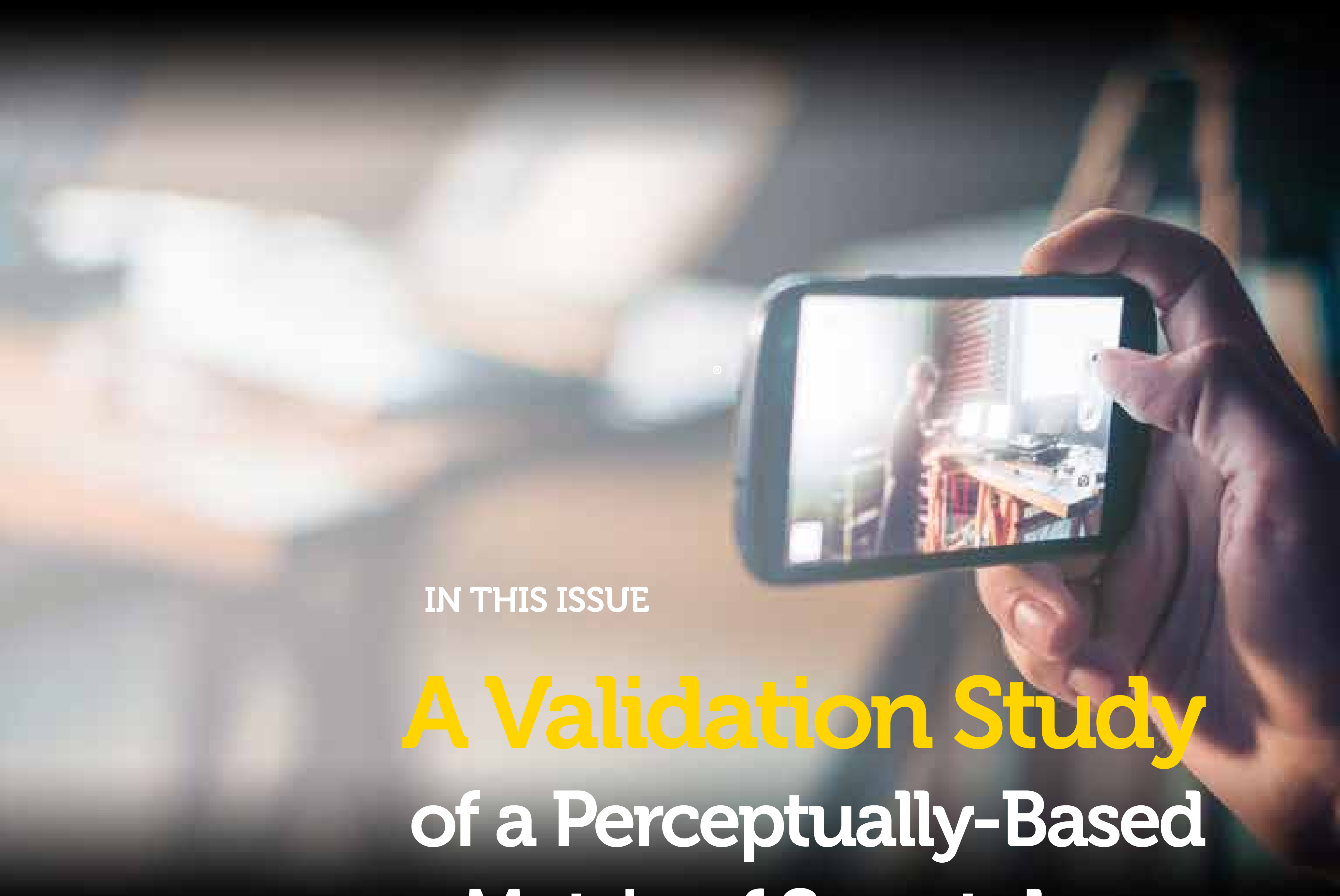
Innovation • Compatibility • Success

STANDARDS UNIVERSITY

June 2017 | Volume 7, Issue 2 | Consumer Electronics



IN THIS ISSUE

A Validation Study of a Perceptually-Based Metric of Smartphone Image Quality

ABOUT THE IEEE STANDARDS EDUCATION E-ZINE

Technical standards are formal documents that establish uniform engineering or technical criteria, methods, processes and practices developed through an accredited consensus process. The purpose of this publication is to help raise awareness of standards, show the importance of standards, present real-world applications of standards, and demonstrate the role you can play in the standards development process. Knowledge of standards and standards activities can help facilitate your professional engineering practice and improve technological developments to meet the needs and improve the lives of future generations.

Serving the community of students, educators, practitioners, developers and standards users, we are building a community of standards education for the benefit of humanity.

Join us as we explore the dynamic world of standards!

CONTENTS

Letter from the Editor - 3

A Validation Study of a Perceptually-Based Metric of Smartphone Image Quality 04-06

Standards for Drone Technology 07-08

Fabrication and Implementation of Wearable Flexible Sensors 09-17

Consumer Autonomy 'On Purpose' 18-19

IEEE P2048 Standards Paving the Road for Virtual Reality and Augmented Reality 20-22

Funny Pages: Standard Fare 23

E-ZINE

Letter from the Editor

Standards for the Virtual World

The world of standards used to be so tangible! You could clearly validate when two components fit together (conformed to certain interoperability standard). Even when we talked about safety or quality matters, it was quite clear whether a process met certain standards. But times are a changin'! Some technologies are now rapidly taking us from the real world into augmented reality and virtual reality. Just to be clear, the interoperability standards are still important; in fact, these applications depend on such complex ecosystems that the adherence to interoperability standards for communication and data is a fundamental requirement. The notion of quality, however, is now built into the bits that make up the digital picture, audio or video and the rate at which it is processed to present the rich experience of reality we seek. As the algorithms continue to benefit from the increased computational power, greater bandwidth, and access to vast quantities of data, we are getting accustomed to highly personalized experiences and services even though there is greater concern over our privacy and personal safety. In this issue of the eZine, the experts are bringing us timely information about some of the emerging standards in camera picture quality, drone technology, augmented reality and virtual reality. We also get to hear from researchers about advanced processes for manufacturing wearable sensors. Just as various audio and video standards brought us improved experiences on mobile devices over the past decade, wearable sensors will bring us near-reality experiences in the coming decade. Can we really be in two places at once? Will we be able to distinguish between the real avatar (self) and the virtual avatar?

While I participated in the development of technical standards for semiconductor and design automation industries, my interaction with government officials on such matters has been minimal. Conceptually, I understood and appreciated the need for strong technical standards to help define regulatory requirements. I also had the opportunity to participate in engineering projects that led to necessary compliance and certification of a few products. On recent Standards Association Board of Governors (SA BoG) meeting in Dublin I was privileged to present Standards Education activities to National Standards Authority of Ireland (NSAI) and Dublin City University. It came as no surprise that the attendees quickly grasped the importance of IEEE's Global Initiative on Ethics. As Artificial Intelligence algorithms get deeply embedded in all the pervasive technology around us from Smart Cars and Smart Homes to Smart Cities, many governments are concerned about the privacy and safety of its citizens. Their proactive interest may lead to direct participation in the P7000 series of standards and possible development of government policies in this domain. The last issue of eZine became a timely reference for them. Insight Centre for Data Analytics Another Standards Education activity that caught the attention of some of the participants was the Standards Game. With humongous amount of data being collected through IoT and GPS devices, interest in the standards for data formats and data access has grown. In turn, the government's interest has grown in how the standards are developed and deployed across different industries. Some of the industry advisors to NSAI quickly picked up on the potential benefits of using the Standards Game to familiarize their staff members with the intricacies of developing new standards. I was very pleased with this dialog and hope they will soon host a session or two of the Standards Game. I can't wait to hear the positive outcome in near future!

Let the virtual games begin!

Yatin Trivedi, Editor-in-Chief, is a member of the IEEE Standards Association Board of Governors (BoG) and Standards Education Committee (SEC), and serves as vice-chair for Design Automation Standards Committee (DASC) under Computer Society. Yatin served as the Standards Board representative to IEEE Education Activities Board (EAB) from 2012 until 2017. He also serves as the Chairman on the Board of Directors of the IEEE-ISTO.

Yatin currently serves as Associate Vice President for semiconductor design services at Aricent Inc. Prior to his current assignment, Yatin served as Director of Strategic Marketing at Synopsys where he was responsible for corporate-wide technical standards strategy. In 1992, Yatin co-founded Seva Technologies as one of the early Design Services companies in Silicon Valley. He co-authored the first book on Verilog HDL in 1990 and was the Editor of IEEE Std 1364-1995™ and IEEE Std 1364-2001™. He also started, managed and taught courses in VLSI Design Engineering curriculum at UC Santa Cruz extension (1990-2001). Yatin started his career at AMD and also worked at Sun Microsystems.

Yatin received his B.E. (Hons) EEE from BITS, Pilani and M.S. Computer Engineering from Case Western Reserve University. He is a Senior Member of the IEEE and a member of IEEE-HKN Honor Society.

A Validation Study of a Perceptually-Based Metric of Smartphone Image Quality

by Katherine Carpenter and Susan Farnand

For years, even as smartphones continued to gain more and more prominence in daily life, there was no standard that rated the quality of images taken by mobile phone cameras. The absence of standards left manufacturers frustrated by their lack of understanding about the impact that design changes had on perceived quality, and consumers were confused about the level of quality that could be expected from the devices they purchased. However, after years of research, the IEEE P1858 CPIQ (Camera Phone Image Quality) Standard was recently published [1]. More than 30 companies took part in the development of this standard, which can be used to consistently evaluate image quality and make comparisons between phone models. The standard was intended to be something that manufacturers could use in the development of particular products and that the industry could use to level the playing field in the evaluation of these products.

