simply water vapour released with high fan speed and is used to remove aromas from previous runs. Figure 9 show a flow chart on the interaction of the user with the system.

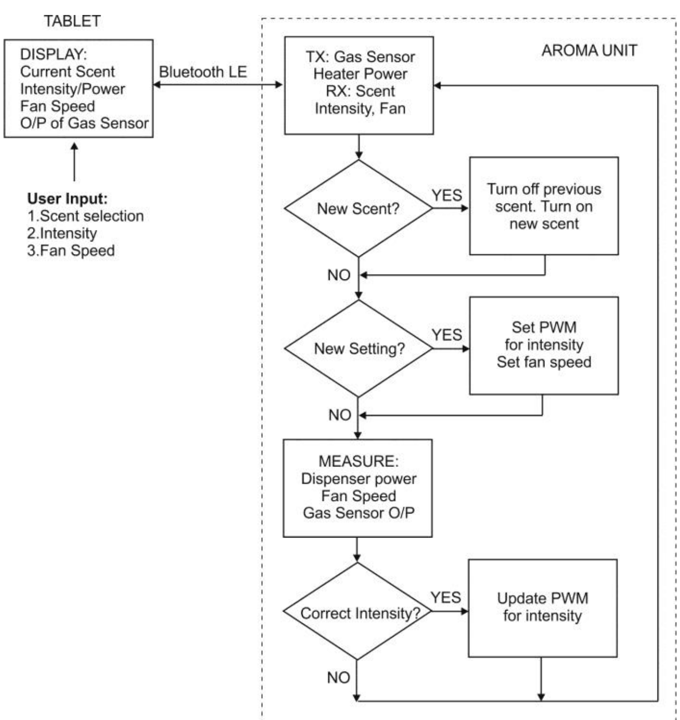

Fig. 9. Flowchart showing the operation of the software.

III. RESULTS

A. *Heating element efficiency*

Initial experiments focused on ensuring the efficacy of our heating approach and time response. Figure 10 shows the change in resistance of a heating element when 9V was applied (≈12W), without PWM control. The essential oil used in these experiments was peppermint with a total volume of 1.5 ml in the vial. This result showed that the heating element reached maximum temperature after around 6 seconds. The heater resistance was calculated by measuring the voltage drop over the heating element and the current through it.

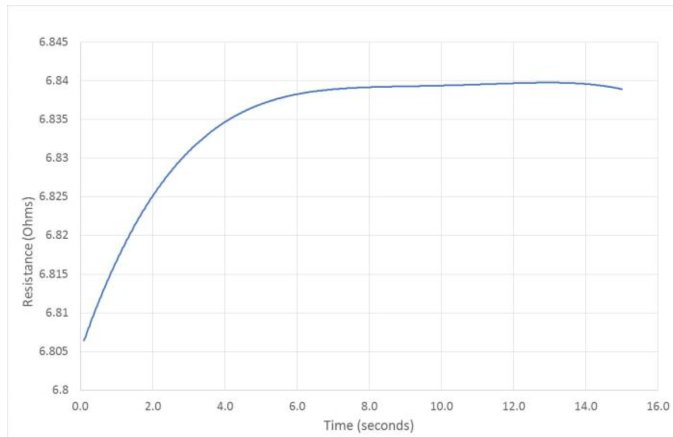

Fig. 10. Change in heater resistance.

By 6 seconds, the aroma dispersers gave off large volumes of vapour that could easily be detected by the human nose. These experiments were repeated multiple times with different aromas, with very similar results. Once validated, we then investigated the output of the aroma unit. The unit is programmed to have three different intensities: high, mid and low. The intensity values were set empirically through user testing. The fan was also programmed to have four settings (low, medium, high and off). The AMS gas sensor fitted inside the unit was also tested (located at the vapour exit of the unit). In this example, grapefruit and cinnamon oil were used, again with 1.5 ml of liquid in the vials. The unit was set to mid-intensity and the sensor output was measured. The output is shown in Figure 11.

