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A Conceptual Design for Smell Based Augmented Reality: Case Study in Maintenance Diagnosis

Jeff Wang[a*], John Erkoyuncu[a], Rajkumar Roy[a]

[a]*Cranfield Manufacturing, School of Aerospace, Transport and Manufacturing, Cranfield University, Cranfield, MK43 0AL, United Kingdom*

* Corresponding author. Tel.: +44 (0) 1234 750111 Ext. 3354; fax: +44 (0)1234 758292. *E-mail address:* Jeff.Wang@cranfield.ac.uk

Abstract

The trend of Industry 4.0 encourages the next generation of manufacturing to be flexible, intelligent, and interoperable. The implementations of the Artificial Intelligence (AI) technology could potentially enhance maintenance in efficiency, and accuracy. However, it will not be a substitution to the human operator's flexibility, decision-making and information received by the natural five senses. Augmented reality (AR) is commonly understood as a technology that overlays virtual information onto the existing environment to provide users a new and improved experience to assist their daily activities. However, AR can be used to enhance all human five senses rather than just overlay virtual imagery. In this paper, a design and a practical plan of smell augmentation for diagnosis is initialised, via a case study in maintenance. The aim of this paper is to evaluate the feasibilities, identify challenges, and summarise initial results of overlaying information through smell augmentations.

Keywords: Augmented Reality (AR), Smell Augmentation, Maintenance

1. Introduction

In today's competitive business environment, the current progress of Industry 4.0 pushes the boundaries of data science and encourages the next generation of manufacturing to be flexible, intelligent, and interoperable. Industry 4.0 uses different technologies to make each manufacturing process more productive, such as internet of things (IoT), augmented reality, cloud computing and cyber-physical computing [1]. Augmented Reality (AR) refers to a technology that can allow the user to see, hear, touch, smell and taste things that others cannot [2]. But more commonly, AR is understood as a technology that overlays virtual information over the real-world objects to create imagery illusions for user to simulate with. On the other hand, many researchers have shown the possibilities of applying AR to other senses rather than visual based information.

As the physical and digital worlds merge, the future manufacturing process is changing dramatically towards intelligence and automation. The AI-powered machines are designed to be a collaborative community, which the future manufacturing process would potentially be using AI-powered machines to assist human operators to produce desired outcomes and humans will be mainly focusing on the operation management. For example, the car manufacturing industry adopts automotive robots (AI technology) to reduce production time on their assembly line. The implementations of AI-powered machines will enhance the manufacturing process in terms of efficiencies, accuracy, complex functions and reduce operating expenditure. AI-powered machines programmed all existing scenarios with their corresponding solutions that aimed to function in automatics and machine learning from new possibilities [3]. However, the AI technology in manufactory will not be a substitution of the human workers,

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because the machine is only capturing, analysing and processing data in an algorithm form [3], and still lacks the abilities of flexible decision making, that uses human five senses and require human to manage the captured data.

The sense of smell is 10,000 times more sensitive than any other senses that the olfactory response is immediate, extending directly to the brain [4]. The Laboratory of Neurogenetics and Behavior department of the Rockefeller University has shown researches that humans can discriminate more than 1 trillion of olfactory stimuli [5], which means that human nose would be 150,000 times more sensitive than eyes (high end visible colour of 7.5 million) and million times more sensitive compare with ears (4000Hz) [5]. The sense of smell is a chemical sense that uses the neuron system to detecting thousands of different chemical molecules that are vaporised and floating in the air, it reach the nostrils and dissolve in the mucus (which is on the roof of each nostril) [5]. This is important for smell augmentation since the olfactory bulbs and limbic system are strongly connected that the sense of smell are imposed with emotions and memories, and also modify conscious thought and learning [4]. However, due to the difficulty of detections and analyses chemical data that there is a research gap of smell augmentation tracked by sensory detections. This paper used a case study to initialise a design and a practical plan of smell augmentation for maintenance diagnosis. The aim is to evaluate the feasibilities, identify challenges, and summarise initial results of overlaying information through smell augmentations.

2. Related work

AR combines the real world with the virtual world to provide a live form of computer-generated graphics, which has been understood as a technology that uses virtual imagery illustrations to overlay over the real environment that digitally enhance user's performance [2]. People can experience AR through Handheld AR equipment (Android smartphones and Apple's ARKit), HMD (Head-Mounted Display) headsets (such as Microsoft HoloLens and Meta 2), Optical head-mounted display (Smartglasses and Data Googles), and environmental AR (Kiosk Systems and interactive AR-Installations) [6]. AR is capable to apply to many different applications, such as education, automotive, entertainment, manufacturing, medicine, architecture, [6] etc.