It is well known that the number of megapixels alone is insufficient for adequately characterizing perceived image quality. To address this, seven metrics, all based on objective measurements, were used to create the new CPIQ standard. The metrics include spatial frequency response (SFR), lateral chromatic displacement (LCD), chroma level (CL), color uniformity (CU), local geometric distortion (LGD), visual noise (VN), and texture blur (TB) [2], [3]. These individual metrics are described in the CPIQ document [1].

The individual metrics were quantified by quality loss (QL) in just noticeable differences (JND). The QL values for each metric were then combined using the Minkowski metric to generate the overall predicted QL, as

$$QL = (\Sigma i(QLi)n\ max)(1/n\ max)$$

where n *max* = 1 + 2·tanh(QLmax/16.9) and QL*max* is the maximum QL for a given test condition for a given camera [3].

In the crafting of this new standard, the following normative references were used to provide information on color management, spatial resolution measurement, methods for measuring camera optoelectronic conversion functions (OECFs), and more:

- IEC 61966-2-1, Multimedia systems and equipment–Color measurement and management–Part 2-1: Color management–Default RGB color space–sRGB
- ISO 7589:2002 Photography–Illuminants for sensitometry–Specifications for daylight, incandescent tungsten, and printer
- ISO 12233:2014 Photography–Electronic still-picture imaging–Resolution and spatial frequency responses
- ISO 14524:2009 Photography–Electronic still-picture cameras–Methods for measuring optoelectronic conversion functions (OECFs)
- ISO 15739:2013 Photography–Electronic still-picture imaging–Noise measurements
- ISO 16067-1:2003 Photography–Spatial resolution measurements of electronic scanners for photographic images–Part 1: Scanners for reflective media

In recent work, the objective results were compared to the results of subjective testing to determine if the objective metrics correlate with the image quality that observers perceive. The subjective results, generated using paired comparison [4], [5] and softcopy quality ruler [6], [7] protocols, serve as independent verification of the standard. The objective measurements that are used in the CPIQ standard were found to be related to the perception of image quality.

The devices in the study were selected from a variety of manufacturers in order to assess a wide spectrum of quality and pixel counts. The devices were from well-known smartphone manufacturers such as Apple, Samsung, and Nokia. A variety of image quality characteristics were analyzed with each camera. In the subjective evaluation, images were taken with each camera of ten real-world scenes. The scenes chosen represented a range of illumination conditions and image content that consumers are likely to photograph, such as flowers and people. They were also selected to resemble the pre-existing set of images used in the softcopy quality ruler experimental protocol. Once all the images were taken, they were cropped so that all images had the same dimensions; care was taken so that the target had the same pixel height in the image, regardless of the pixel height of each camera. The same images were used in both the paired comparison experiment and the softcopy quality ruler experiment.

Twenty observers participated in each experiment; the observers were tested for color deficiency and acuity prior to participation. In the paired comparison experiment, a pair of images of the same scene taken with two different smartphones were presented on the calibrated display, as shown in Figure 1. The participants were directed to press the arrow key on a keyboard corresponding to which image of the two they preferred. Preference was explained to be a result of multiple factors, such as sharpness, color, and noise present in each image, but not image composition or facial expression. The order of presentation was randomized for each observer.

Figure 1—An observer participating in the paired comparison experiment.

In the softcopy quality ruler assessment, two images were again displayed next to each other on the same display. However, in this case, one was a ruler image and the other a test image. The GUI incorporated a slider bar that participants were asked to use to adjust the sharpness of the ruler image. The participants moved the slider bar until they felt that the overall quality of the ruler image matched the quality of the test image. The image set order was randomized for each observer, but the assessment was performed for each image of an individual scene before moving to a new scene.

The paired comparison results were analyzed by finding the probability and the corresponding z-score that each image would be selected as preferred. SQS values on an absolute quality scale were determined for the softcopy quality ruler study. A correlation coefficient was then calculated for the relationship between the SQS values from the quality ruler and the z-scores from the paired comparison. Seven out of the ten scenes were found to have highly correlated results for the paired comparison and quality ruler tests. Eight of the nine cameras tested had highly correlated results for all ten scenes. The results indicated that either experimental approach would provide a measure of perceived image quality.

The subjective results were then compared to the objective results with the ten scenes grouped into three categories based on the lighting conditions under which the images were taken: daylight, indoor lighting, and low light (see Figure 2). The objective metric results were found to be fairly well correlated with the subjective assessment of image quality, although they also serve as evidence that there is still room for improvement, especially with low light scenes. This work continues, with the goal of providing objective metrics that provide an accurate measure of perceived quality for manufacturers to use in the development of their products and consumers to use for making more informed purchases.

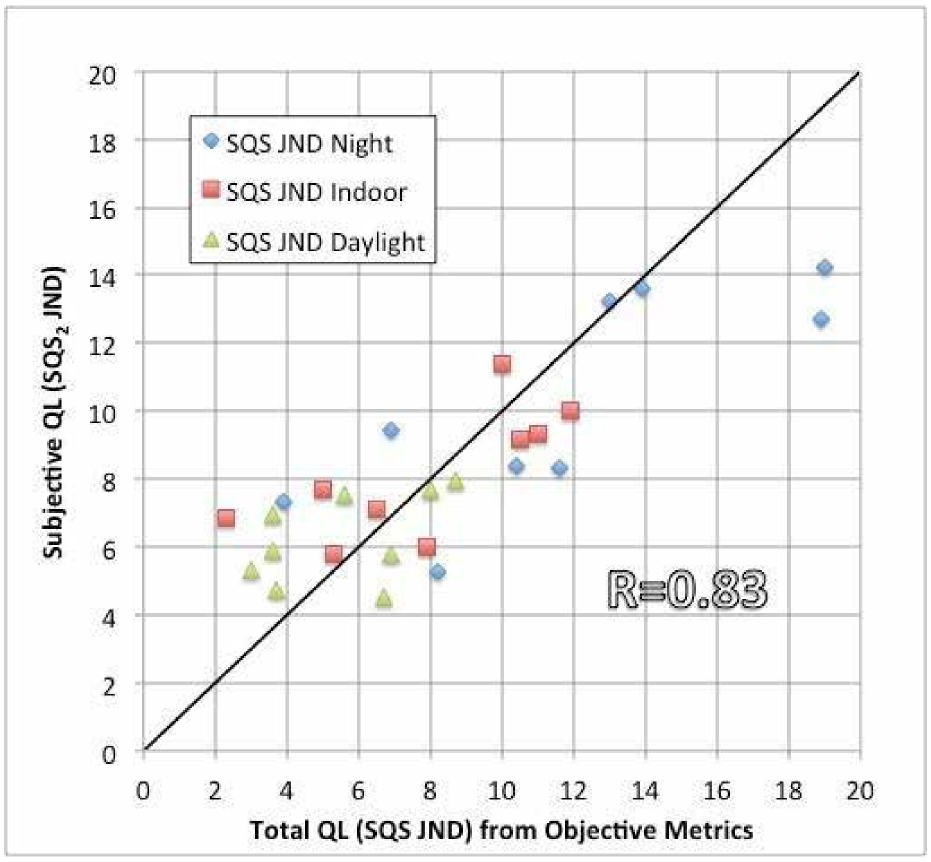


Figure 2—The subjective results relative to the objective metrics expressed in terms of Quality Loss [2].

This new standard is expected to be used by manufacturers of smartphones and smartphone components to evaluate the effects of design choices on output image quality as well as by testing labs to provide a common language for reporting image quality results to their customers and to consumers. To provide further assistance to manufacturers and testing labs, work on CPIQ continues in areas such as exposure control, automatic white balance, and video capture, to name just a few. An additional standard, which will incorporate the results of this work, is expected to be published in May 2018. The publication of this standard will bring the imaging community another step closer to a complete body of standards for measuring and quantifying perceived image quality. What remains includes evaluation of special camera functions such as High Dynamic Range imaging and Portrait mode.

References

IEEE P1858, IEEE Standard for Camera Phone Image Quality (CPIQ), May 2017.

Baxter, D., F. Cao, H. Eliasson, and J. B. Phillips, "Development of the I3A CPIQ spatial metrics," Proc. SPIE 8293, p. 829302, Jan. 2012.

Jin, E. W., J. B. Phillips, S. Farnand, M. Belska, V. Tran, E. Chang, Y. Wang, and B. Tseng, "Towards the development of the IEEE P1858 CPIQ standard—A validation study,"

Electronic Imaging, vol. 2017, no. 12, pp. 88–94, 2017.
Torgerson, W. S., Theory and methods of scaling, New York, NY: J. Wiley & Sons, 1958.
Engeldrum, P. G., Psychometric scaling: A toolkit for imaging systems, Winchester, MA: Imcotek Press, 2000. Jin, E. W., B. W. Keelan, J. Chen, J. B. Phillips, and Y. Chen, "Softcopy quality ruler method: Implementation and validation," Proc. SPIE 7242, p. 724206, 2009.
Jin, E. W., and B. W. Keelan, "Slider-adjusted softcopy ruler for calibrated image quality assessment," Journal of Electronic Imaging, vol. 19, no. 1, p. 011009, 2010.

Katherine Carpenter is a 2nd year PhD graduate student in the Program of Color Science at the Rochester Institute of Technology. She received her BS in physics from SUNY Oneonta. She executed the subjective evaluation of the CPIQ objective metric. She can be reached at kmc2582@rit.edu.