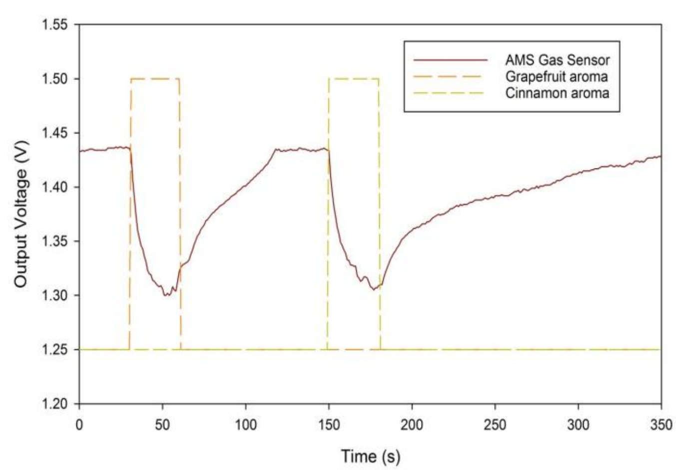

Fig. 11. AMS gas sensor response to grapefruit and cinnamon aroma.

The results indicate that the gas sensor is able to measure the change in environment after aroma release. The sensor follows a typical power law response to chemical concentration and the two oils produced a similar result sensor response (though different user experience). Interestingly, the sensor showed different recovery periods. This indicates that some molecules will be more "sticky" than others and the time taken to clear out of the system.

The output of the unit was independently calibrated using a commercial VOC detection system (Volatile Organic Compounds, Tiger, Ion Science, UK). This gives an indication of the total VOC (in ppm) as produced by our aroma generator. Initial experiments used the PID to calibrate the internal gas sensor. Figure 12 shows the output of the system to a 60 second pulse of cinnamon oil. The results indicate that the gas sensor output is not as accurate nor as responsive as the PID. This was expected as the Tiger gives a linear VOC output and the gas sensor follows a power law response. It is interesting to observe that when the fan is set high and the heating element is turned off, there is a short, high intensity pulse of aroma as the inside of the aroma generator is flushed out. It also shows that the gas sensor gives a good indication of the length of time before the system is clean and can be used for further aroma releases.

Next, we investigate the effect of distance from the aroma generator to the concentration experienced by the user. As the user will not be in direct contact with the generator, we are interested in the delay before the user can experience the aroma and at what intensity this would occur. Figure 13 shows the Tiger output measured 10 cm, 20 cm and 30 cm away from the unit, using a mid-setting. As expect, the further away from the unit the user is, the lower the concentration of aroma is experienced.

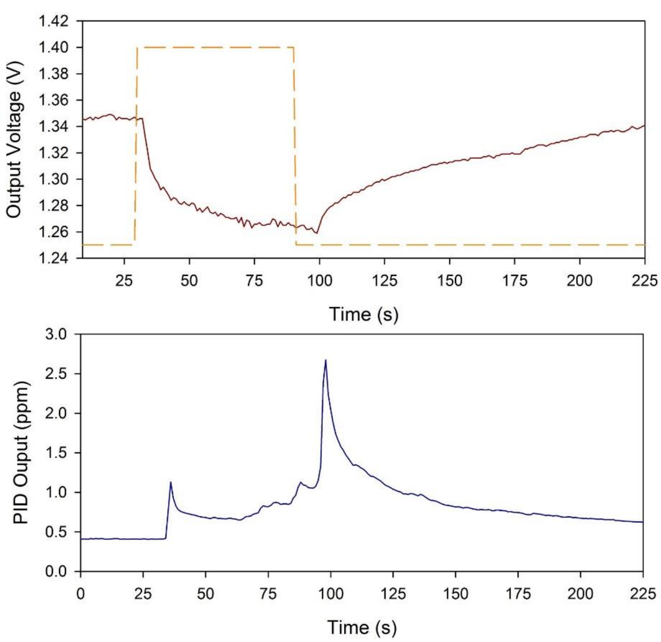

Fig. 12. AMS gas sensor and Tiger PID output to a pulse of cinnamon oil.

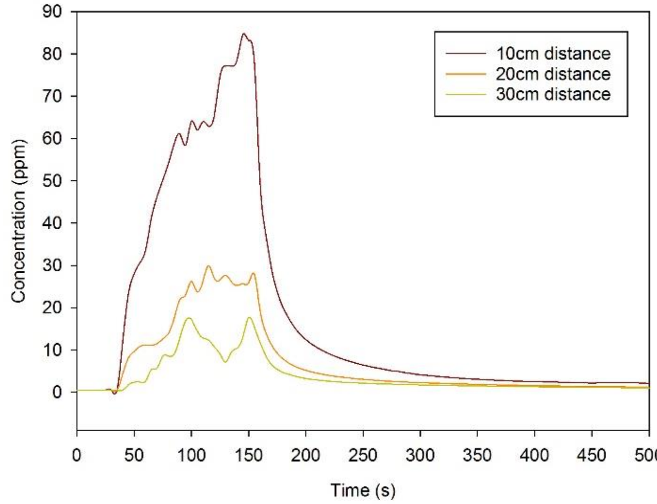

Fig. 13. Tiger PID output to a pulse of peppermint oil, at 3 distances.