On the other hand, many researchers believe that AR can be used to overlay information using all other senses as well rather than only visual based. For example, Azuma has mentioned in his review of AR that "almost all work in AR has focused on the visual sense: virtual graphic objects and overlays. But augmentation might apply to all other senses as well." [7] Lindeman and Noma summarized a classification of the existing and envisioned techniques for the sensory modalities AR [7] (see Table 1.). But the issue of the mentioned Multimodal Augmented Reality techniques in this table is that overlaid visual information are restricted to exist with each senses' application, and must be as realistic as possible.

Hanna Schraffenberger el at (2016) has listed a few examples of multimodal AR and suggested that users should be able to experience AR even with their eyes closed [8]. It is agreed that "Virtual content can take non-visual and multimodal" [8]. This is because the multimodal simulations of AR system is created by sensors that captures the real life surroundings; use interfaces to register user's inputs; a computer processor to analyse and calculate data and use interfaces to output the data and information. It is a life circle of the HCI (Human computer Interaction) [9]. Therefore, it can be applied to any kind of input sensory data only if the system recognises and it is able to analyse such inputs, link and extract from the existing database, and instruct the interfaces to provide the correct corresponding outputs. However, current literatures have not shown a clear definition of Multimodal AR, but according to the definition of Multimodal HCI and multimodality [9] that the Multimodal AR can be defined as use multiple inputs and outputs to augment a particular sense.

Table 1. A classification summary of the existing and envisioned techniques for AR across Multiple Sensory Modalities by Lindeman and Noma [7]

Location Of Mixing	Visual	Audio	Haptic	Olfactory	Gustatory
Environme nt	Optical see through (HMPD), projecto rs	Speake rs	3D Printer	Odour Emitter, Air Canon, Wearable	Food-Mixing Device, Edible Bits
Sensory subsystem	Retinal Display	Acousti c-Hear Throug h	Actuated Stylus, Heat Pad, Vibrotact ile Suit		Taste-Tube in Mouth
Computer	Video See Throug h	Microp hone-hear-Throug h	Exoskelet on	Mask-based Display	Feeding tube In mouth, Tongue Patch

Many researchers have mentioned of using multimodal within the context of smell, and some projects listed by Hanna Schraffenberger [8] have developed a smell augmentation. Charles Spence discusses about the possibilities, benefits and challenges of digitizing the chemical senses [10]. He mentioned that the most important aspect of digitizing chemical senses is sensing/detection of the sensations, and uses an electronic nose to identify smells. However, the current method for smell based AR are using Wifi location and camera captures. For example, the Dead Man's Nose prototype were developed by Stuart Eve [11] Archaeology that functions by locate the user though WiFi and overlaid the smells and visual element into the real world according to coordinates (or areas) modeled in a GIS layer [11]. In addtion, the MetaCookie+ change the perceived taste of a cookie by overlaying visual and olfactory information onto a real cookie with AR [8]. In which, the smell simulation created by the the MetaCookie+ [8] is similar to the developments of smell augmentations in Virtual reality (VR) that using camera to track input and extracting fixed data of fixed scenarios. The current development of products and prototypes in related smell with VR are the Feel-real mask, Nosulus rift, smell-o-vision, virtual cocoon and VAQSO VR. These products are the mask-type olfactory displays [7] that aiming to stimulate human five senses for VR gaming and movies that gives user a greater experience to enjoy the Virtual world.

Fig.1. below shows an example of mask-type olfactory displays. In which, the olfactory is captured inside of the nature chemical container and will only release the output when the

user positioned at certain programmed location (X, Y, Z) or achieved certain designed objects. For example, an experimental demonstration of a female participant was participant in a Virtual Reality game, she was also wearing a VAQSO VR set and able to smell the odour of a cup of coffee as her character picks up the object [12]. In VR smell simulation, artificial olfactory is created by combine and vaporise several natural chemical liquids at the same time with different concentrations similar to the principal of a digital fragrance box or electronic cigarettes. However, it was mentioned by Mr. Takamichi Nakamoto (Head of the lab at the Tokyo Institute of Technology) that the current development isn't successful, because it's difficult to collect and syndicate of olfactory that huge amount of data are required to establish the components required for different aromas [13].