Susan Farnand is a Visiting Assistant Professor in the Program of Color Science at the Rochester Institute of Technology. Her research interests include human vision and perception, color science, cultural heritage imaging and 3Dprinting. She received her BS in engineering from Cornell University, her Masters in Imaging Science and her PhD in Color Science from the Rochester Institute of Technology. She began her career at Eastman Kodak, designing and evaluating printer systems. She is Publications Vice President of the international Society of Imaging Science and Technology and serves as an Associate Editor for the Journal of Imaging Science and Technology. She participates in several Standards efforts including ISO TC 42 JWG26 Archival Imaging and IEEE CPIQ. She can be reached at susan.farnand@rit.edu.

Standards for Drone Technology

by Dr. Ahmed S. Khan

During the past two decades, drone technology has evolved from an emerging into a developed technology serving a multitude of applications such as recreation, search and rescue, inspection, security, surveillance, science and engineering R & D, aerial photography, aerial imaging and mapping, surveying, TV news coverage, agricultural and environmental monitoring, moviemaking, law enforcement, and unmanned cargo transport.

Drones are also known as Unmanned Aerial Vehicles (UAV) or Unmanned Aircraft Systems (UAS). The FAA defines a drone or UAS as an aircraft without a human pilot on board. Instead, the device is controlled by an operator on the ground. The FAA has established the following regulations and guidelines for flying drones in the United States for recreational and commercial purposes (see grid below).

According to the Association for Unmanned Vehicle Systems International (AUVSI), by 2025 more than 100,000 new jobs related to UAS technology will be created in the United States. On the technological horizon, drones appear to be ubiquitous, but unfortunately the development and adoption of national and international standards is lagging behind the pace of development of drone technology.

	Flying for recreational use	Flying for commercial use
Pilot Requirements	• No pilot requirements	• Must have Remote Pilot Airman Certificate • Must be 16 years old • Must pass TSA vetting
Aircraft Requirements	• Must be registered if over 0.55 lbs.	• Must be less than 55 lbs. • Must be registered if over 0.55 lbs. • Must undergo pre-flight check to ensure UAS is in condition for safe operation
Location Requirements	• Five miles from airports without prior notification to airport and air traffic control	• Class G airspace*
Rules of Operation	• Must ALWAYS yield right-of-way to manned aircraft • Must keep the aircraft in sight (visual line-of-sight) • UAS must be under 55 lbs. • Must follow community-based safety guidelines • Must notify airport and air traffic control before flying within five miles of an airport	• Must keep the aircraft in sight (visual line-of-sight)* • Must fly under 400 feet* • Must fly during the day* • Must fly at or below 100 mph* • Must yield right-of-way to manned aircraft* • Must NOT fly over people* • Must NOT be guided from a moving vehicle*
Example Applications	• Educational or recreational flying only	• Flying for commercial use (e.g., providing aerial surveying or photography services) • Flying incidental to a business (e.g., conducting roof inspections or taking photos of real estate)
Legal or Regulatory Basis	• Public Law 112-95, Section 336: Special Rule for Model Aircraft (FAA Interpretation of the Special Rule for Model Aircraft)	• Title 14 of the Code of Federal Regulations

The International Organization for Standardization (ISO) is an international organization with the membership of more than 160 countries; it has completed 14 UAS standards, and a number of new standards are due for completion in 2018. One such standard being developed is the ISO/TC 20/SC 16 for unmanned aircraft systems, encompassing their design and development, manufacturing, delivery, maintenance, classification, and characteristics; the materials, components, and equipment used during their manufacturing; and their safe operation, with the joint use of airspace by unmanned and manned aviation. The UAS standards project ISO/TC 20/SC 16 has the support of 18 standards organizations based in the United States, the United Kingdom, China, Russia, Japan, France, and Germany. The UAS standards project is in the process of developing standards with support from academe, industry, and governments.

Globally, drone flying is growing as a hobby. Drones flying dangerously close to commercial aircraft pose safety concerns and violate federal rules of operation. According to the International Air Transport Association (IATA), between January 2013 and August 2015, there were 856 cases worldwide of drones flying very close to planes.

The public debate is heating up about the use of drones for recreational and commercial purposes, and questions have been raised about their safety, security, and associated ethical and social issues. There are concerns about invasion of privacy and erosion of civil liberties.

As the technical experts and policy makers strive to develop standards at national and international levels, they ought to ponder the following questions:

- How to legally address, at national and international levels, damage to public property and fatalities caused by failures of drone technology?
  How to deal with the unintended consequences of drone use?
- How to effectively manage recreational and commercial drone traffic?
- How to effectively track recreational and commercial drones?
- How to develop GPS-based flying corridors for recreational and commercial drones?
- How to effectively assign electronic addresses for identifying recreational and commercial drones?
- How to avoid violating public privacy and safeguard civil liberties?

Answers to these questions will lead to the development and adoption of national and international standards. Once such standards are developed, drone technology can safely be used for the benefit of society both for recreation and for cross-border commercial deliveries in the United States, Canada, Europe, and other international regions.

Dr. Ahmed S. Khan is a Professor of Electronics and Electrical Engineering in the College of Engineering and Information Sciences at DeVry University, Addison, Illinois. Dr. Khan has thirty-four years of experience in research; instruction; curriculum design, development, evaluation, and implementation; and program accreditation, management, and supervision. Dr. Khan received an MSEE from Michigan Technological University, an MBA from Keller Graduate School of Management, and his Ph.D. from Colorado State University. His research interests are in the areas of nanotechnology and the social and ethical implications of technology. He teaches Wireless Engineering, Network Engineering, Fiber Optic Communications, Science Technology and Society (STS), and Project Management. He also advises students on their senior design projects. He is the author of many educational papers and presentations and has authored/coauthored many books, including most recently Nanotechnology: Ethical and Social Implications (CRC Press, 2012).

Fabrication and Implementation of Wearable Flexible Sensors

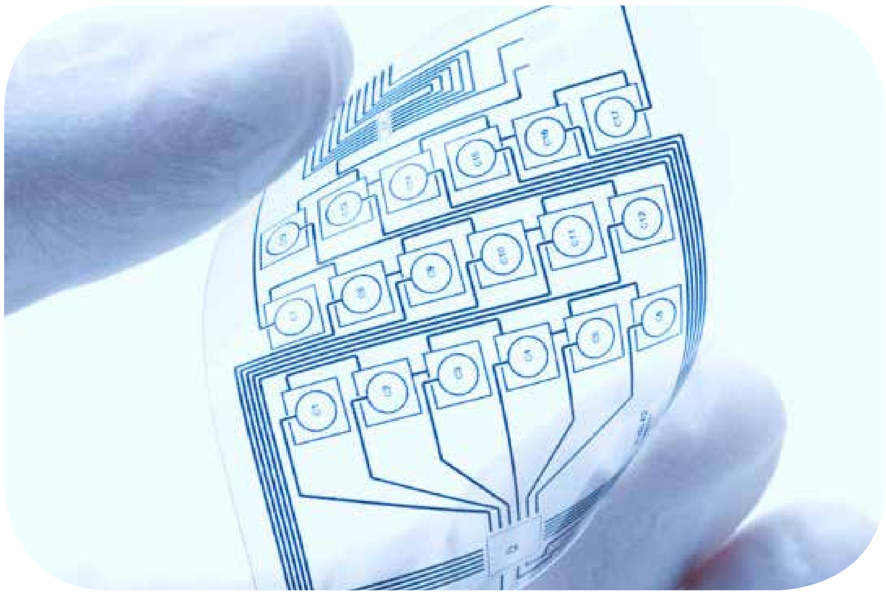
by Anindya Nag and Subhas Mukhopadhyay

Abstract

The article gives a brief description of the design, fabrication, and implementation of wearable flexible sensors developed with a laser cutting technique. The approach used standardized protocols on the raw materials processed for the development of the prototypes. Four distinct types of sensor prototypes were prepared with different organic polymers as substrates and allotropes of carbon and aluminum as electrodes. The processed materials were selected based on the targeted application. These sensor patches were used for monitoring limb movements and respiration, tactile sensing, and urinary incontinence detection.

Introduction

The intervention of sensors [1] in different applications has led to a significant change in human quality of life. This in turn has triggered an increase in the demand for sensors with better performance in terms of cost, durability, and sensitivity. The materials used for developing a sensor largely depend on its application. For example, a sensor attached to a person to detect a fall would require electrodes and substrates to be developed with materials having the highest possible conductivity and flexibility, whereas for monitoring a heartbeat, a much smaller device with greater sensitivity would be needed. Therefore, the fabrication of a sensor is the most important step in determining its application. Approximately three decades ago, when sensors were first introduced, silicon sensors were most commonly developed and used because of their unique advantages, including compactness, ease of implementation, and particular electrical properties. This led to the use of the sensors in different heterogeneous applications such as gas sensing [2], [3] and determining the various constitutional elements of food products like beverages [4], [5] and meat [6]. Even though silicon sensors came to be a popular choice, they possessed certain disadvantages, which led researchers to search for better options. Flexible sensors were developed to replace the existing rigid ones, with electrodes and substrates prepared using malleable materials. A high tolerance for strain, lower fabrication costs, and great bendability are some of the advantages these sensors offer over those made of silicon. Polymeric materials often used in developing the substrates for flexible sensors include polydimethylsiloxane (PDMS) [7], polyethylene terephthalate (PET) [8], and polyimide (PI) [9].