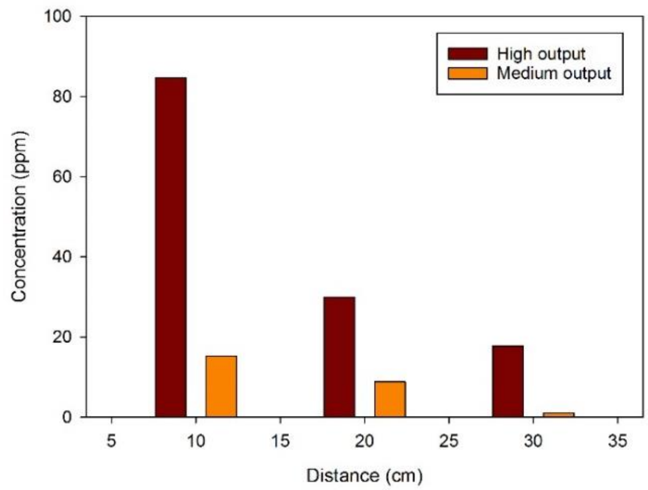

Fig. 14. Effect of distance and settings on output concentration.

Figure 14 shows the effect of varying the distance and output settings. The results demonstrate that we are able to have some control over the aroma concentration provided to the user.

Lastly, we investigated the reproducibility and accuracy of the system. Figure 15 shows the Tiger output to a 30 second pulse of peppermint oil. The pulse was repeated three times and measured 20 cm away from the unit, with high intensity and medium fan speed settings.

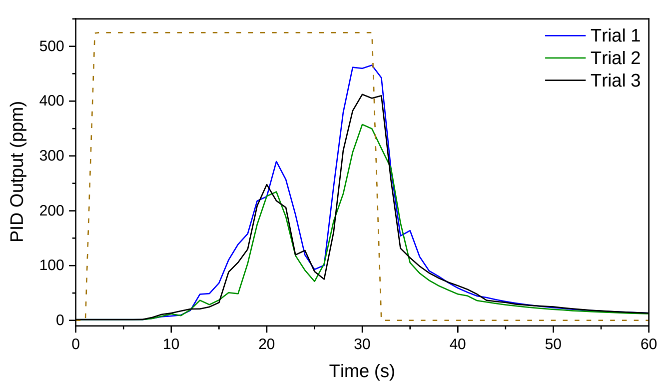

Fig. 15. Reproducibility and accuracy measurements using peppermint oil.

The results demonstrate that we have good control over the aroma pulse. Two peaks are observed for each trial. The first peak occurs during initial release of the aroma, as the heating element starts to heat the peppermint oil. After 20 seconds, the measured intensity drops before rapidly increasing again. At this point, the liquid oil is heated to form a high intensity mist. The maximum intensity peaks range from 350-450 ppm, which creates an approximately equivalent perceived odour. The heating element is then switched off and the fan flushes out the remaining aroma in 15-20 seconds.

We believe that by controlling the heater power, fan speed and turn on rate of the release mechanism we will be able to control the aroma delivery rate for different applications and locations. Clearly, the amount of aroma required will be a function of room size, user location (for example, watching television will be different to a user interacting with a computer display), how rapidly the aroma can be dispersed and what level of aroma intensity is required for a specific application. Our system can switch between aromas within a few seconds, however, in practice it takes a little longer for the previous aroma to clear around the user, before being presented with a new smell. In our user trials, the subject sat in a normal lab environment, around 20 cm away from the generator unit. The smell dissipated fairly rapidly (less than 30 seconds), though there was positive air movement in the lab. The use of an app to control the aroma release makes it simpler for the user to operate. This can be easily integrated into a mobile phone or other portable device. However, there is still work to do in integrating aromas with sound and vision. We are now investigating how this can be done and will be running larger user trials of the equipment.