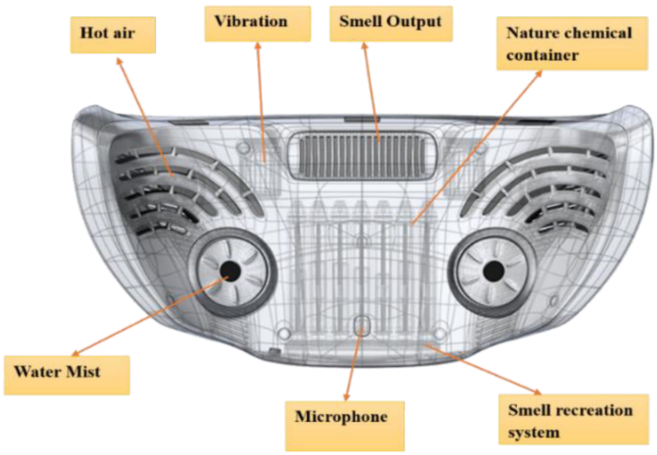

Fig.1. Illustration of the FEELREAL sensory mask [12]

In summary, the above literature has investigated on the current applications and hardware for traditional Augmented Reality, focus on multimodal smell augmentation in its current development and possibilities, and considered at the current method of overlay smell information onto real objects by Wifi and imagery captures. This paper has also looked the current development and successes of smell augmentations in Virtual Reality. The research gap has been highlighted as overlay smell information onto real objects by sensory detections and precise system communications. This research aims to develop a multimodal AR system to overlay smell information by analyse the aroma though electronic nose. The way how electronic nose work is to identify the chemical compounds of the sample and recognises by their electronic patterns signal, and finally transfer into numerical data for the system to analyse. However, Two challenges are summarised from a paper of David Harel el at (2016) [14] in odour recognition and reproduction: Firstly, the concept of the machine distinguishing the difference between similar olfactory (caramel, vanilla, and strawberry are described as sweet). Secondly, the way it distinguishes a particular smell in a mixed environment.

3. Conceptual Design

This paper has created a concrete image to define the process and concept of the smell based AR. Fig.2. below shows the features and functions of the conceptual design. The aim is to enhance maintenance in early diagnosis by using AR to simultaneously overlay both visual and smell information that allows maintainers to fast react to the situation and make decisions without delay. Furthermore, it will enhance maintenance by minimising errors, decisions making, enhancing accuracy and reducing time in diagnosing.

3.1. Case study

A recent case study of the Cranfield maintenance workshop was conducted by interviews, observations and questionnaires to:

1. Analyse the application of Multimodal AR.
2. Determine which of the five senses is important to be augment among with visual display
3. Identify benefit of AR in maintenance.

The workshop mainly conducts milling machine, drilling machine and lathe machine that was between 30-50 years old, and 40% were rebuilt, refurbished or customised machines. This case study has been chosen, because it is suitable for the mainstream market of manufacturing industry. As mentioned earlier in Section 1 that the future manufacturing process will potentially move towards intelligent and automation, but the current workflow and machines remain the same, especially in many big manufacturing countries. It is very common that businesses have not got the intentions to invest in high technologies unless it is necessary and can generate more profits for the business.

According to the interview with the Head of Technical Support Services at Cranfield University (48 years experiences) that the internal maintainers are capable to solve most of the issues within the early stage, and external experts will be hired when issues are beyond control. Moreover, there is value in early detections of potential failures and could potentially avoid serious damages, unnecessary cost, and lead to time-saving. By implementing smell augmented AR will allow maintainers to receive information of machine faults without delay and reduce the potential impact of failures by diagnosis. This is because, unusual sound or smell are the main features of machine faults before the alarm, and experienced maintainers will immediately understand the situation and start to minimise the risks, as unexpected conscious will force human to process with an immediate decision. For example, if a person touches a searing hot pan by accident, he/she will withdraw his/her hand from the stimulus and immediately seek a way to solve the issues before he/she realized what just happened, because human brain will naturally react and respond to an external stimulus (sound, light, smell, taste, touch) [4].

This paper hypothesis that smell is more useful than sound, because when maintainers work long hours in a daily operated noisy and smelly environment, their smell and hiring senses are not often as reactive. The sense of sound is a pressure wave created by vibrating objects [5] and adult zebrafish inner ear can detect sound frequencies up to 4000 Hz, while larvae are sensitive to frequencies up to 1200 Hz [5]. Whereas, the sense of smell is 10,000 times more sensitive than any other senses, because unlike senses that must through the body via neurons and the spinal cord before reaching the brain whereas olfactory response is immediate, extending directly to the brain [4].