The main differences between these polymers relate to their mass density and flexibility. The reasons behind the use of each of these materials are explained in the following section. Conductive materials commonly used with the electrodes of flexible sensors include silver [10], carbon [11], and aluminum [12]. One of the biggest advantages of using flexible sensors is that, as wearable devices, they can be used for unobtrusive tracking. The sensors along with the embedded system are attached to the body or to clothing in order to study a particular trait. In this way, the person under observation can be discreetly monitored without any discomfort or hampering of privacy. Researchers have emphasized that monitoring physiological parameters [13], [14] and body movements [15], [16] in particular could not be done with silicon sensors due to their rigidness. Various fabrication techniques are used to process the raw materials for developing the flexible sensor prototypes. Some of the more common ones are photolithography [17], screen printing [18], and laser cutting [19]. Among these, laser cutting is the easiest and quickest method for several reasons—namely, ease of sample preparation, the ability to create smooth edges, and the lack of need for experts. This article briefly describes some of the flexible sensors developed with the laser cutting technique using standardized protocols. Laser cutting has been an established technique for curving flexible sensors for some time [20], [21]. Different kinds of laser cutting machines varying in their output power are available. Those most commonly used for fabrication purposes are CO2 laser engravers [22], [23]. Design software is configured along with the laser system, with the dimensions of the prototype assigned manually. This design is transferred to the laser engraving stage to replicate these dimensions on the sample.

Fabrication of the Sensor Prototypes

The entire fabrication process was carried out inside a cleanroom with fixed temperature and humidity levels [24]. The classification level 209E, defined by federal standards, is followed by cleanrooms worldwide [25]. These standards have laid down rules regarding the amount of molecular contamination in the air per volume present in different ISO classes. The fabrication of these sensor prototypes was carried out in ISO class 6 [26], [27].

Each step in the fabrication of the sensor prototypes was taken for particular reasons. The first sensor patch was developed by forming a nanocomposite between PDMS and multi-walled carbon nanotubes (MWCNTs) [15]. The reasons for using PDMS as the substrate material for the sensor were its low cost and quicker production time [28]. Laser cutting of PDMS has been done by researchers a considerable number of times, especially in developing microfluidic channels [29]–[31]. CNTs were considered over other nanoparticles because of their light weight, high electrical conductivity, and mechanical stability. High purity, higher electrical conductivity, and less chance of defects are some of the reasons why MWCNTs were chosen over single-walled carbon nanotubes (SWCNTs) [32]. Carboxylic group (-COOH) functionalized MWCNTs were considered as the conductive material due to their high oxidative and metallic properties [33], [34]. CNTs by wt. % considered for dispersion in PDMS were determined from [35], where a range of 1 wt. % to 4.5 wt. % was taken to develop the composite electrodes. After an optimization was done on the sample, between the conductivity of the nanocomposite and the dispersion of MWCNTs into PDMS, 4 wt. % was fixed to form the electrodes. Fig. 1 shows an SEM image of the nanocomposite formed with 4 wt. % of MWCNTs in PDMS. The black and white areas in the image represent the CNTs and PDMS, respectively. Fig. 2 shows the different steps followed during the fabrication process.

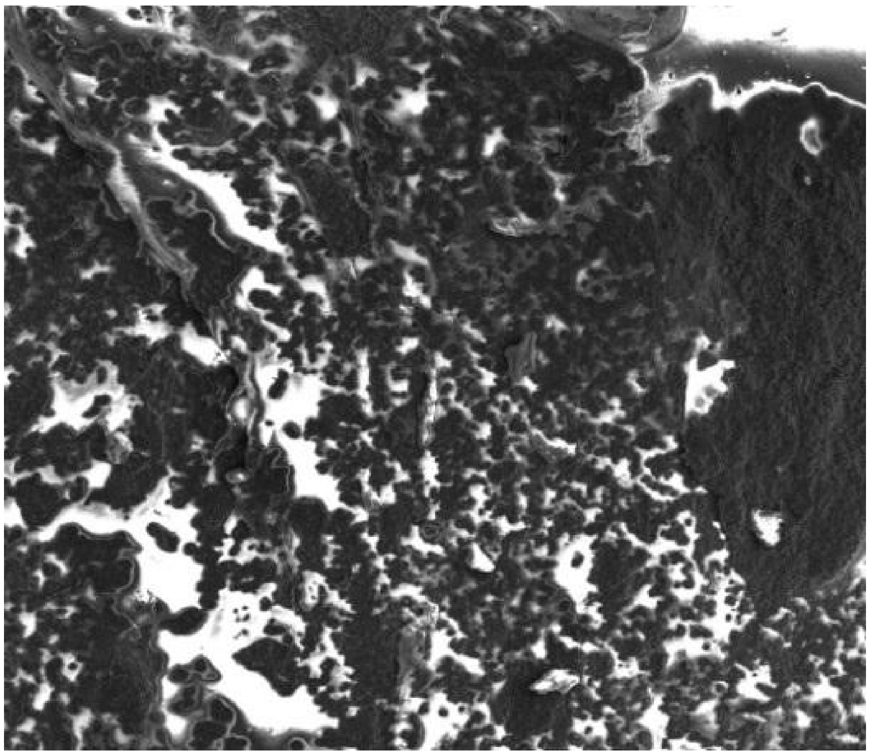


Fig. 1. SEM image of the developed CNT-PDMS nanocomposite [15].

Fig. 2. Individual steps followed during the fabrication of the CNT-PDMS-based flexible sensor [15].

After the pure PDMS was cast on a template [2(1)], it was desiccated [2(2)] and cured [2(3)] at 800 °C for 8 hours. This formed the substrate of the sensor patches. Then a layer of the formed nanocomposite was cast on the cured PDMS [2(4)]. The height of both the uncured PDMS and nanocomposite were adjusted by a casting knife. The height of the polymer and the nanocomposite were adjusted to around 1 mm and 600 microns, respectively. The nanocomposite layer was then desiccated [2(5)] and cured [2(6)] with the same duration as that of PDMS. Then, the formed sample was taken for laser cutting [2(7)] to scan off parts of the cured nanocomposite layer from the PDMS layer in order to form the electrodes. The CO2 laser machines used for designing the electrodes followed a standardized ISO 115616-2:2003 [36]. This standard determines the accuracy, precision of measurement, repeatability, and trajectory. Universal Laser Systems [37] were used to perform the laser cutting for designing the electrodes. Similar to that for cleanrooms, this standardized protocol also separated the laser cutters into different classes [38]. These classes differ in terms of identified risks, hazards, and safety. These systems complied to and operated with a Class 4 laser system [39], [40]. Power, speed, and z-axis were the three parameters of the laser system that were optimized during the procedure.

While power (W) referred to the amount of energy of the laser on the sample, speed (m/min) determined how rapidly the laser nozzle would move over the processed sample. The z-axis (mm) determined the height of the platform of the system in order to adjust the focal point of the laser nozzle on the sample. Based on the cuts obtained on PDMS in [30], adjustments were made to both power and speed. Table 1 gives the different combinations tried during the process of optimizing power and speed settings.

Power (W)	Speed (m/min)	z-Axis (mm)	Thickness of the electrodes (microns)
1.2	4.2	2	137
2.4	7	2	140
12	42	2	150
24	70	2	175
42	126	2	180

Table 1. Different Power and Speed Combinations Tried During the Experimental Process [15].

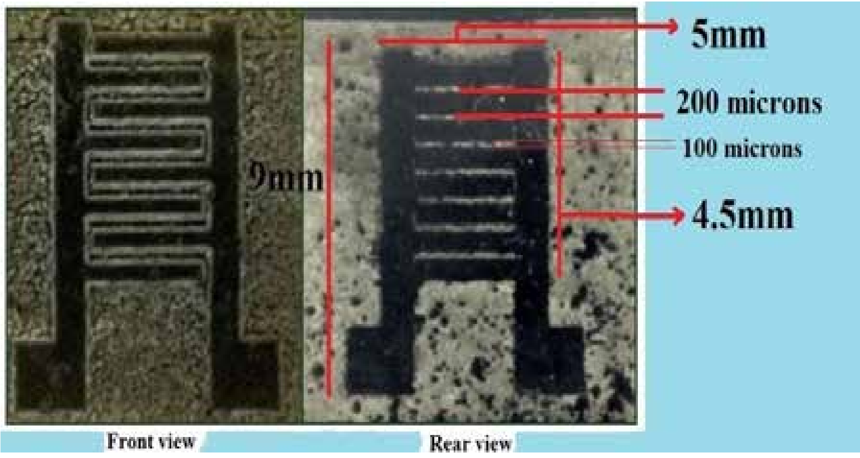


Fig. 3. Front and rear views showing the dimensions of the sensor patch [15].

A series of short-circuit tests proved a power of 24W and speed of 70 m/min to be the most viable setting. Fig. 3 shows the front and rear views of the sensor along with its final dimensions. A pair of the three electrodes was formed with a thickness of 200 microns and an interdigital distance of 100 microns.

The second sensor prototype was developed with metallized PET films [41]. One side of the PET film was covered with aluminum (Al). Due to the use of a single raw material, the structure of this sensor is different from other sensors. High flexibility, smooth cut edges, and the absence of any post-processing steps are some of its advantages, due to which PET was chosen as the substrate material [42], [43]. Al nanoparticles also have certain advantages that make it a viable option for the electrode material [44]. Some PET films possess high corrosion resistance, high electrical and thermal conductivity, and flexibility [45]. A schematic diagram of the fabrication steps is given in Fig. 4 [41].