IV. Conclusion

In this paper, we show our current work in developing a simple, portable computer smell/aroma generator for use in a range of entertainment applications. The present unit holds 8 different liquid phase aromas (in our case essential oils) that can be released by the user through a computer software interface. The release mechanism is a thermal heating approach and is used in combination with a capillary tube inside the aroma dispenser. In the future, we will be connecting our system to a VR configuration to evaluate its effectiveness when undertaking real olfactory display tasks with users.

References

[1] D.A. Wilson, R.J. Stevenson, R.J., "Learning to smell: olfactory perception from neurobiology to behaviour", 2006. JHU Press.

[2] C. Marina, J. W. Gardner, Z. Ráczu, S. Pathak, T. C. Pearce, J. Challiss, D. Markovic, A. Guerrero, L. Muñoz, G. Carot, B.S. Hansson. "Biomimetic insect infochemical communication system." In Sensors, 2009 IEEE, pp. 1358-1361, 2009.

[3] H. Rheingold, "Virtual Reality", Summit Books, 1991.

[4] Y. Yanagida, "A survey of olfactory displays: Making and delivering scents" Sensors, IEEE, pp. 1-4, 2012.

[5] G. Devashish, M. Sajwan. "Aroma Tells a Thousand Pictures: Digital Scent Technology a New Chapter in IT Industry." International Journal of Current Engineering and Technology 4, no. 4, pp. 2804-2812, 2014.

[6] S. Sugimoto, D. Noguchi, Y. Bannnai, K. Okada, "Ink jet olfactory display enabling instantaneous switches of scents" Proc. 18th ACM Int. conf. on Multimedia, pp. 301-310, 2010.

[7] S.H. Abid, Z. Li, R. Li, J. Waleed, "A Novel Olfactory Displays' Scent Dispersing Module", Int. J. of Hybrid Information Technology, ACM, 8(1), pp.435-442, 2015.

[8] Y. Yanagida, S. Kawato, H. Noma, A. Tomono, N. Tesutani, "Projection based olfactory display with nose tracking". Virtual Reality, Proceedings. IEEE, pp. 43-50, 2004.

[9] T. Nakamoto, M. Kinoshita, K. Murakami, A. Yossiri, "Demonstration of improved olfactory display using rapidly-switching solenoid valves", Virtual Reality, IEEE, pp. 301-302, 2009.

[10] D. H. Kim, Y. H. Cho, K. Nishimoto, Y. Kawakami, S. Kunifuji, and H. Ando, "Development of Aroma-card Based Soundless Olfactory Display," Proc. 16th IEEE Intl. Conf. on Electronics, Circuits, and Systems (ICECS), pp. 703-706, 2009.

James A. Covington, received his BEng 1996 in Electronic Engineering at Warwick University and remained their receiving his PhD 2000. His PhD was on the development of CMOS and SOI CMOS gas sensors for room temperature and high temperature operation. He worked as a research fellow for both Warwick University and Cambridge University on the development of gas and chemical sensors. He was appointment as a lecturer in 2002 in the School of Engineering, University of Warwick, being promoted to Associate Professor in 2006 and is now a Professor in Electronic Engineering. He heads the BioMedical Sensors Laboratory, School of Engineering. He has authored or co-authored over 150 technical papers and patents. His current research interests focus on the development of micro-analysis systems, electronic noses and ratification olfaction, employing a range of novel sensing materials, device structures and micro-fabrication methods for applications with the environmental and medical application domains. More recently, based on his experience in gas sensing, applied these skills in developing olfactory displays and related aroma based technologies.

Samuel O. Agbroko is a PhD student at the School of Engineering, University of Warwick. He received his bachelor's degree in Mechanical Engineering from University of Benin, Nigeria in 2010 and his MSc in Mechanical Systems from the University of Warwick in 2013. His areas of interest include mechatronics, digital and analogue electronics, embedded systems, software development, and emerging gas sensor technologies. His current research focuses on developing novel gas chromatography ion mobility spectrometry devices and software for biomedical applications.

Akira Tiele is a PhD student at the School of Engineering, University of Warwick. He completed his Master's degree in Electronic Engineering (Hons) at Warwick in 2016. His research focuses on methodological considerations and applications of clinical breath analysis. Other research interests include the development of gas analysis devices for indoor air quality (IAQ) assessment, agricultural monitoring and aroma generation.