Researchers has also shown that humans can discriminate more than 1 trillion of olfactory stimuli [5], and smell is also the only sense that directly link to the amygdala, part of the brain closely involved in our feelings, meaning that scents can be particularly evocative of powerful emotional memories [5].

3.2. The Conceptual Design

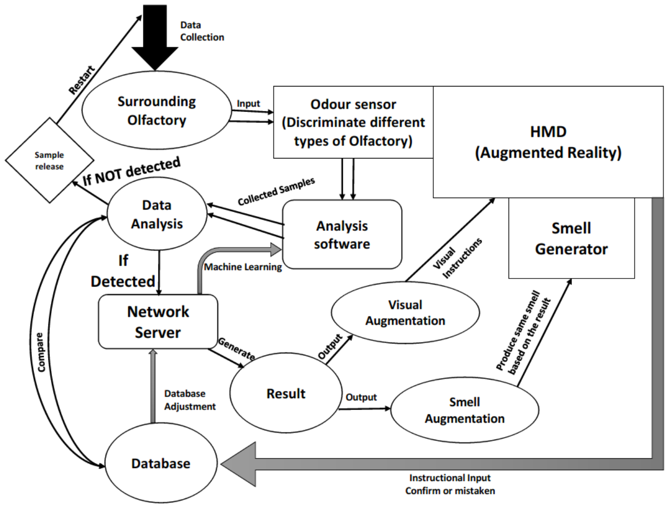

Fig.2. Schematic illustration of smell based Augmented Reality

A conceptual illustration of the project can be found in Fig.2. It is a design of a Wearable Augmented Reality (WAR) that contains a sensory detection system, an AR headset display and a smell generator. The way how it functions is:

1. An electronic nose automatically captures surrounding chemical compounds into a chamber and transfers the data into numerical patterns.
2. Collected samples will be sent to the analyse software that compares to a database with the predefined aroma intensity, aroma classifications and safety index.
3. If samples are not triggered the predefined index then the process will automatically ended, release the collect sample and restart a new process until index triggered.
4. Analysis software will generate a result if analysed samples have triggered the predefined safety index.
5. Result will be delivered to the user by the sense of visual and smell simultaneously.
6. Visual Augmentation shows the cause of the failure and options for user to confirm or disconfirm the failure.
7. Smell augmentation will be achieved by evaporates the volatised liquid made of natural chemicals.
8. User will be able to confirm or disconfirm this result by send instructions to make adjustments for machine learning through the WAR.

3.3. Challenges and Practical plan

The challenge of this smell based AR project is the recognition and building an olfactory database. For instance, Harel et al (2016) [14] has mentioned in his paper that analysing and synthesising odours is not just a matter of wavelengths obtained from a set of mathematical formula [14]. As mentioned earlier in Section 2 that the main challenge is to distinguish the difference between similar data inputs, distinguish a smell from a mixed environment. In other word: "how the system track and differentiate the particular instinct from other chemical compounds accurately" should be the main task to solve in the practical plan of the research.

Therefore, primarily the most essential part of this practical plan is to build a database that maps different causes of the same described smell, as it gives the system a basic function of recognition and identifies the burning and oil leak smell from surroundings. For example, after this step the analysis software should able to identify the difference between wood burning, metal burning, and chemical burning and machine faulty. Secondly, this research classifies the smell generated by machine and analyses their intensity, because the intensity smell generated by machine can be different from machine to machine and case to case. For example, system needs to be able to identify the temperature change of the oil leak and burning intensity. Therefore, the researcher will making adjustments to the electronic nose (tracking system) by testify the needs of additional sensors. Thirdly, this research analyse and validate the natural chemical and the harder used for generating aroma in a high performance, low cost perspective and light weight consideration. Fourthly, the researcher will then mainly focus on the software development, hardware implantation, and validations. In other words, the researcher plan to implant the tracking system, database, and analyse software for the AR headset to be testify the applicability and adjust the hardware used for the machine learning feature. And finally, all hardware used (Electronic nose, Augmented Reality headset and Odour generator) will be integrated into a one wearable AR (WAR).