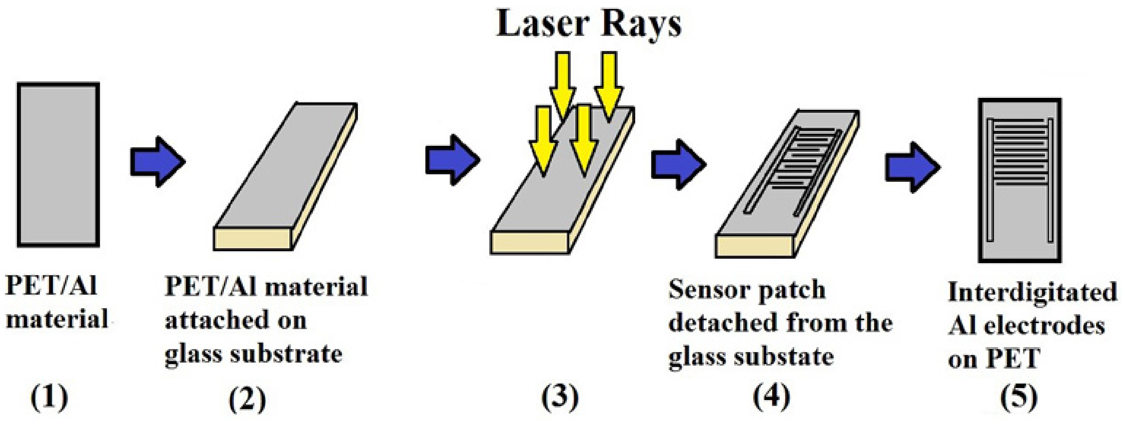


Fig. 4. Schematic diagram of the individual steps followed to develop the flexible sensors with metallized PET films [41].

Initially, the metallized PET films were attached to a glass substrate with the Al side facing the laser nozzle. The difference between the Al and PET is the former being shinier than the latter. The sample was taken to the laser platform to form the electrodes. The laser cutting was done by the same instrument used for the CNT-PDMS-based sensor prototype.

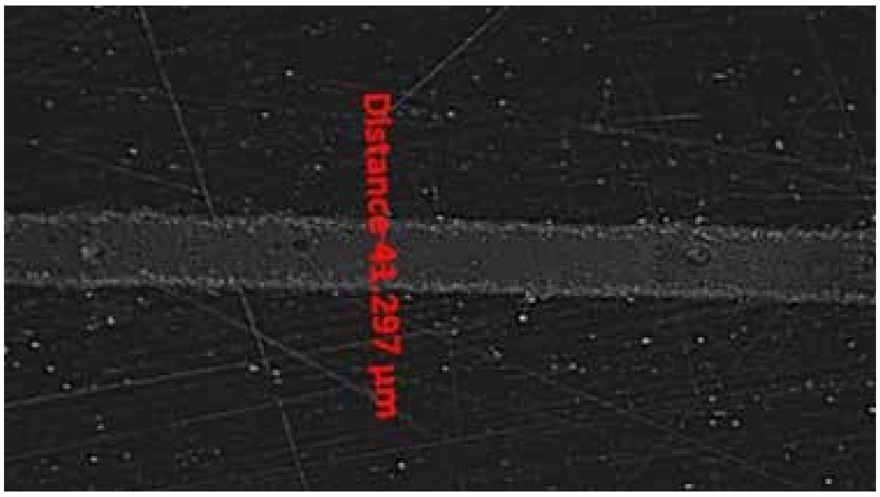


Fig. 5. Thickness of the electrode line obtained after optimization of laser parameters [41].

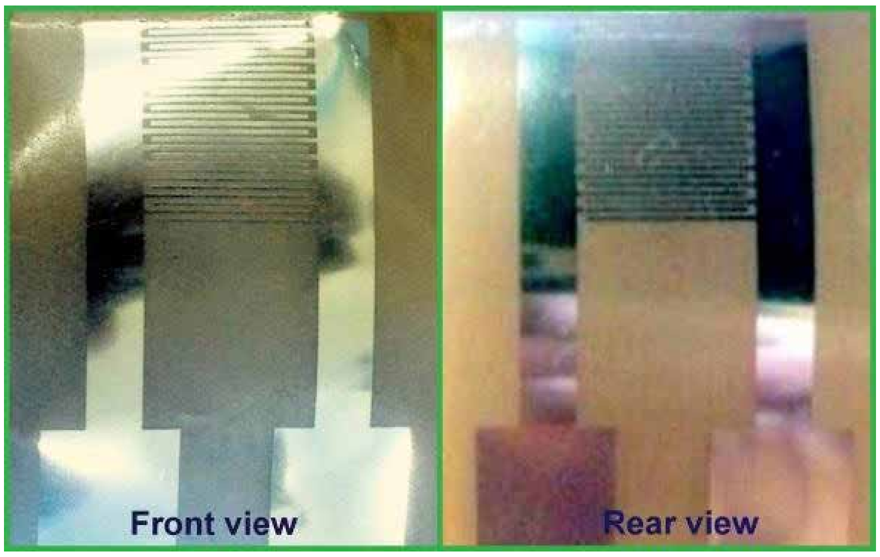


Fig. 6. Front and rear view of the sensor patch. The front is noticeably shinier than the back due to the presence of aluminum as the electrodes [41].

An optimization was again conducted on the laser parameters to determine the thickness of the electrode line. A trade off was made between the thickness and the depth of the line piercing the sample. Fig. 5 shows the thickness of the electrode obtained after optimization to be around 42 microns. This thickness was kept constant for all the electrode lines in the sensor patch. The optimized values were power: 12.6 W, speed: 70 m/min, and z-axis: 1.2 mm. Fig. 6 shows the front and rear view images of the finished product [41]. The total sensing area of the patch was 44 mm2 with a thickness of 500 microns and 300 microns of the substrate and electrodes, respectively. A pair of 12 electrodes was formed with each one having a length and width of 1.2 mm and 41 µm, respectively. The interdigital distance was 150 microns.

The third type of sensor prototype developed by laser cutting was based on photothermal induction of the polymer films to form graphene [46]. This led to an idea to develop a sensor patch using the induced conductive material to form the electrodes. The advantages of this sensor prototype are its low cost and its highly conductive material. The conductivity of the electrodes of these graphene sensors was higher than those developed with CNT-PDMS and

PET-Al. Commercial PI films were used as the raw material for processing. In addition to having smooth and precision cuts up to the micron range and very high flexibility [47], another substantial benefit of using PI is its excellent thermal properties, which would be advantageous while processing it with CO2 lasers [48], [49]. The schematic diagram of the fabrication steps of the graphene sensor prototypes is given in Fig. 7. Commercial PI film [7(1)] was attached to the glass substrate in order to have a smooth surface before laser induction. The laser cutting was done on the attached films [7(2)] to form powdered graphene. The shape of the induced powder was as designed in the laser system. The optimized values of the laser parameters used during this process were power: 9 W, speed: 70 m/min, and z-axis: 1 mm. The sp3 hybridized carbon atoms in the PI films were photothermally induced to form sp2 hybridized atoms in the graphene.

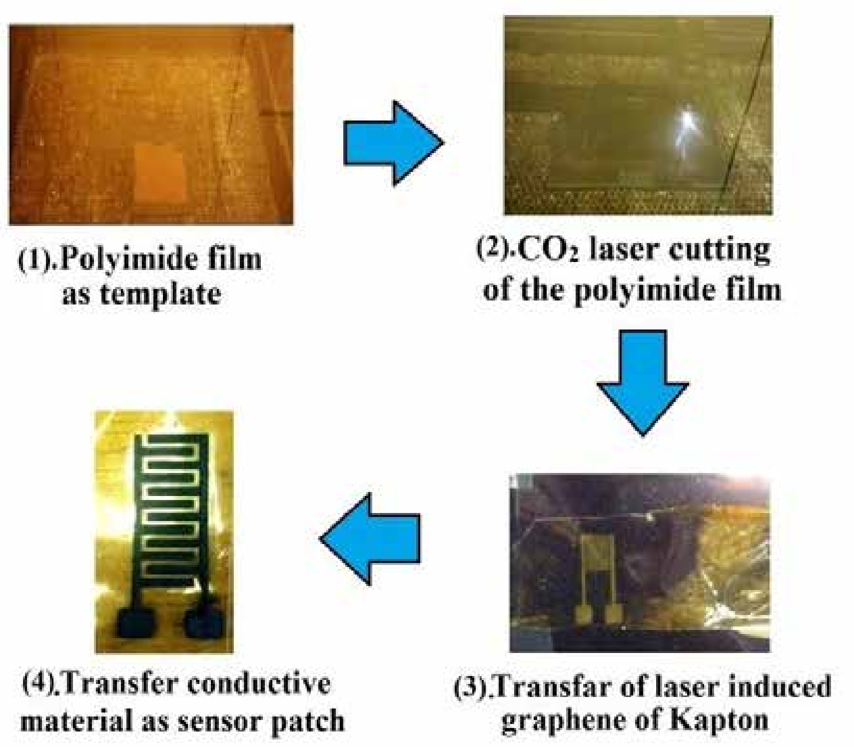


Fig. 7. Fabrication steps followed to form the graphene sensor prototypes from commercial PI films.

Fig. 8. Final sensor prototype.