3.3.1. Methods

The Observations, Restriction scenario analysis and Case study methodology are essential to be used for validating this practical plan. This is because smell is extremely hard to be described and requires such methodologies to collect highly reliable primary data from the real environment. Restriction scenario analysis is used to simulate the cause of the situation within a restricted condition that testify the intensity of the aroma. For example, it is common for a machine to have a small amount of engine oil leaking due to its age and produce a small amount of burning when it is over heated in long hours of operation, but the numerical pattern can be dissimilar due to the different temperature and brand of the engine oil. Therefore, the researcher intend to design the situation, practice and identifying the numerical pattern differences of the same aroma by different cause (chemical burning, metal burning, electronic burning, etc.) and also the differences of the temperature change. The data collected from these methodologies are used to analyse and testify whether the electronic nose (tracking system) requires additional sensors, and also used to build the database for machine learning. And then the researcher intends to verify the adjustments of the practical plan by qualitative questionnaires that used to collect valuable feedbacks from maintainers of their experiences, opinions, and satisfaction of the project. Finally, all three of structures of interviews are used to validate the final completed WAR headset with the relevant audiences on "how Multimodal smell augmentation will enhance decision making in maintenance and diagnosis". Maintainers are targeted with unstructured interviews for them to develop unexpected opinions. Semi-structured interviews were used to collect more reliable and comparable qualitative data from the management perspective. In addition, well-structured interview will be used to focus on the adjustment towards the industrial opinions.

3.4. Initial Results

During the design process, a semi-structured interview (1.5 hours) and a questionnaire of the workshop condition were conducted with the Head of Technical Support Services at Cranfield University. This interview was very helpful that helped to determine:

- How Multi-Sense Augmentation could benefit the maintenance Team.
- Identifying the most efficient sense of diagnosis.
- Identifying the challenges, decision making and problem-solving

The workshop manager (with 52 years of mechanics engineering experience) guided the researcher for an observation and had an unstructured interview of the topic. As a result of this observation, the workshop were clean and bright, sized about 50-60 square meters, surrounded with loud noises when the machine was operating and diffused with smells of oily, coolant and metal burning aroma. It is certain that when the workshop operates the maintainer's nose and ears are generally muted with unusualness.

It was identified that 60% of the machines are British made, aged between 40-50 years old and cost between £3000-£5000. Machine faults can be caused by coolant ran off, bearing and drive key failing, and electric problem. The cost of hiring an external expert is about £600-£650 a day. The workshop manager confirmed that early detection could help them in decision making, extend the health of the machine, and saving cost (predicted in my research contribution), but also suggested that augmented smell will enhance them in faster reactions than sound, because when the workshop gets very lousy, they often ignore the sound of everything. A "Multi-sense augmented reality to Maintenance Survey" was provided to 10 maintainers after the interview, which was used to collect detailed information on the status of the workshop, existing difficulties and problem-solving, and their opinions on the AR technology and augmented human five senses in maintenance. As a result, machine fault can be caused by coolant ran off, bearing and drive key failing, and electric problem. The workshop manager suggested that typically burning and oil leaking smell are the most possible outcome when issues occur. The result of the survey shows that how to describe smell is really difficult for the maintainers, because maintainers would describe machine fault by burning smell and oil smell, but could not classify the cause of it. Therefore, it proves that identifying the exact smell of machine failure itself is extremely important to differentiate from other causes of burning and oil leaking smell.

Furthermore, interview feedbacks were collected from 3 different maintainers whom each have over 40 year's experiences:

- Interviewee No.1 (Well-structured interview) – Clearly shows no interest in the technology and has no idea of the future potential of the development.
- Interviewee No.2 (Semi-structured interview) – Shows interest to the technology, sees the future potential and gives useful feedbacks.
- Interviewee No.3 (Unstructured interview) – Lack of responsibility to the Job's nature, already used to the comfort zone and suggest that a WAR (Wearable AR) is too heavy to wear, and affects his job performance.

Without judging the right or wrong of their opinions it shows the expectations of the future clients. Currently, there is only one positive feedback out of the three interviewees, especially the interviewee 3 made a few good comments. For instance, slackness is very common in the workshop, he questioned about the weight, the use and the attraction of this technology to his performance. In other word:" Why would the future clients purchase a heavy device for decision making, whereas they have already known the solving solutions?" Therefore, the result shows that the future development of this technology needs to be more persuasive with light weight design, attractive capability and usability, and enhancing the daily performance to be more practical and reliable.

Additionally, apart from the results from the case study this research also compares electronic nose with of other odour tracking methods (such as, Gas chromatography, Wasp Hound odour detector, Chemosensors, etc. [10]). This research also practiced on different types of electronic odour sensors, and investigated on new methods of digital scent technology for smell reproduce, such as Vaporise methods and Neuroscience methods. As a result, the researcher decide to redevelop the OMX-SRM [10] (a handheld electronic nose that used to detect and measure the odour strength, intensity and dilutions) into a mountable compound for the WAR headset to analyse the intensity of smell by determined air flow, odour concentration and odour duration.

4. Discussion and Conclusions

A case study of a newly repaired BMW 3 series owner was able to constantly smell the burning aroma of the engine as he drove on the railway. Instead taken this issue seriously, the driver thought it was a mistake since there was no signs shown on the cluster and the vehicle were running without any issues for the next few days. However, the car failed miserably by making loud noises and shakes terribly after he went to holidays for five days and parked outside in the sun. It appears that the engine coil was aging, and the spark plug has also broken during the journey to the garage. As a result, it cost more than £100 to repair including the cost of diagnosis, an engine coil, a spark plug and profits of the garage with VAT. He was fortunate that this was the cheapest he found, but a coil can be purchased for £25 and spark plug cost £6.5, and could be easily replaced without any mechanical knowledge.

Based on this case study, it seems that the driver could have prevented such loss if the machine faulty of the vehicle was diagnosed by the sense of smell. However, there was no sensor(s) to detect this matter and able to notify the user of this fault. This example could leads to a new application of AR through installing heat resisted odour sensors inside of the engine bay to detect the smell intensity that generated area by areas, and connect an OBD (on-board diagnostics) device to the vehicle. User will then receive an accurate description of what was failed by virtual content and what smell has been produced by artificial smell simulation. Therefore, it will be very useful to the consumers if they could explain the mechanical issues to the garage in detail or simply replace by themselves. However, the challenge of this implantation is that the chemical tracking needs to be high accurate, because the engine can produce small oil leak when the gesture is aged, and the burning aroma is very common within this narrow space when the car reaches up to 95 degrees, which is more difficult to distinguish the difference between oil leak and burning aroma. However, this paper hypothesises that it will be easier for the machine learning compares with an open aired environment, because there are only limited possibilities of aroma generated causes and there described conditions with a narrow space. This suggests that once the system has registered such possibilities and learned the strength of intensity within the bonnet, any unusual chemical compound detected could potentially saves a fortune to the users.

In conclusion, the Industry 4.0 encourages the next generation of manufacturing to be flexible, intelligent, and interoperable. The main features of machine faulty are occurred with an unusual sound or smell, but sound can be easily misheard or confused, and smell can gradually acclimate to the environment and hard to notice distinct after long hours of operating. Therefore, it could be very useful to use high-end technologies to detect the machine faults by sensory detections and immediately augment their senses for diagnosis purposes. Augmented Reality (AR) as part of the Industry 4.0 in HCI (Human computer interaction) which has been commonly understood as a technology that overlays virtual information on top of the real objects. Although, the current literature review have not shown a clear definition of multimodal AR, but this PhD defines multimodal AR to be either or all definitions of: using a single data input interface to augment on multiple senses at the same time; using multiple data input interfaces to augment on a single sense augmentation; using multiple data input interfaces to augment on multiple sense augmentations.

This paper hypothesises that smell augmentation can be more precise and noticeable for the maintainers and have initalised a plan for a multimodal AR system that uses a single data input interface (odour detection and analyse) to augment on multiple senses (visual and smell) simultaneously for maintenance diagnosis. This is because the human brain will naturally react and respond to an external stimulus, but the olfactory bulb is part of the brain's limbic system, and smell is closely linked with learning and memory. Therefore, unlike other diagnosis methods that might horrify the maintainers when they are focus, that smell is an indirect but very noticeable sense that will alert the maintainers without terrifying them. In which, the future maintenance could be benefited and enhanced by potentially avoids serious damages, unnecessary cost, and downtime. However, apart from the challenges of distinguishing the differences between similar described smell, there are many other challenges of the uncertainly of analysing dynamic olfactory. Furthermore, a future work recommendation of the technology development could be extend into three directions: The material of the sensor to the sensitivity, intensity and capability; the analysing speed, network server and big data; dynamic aroma reproduces by mixing with different chemicals.

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