The graphene powder was then transferred to Kapton tapes via manual stress [7(3)] for using the powdered material as the electrodes [7(4)]. The final prototype is shown in Fig. 8. The sensor patch had a pair of 6 electrodes with a sensing area of 102 mm2. The length and width of the electrode were 5 mm to 1 mm, respectively, with a distance of 500 microns between consecutive electrodes. One of the issues was the change in properties of the induced graphene during its transfer. Thus, the manual pressure exerted on the Kapton tapes during the transfer had to be done carefully as a minute of discontinuity in the transferred form would have made the sensor invalid. The change in resistivity was > 50 Ω between the formed and transferred material.

Figs. 9(a) and 9(b) give the SEM images of the top view of the sensor showing the transported material on the Kapton tapes. It can be seen that the edges of the sensor prototype are relatively smooth and perpendicular to the surface.

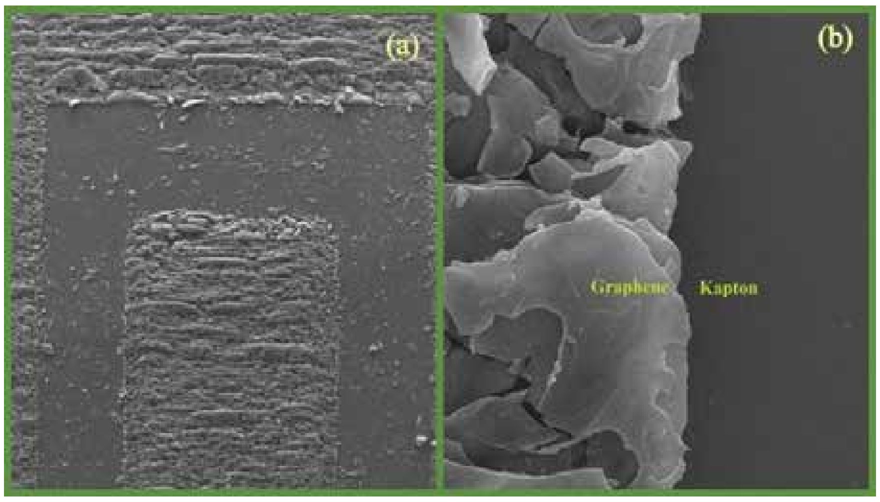


Fig. 9. SEM images of the transferred graphene on Kapton tapes.

Working Principle of the Sensor

All the sensor prototypes designed and fabricated were based on the principle of capacitive sensing. The electrodes were interdigitated with a fixed interdigital distance between two consecutive electrodes. The working principle of the sensor prototypes is shown in Fig. 10 [50]. The parallel plated electrodes were made co-planar to obtain a non-invasive single-sided measurement. The electrodes were designated as either an excitation or sensing electrode. An electric field was generated between the oppositely charged electrodes when a time-dependent voltage was provided to the excitation electrode. This generated field would bulge from one electrode to another due to the planar structure of the sensor.

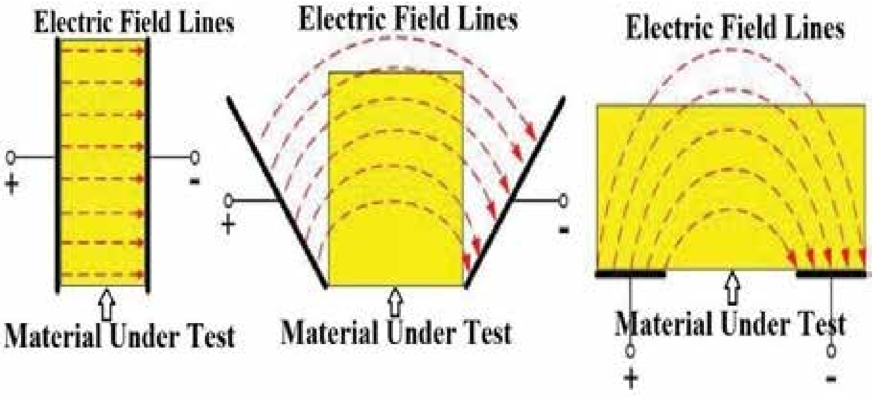


Fig. 10. Working principle of the fabrication sensor prototypes [50].

When any material was kept in contact or within close proximity to the sensor, the electric field would penetrate through the material while traveling from one electrode to another. This would change the properties of the field studied to determine the characteristics of the material under test (MUT). Due to the flexible nature of the sensor patches, the expansion and contraction caused by the strain applied to it would trigger a change in response [15]. Capacitance can be defined by

$$C = \frac{\epsilon_0 * \epsilon_r * A}{d} \qquad \text{(i)}$$

where

C is the capacitance of the material.

Eo is the absolute permittivity;

Er is the relative permittivity of the material;

A is the effective area of the sensor patch;

d is the effective distance between the electrodes.

Area (A) can be divided into the length (L) and width (W) of the sensor patch. When a strain was applied to the sensor patch, this would lead to a change in the resultant area (A) and interdigital distance (d) of the patch. This would result in the change of the overall capacitance, which can be given by

$$\Delta C \approx C * \left(\frac{\Delta L}{L} + \frac{\Delta W}{W} - \frac{\Delta d}{d}\right) \qquad \text{(ii)}$$

where ΔC is the change in capacitance and ΔL, ΔW, and Δd are the changes in length, width, and interdigital distance, respectively. Fig. 11 provides a schematic of this principle.

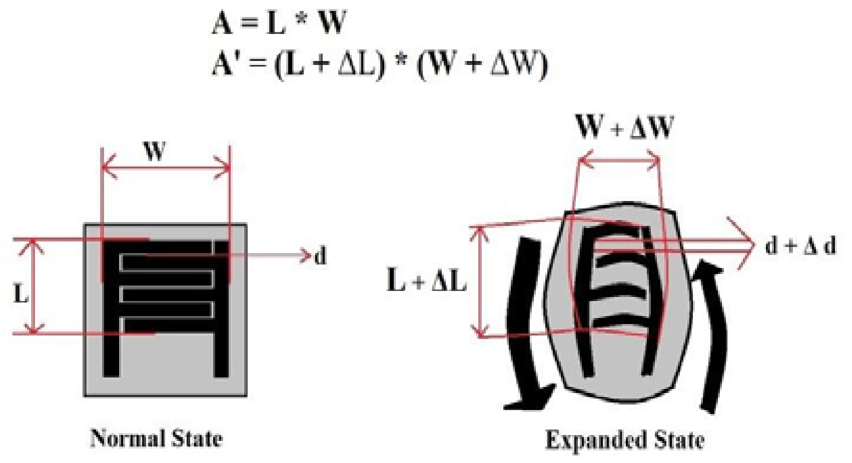


Fig. 11. Working principle of the sensor prototypes causing a change in its response due to the applied strain [15].

Experimental Results

The fabricated prototypes were used as wearable sensing devices and utilized to monitor different physiological parameters. A HIOKI IM3536 LCR high-precision meter was used to collect the response of each sensor and store it on a computer via a USB-USB cable. The sensor was connected to the LCR meter at one end with Kelvin probes and attached at the other end using biocompatible tapes. A slow mode of testing was employed to minimize the error rate up to <0.05%. The CNT-PMDS-based sensor was used to monitor the movement of limbs by attaching the sensor to the elbow and knee of an individual. A prior profiling of the sensor with a frequency sweep between 10 kHz and 10 MHz provided an optimum frequency of 150 kHz. This frequency was fixed while performing the experiments. Figs. 12 and 13 show the changes in capacitance with the movement of the left arm and left leg, respectively [15]. "Flexed" and "extended" were the terms used to describe when the limbs were bent and kept straight, respectively. It can be seen that the flexed position causes a rise in capacitance, unlike the extended position. This occurred due to the change in the area (A) and interdigital distance (d) of the patch. The two conditions were repeated in an oscillatory motion to check the stability in the response of the sensor patch.

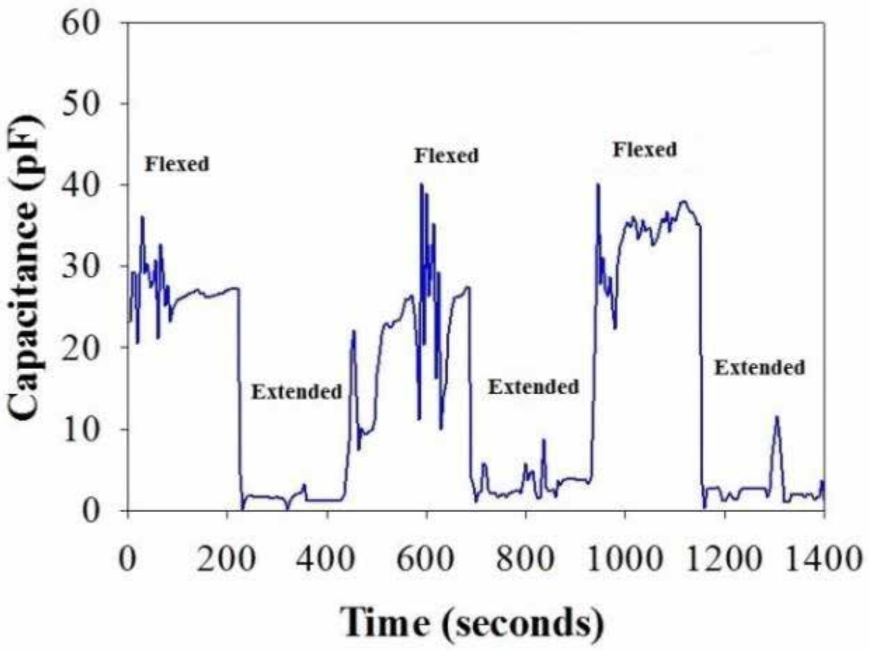


Fig. 12. Response of the sensor patch regarding capacitance towards the movement of the left arm [15].

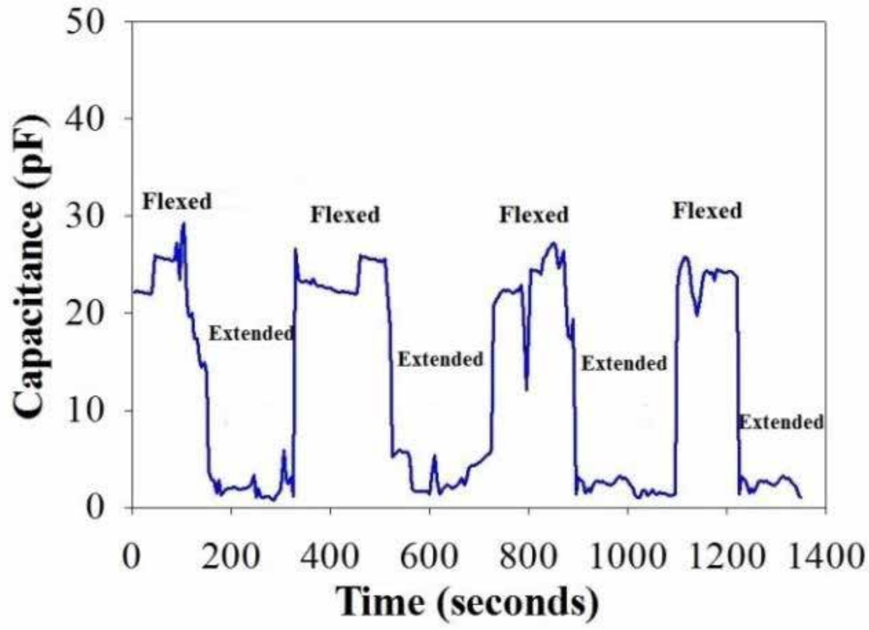


Fig. 13. Response of the sensor patch regarding capacitance towards the movement of left leg [15].

The sensor was further utilized to monitor respiration by attaching it to the lower part of the diaphragm of a human body. Fig. 14 shows the response of the sensor connected to two separate individuals. An increase in capacitance occurred with exhalation and decreased with inhalation.

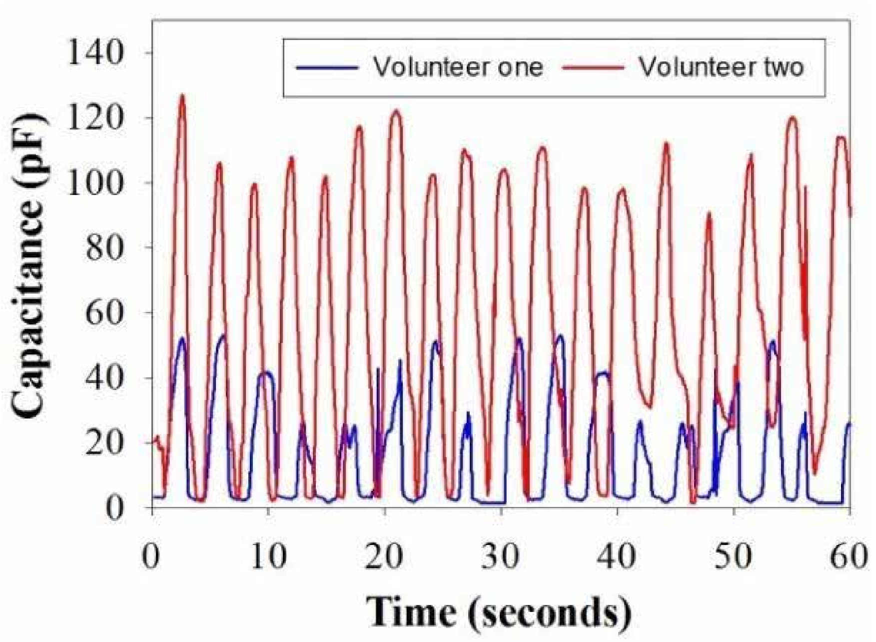


Fig. 14. Response of the sensor patch towards the monitoring of respiration of two volunteers [15].

The sensor developed with metallized PET films was used for tactile sensing [41]. This idea was proposed to overcome the drawbacks faced by existing prosthetic limbs, currently constructed using Carbon, Kelvin, and Dacron. The brittle nature and stiffness of these materials causes damage to the tissues in the areas of contact. Thus, the PET-Al sensor is an ideal replacement for these materials in the manufacturing of prosthetic limbs. Tactile sensing is a growing phenomenon with many applications, especially related to strain sensing [51], [52] and artificial intelligence [53], [54]. Fig. 15 shows the response of tactile sensing on the sensor patch. After profiling for a frequency sweep between 1 kHz and 1 MHz, a sensitive region of 200 kHz to 800 kHz was identified for this particular sensor patch.

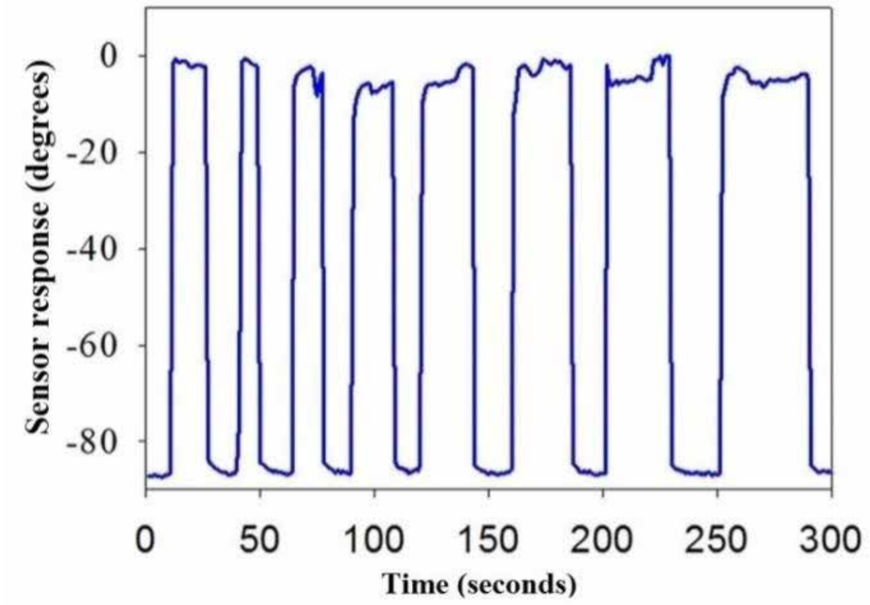


Fig. 15. Response of the sensor towards tactile sensing [41].

A frequency of 305 kHz was fixed while performing the experiments. Manual pressure was applied to the sensing surface of the patch to determine the change in its response, and this response was calculated in phase angle against time. The value was found to decrease when pressure was applied to the sensor. This occurred due to an increase in reactance of the sensor. The stability in the response was checked by repeating the tactile motion in an oscillatory fashion. The graphene-PI sensors were employed to test different salt concentrations in order to investigate an idea for urinary incontinence faced by the elderly. Urinary incontinence, in simple terms, can be defined as a loss of control of the urinary bladder, leading to the accidental or involuntary loss of urine. This can cause embarrassment for the person suffering from it. This problem can be triggered by high levels of stress, stones in the urinary track, multiple sclerosis, Parkinson's disease, etc. Pregnancy, childbirth, and menopause make urinary incontinence more common among women than men. The aim would be to design a low-cost system that could be operated by nonexperts to detect urinary incontinence. Among the various elements which comprise urine, salt in the form of sodium ions is present. Therefore, experiments were conducted with different salt concentrations to assess the ability of the sensor to detect such small concentrations. A series of solutions ranging from 5 ppm to 30 ppm with a difference of 5 ppm were prepared by mixing laboratory-grade sodium chloride and de-ionized water (resistance: 18.2 MΩ). A principal solution of 100 ppm was initially prepared from the dilution solutions, which were formulated by pipetting. A frequency sweep was done between 10 Hz and 10 kHz to determine the sensitive region of the patch. The response of the sensor patch regarding phase angle vs. frequency is shown in Fig. 16. One of the frequencies was fixed from the sensitive region to develop a characteristic curve of the sensor. Fig. 17 shows the curve developed with the sensor response in terms of resistance (MΩ) vs. concentration (ppm). This frequency would be fixed in the sensor to form an embedded system in the process of developing a complete urinary incontinence detection system.

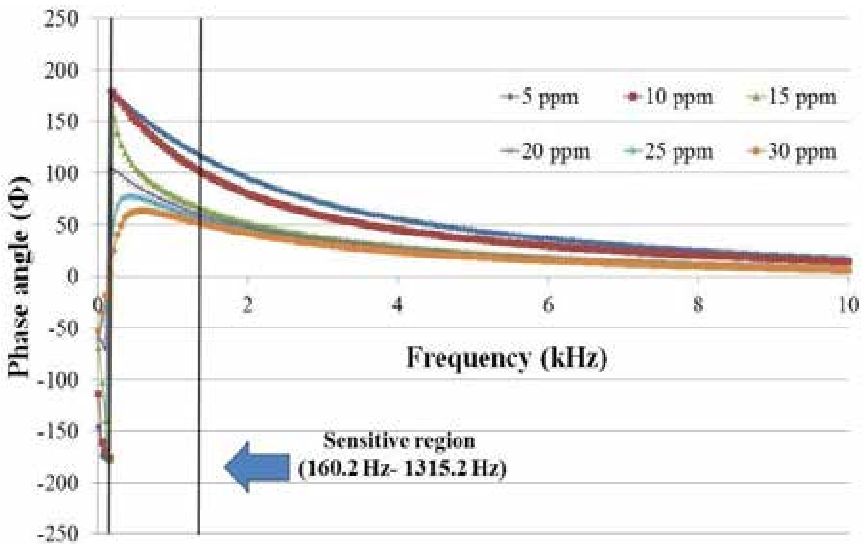


Fig. 16. Response of the graphene-PI towards different salt concentrations. The frequency-sensitive region was obtained by testing the sensor with a frequency sweep between 10 Hz and 10 kHz.

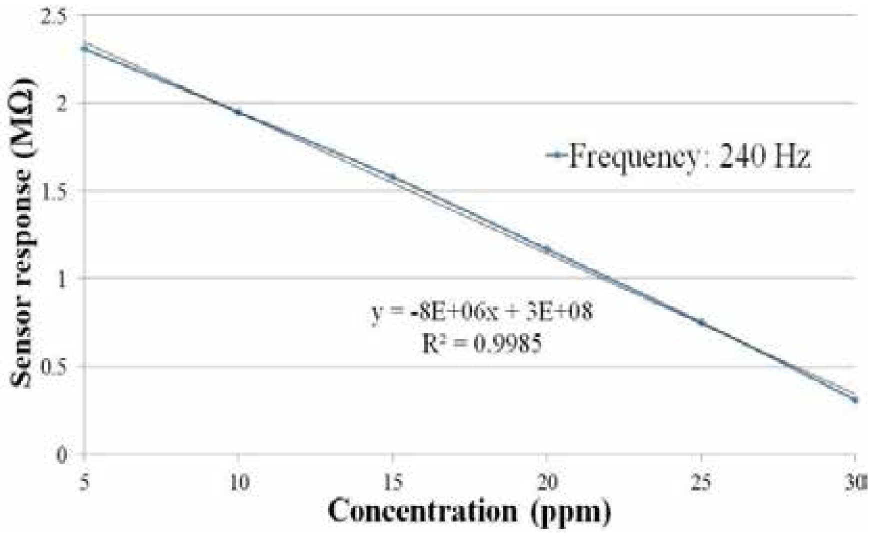


Fig. 17. Standard curve for different tested concentrations in terms of resistance.

Conclusion

The design, fabrication, and implementation of some novel wearable sensors were explained in this article. In order to develop the sensors, three different types of flexible materials were selected based on their particular properties. A laser cutting technique was employed in curving the electrodes in all three sensor prototypes. These sensor patches were utilized to monitor different physiological parameters on a primary scale. Limb movements, respiration, tactile sensing, and urinary incontinence detection were focused on as primary applications for the fabricated sensors. The next step would be to develop more wearable flexible sensors based on the ideas imparted in this article and also utilize these developed sensors to monitor other physiological parameters.

Acknowledgment

The authors would like to acknowledge King Abdullah University of Science and Technology (KAUST), Saudi Arabia, for providing research facilities for designing and developing the sensor prototypes. The authors would also like to thank Macquarie University for the opportunity to characterize and test the fabricated prototypes.

References

1. M. Sze, Semiconductor sensors, New York, NY, USA: Wiley, 1994.
2. A. Nag, A. I. Zia, X. Li, S. C. Mukhopadhyay, and J. Kosel, "Novel sensing approach for LPG leakage detection: Part I—Operating mechanism and preliminary results," IEEE Sens. J., vol. 16, no. 4, pp. 996–1003, Feb. 2016.
3. A. Nag, A. I. Zia, X. Li, S. C. Mukhopadhyay, and J. Kosel, "Novel sensing approach for LPG leakage detection—Part II: Effects of particle size, composition, and coating layer thickness," IEEE Sens. J., vol. 16, no. 4, pp. 1088–1094, Feb. 2016.
4. A. I. Zia et al., "Development of Electrochemical Impedance Spectroscopy based sensing system for DEHP detection," in 2011 5th Int. Conf. Sensing Techonology (ICST), pp. 666–674.
5. A. I. Zia, M. S. A. Rahman, S. C. Mukhopadhyay et al., "Technique for rapid detection of phthalates in water and beverages," J. Food Eng., vol. 116, no. 2, pp. 515–523, 2013.
6. S. C. Mukhopadhyay and C. P. Gooneratne, "A novel planar-type biosensor for noninvasive meat inspection," IEEE Sens. J., vol. 7, no. 9, pp. 1340–1346, Sept. 2007.
7. G. Comina, A. Suska, and D. Filippini, "PDMS lab-on-a-chip fabrication using 3D printed templates," Lab Chip, vol. 14, no. 2, pp. 424–430, 2014.
8. M. X. Jing, C. Han, M. Li, and X. Q. Shen, "High performance of carbon nanotubes/silver nanowires-PET hybrid flexible transparent conductive films via facile pressing-transfer technique," Nanoscale Res. Lett., vol. 9, no. 1, pp. 1–7, Oct. 2014.
9. J. H. Moon, D. H. Baek, Y. Y. Choi et al., "Wearable polyimide–PDMS electrodes for intrabody communication," J. Micromech. Microeng., vol. 20, no. 2, p. 025032, Feb. 2010.
10. D. Langley, G. Giusti, C. Mayousse et al., "Flexible transparent conductive materials based on silver nanowire networks: A review," Nanotechnology, vol. 24, no. 45, pp. 452001, Oct. 2013.
11. M. Amjadi and I. Park, "Carbon nanotubes-ecoflex nanocomposite for strain sensing with ultra-high stretchability," in 2015 28th IEEE Int. Conf. Micro Electro Mechanical Systems (MEMS), pp. 744–747.
12. S. Karki and J. Lekkala, "Film-type transducer materials PVDF and EMFi in the measurement of heart and respiration rates," in IEEE Int. Conf. Eng. Medicine Biology Soc. (EMBS), pp. 530–533, 2008.
13. Y. Jiang, H. Hamada, S. Shiono et al., "A PVDF-based flexible cardiorespiratory sensor with independently optimized sensitivity to heartbeat and respiration," Procedia Eng., vol. 5, pp. 1466–1469, 2010.
14. Y. Y. Chiu, W. Y. Lin, H. Y. Wang et al., "Development of a piezoelectric polyvinylidene fluoride (PVDF) polymer-based sensor patch for simultaneous heartbeat and respiration monitoring," Sens. Actuators A-Phys., vol. 189, pp. 328–334, Jan. 2013.
15. A. Nag, S. C. Mukhopadhyay, and J. Kosel, "Flexible carbon nanotube nanocomposite sensor for multiple physiological parameter monitoring," Sens. Actuators A-Phys., vol. 251, pp. 148–155, Nov. 2016.
16. S. Yao and Y. Zhu, "Wearable multifunctional sensors using printed stretchable conductors made of silver nanowires," Nanoscale, vol. 6, no. 4, pp. 2345–2352, 2014.
17. E. F. Nuwaysir, W. Huang, T. J. Albert et al., "Gene expression analysis using oligonucleotide arrays produced by maskless photolithography," Genome Res., vol. 12, no. 11, pp. 1749–1755, Nov. 2002.
18. W. Y. Chang, T. H. Fang, H. J. Lin, Y. T. Shen, and Y. C. Lin, "A large area flexible array sensors using screen printing technology," J. Display Technol., vol. 5, no. 6, pp. 178–183, June 2009.
19. M. Schuettler, S. Stiess, B. V. King, and G. J. Suaning, "Fabrication of implantable microelectrode arrays by laser cutting of silicone rubber and platinum foil," J. Neural Eng., vol. 2, no. 1, pp. S121–S128, Mar. 2005.
20. G. Chryssolouris, Laser machining: Theory and practice, New York, NY, USA: Springer Science & Business Media, 1991.

21. J. Hillman, Y. Sukhman, D. Miller, M. Oropeza, and C. Risser, "Multiwave hybrid laser processing of micrometer scale features for flexible electronic applications," in Proc. SPIE. 9736, Laser-based Micro- and Nanoprocessing X, p. 97360E, Mar. 2016.
22. A. Kumar, N. S. Bandeshah, A. N. Nripjit et al., "State of the art of CO2 laser beam machining," Int. J. Emerg. Technol. Adv. Eng., vol. 4, no. 4, pp. 993–999, 2014.
23. "Laser engraving and cutting system." [Online]. Accessed on Apr. 14, 2017.
24. "FEDERAL STANDARD 209E FOR CLEANROOM." [Online]. Accessed on Apr. 14, 2017.
25. "FS 209E and ISO 14644 cleanroom classification standards." [Online]. Accessed on Apr. 14, 2017.
26. "FS209E and ISO cleanroom standards." [Online]. Accessed on Apr. 14, 2017.
27. "ISO cleanroom classifications." [Online]. Accessed on Apr. 14, 2017.
28. "PDMS: Fabrication and key features." [Online]. Accessed on Apr. 14, 2017.
29. Z. Isiksacan, M. T. Guler, B. Aydogdu, I. Bilican, and C. Elbuken, "Rapid fabrication of microfluidic PDMS devices from reusable PDMS molds using laser ablation," J. Micromech. Microeng., vol. 26, no. 3, p. 035008, 2016.
30. A. W. Holle, S. H. Chao, M. R. Holl, J. M. Houkal, and D. R. Meldrum, "Characterization of program controlled CO2 laser-cut PDMS channels for lab-on-a-chip applications," in IEEE Int. Conf. Automation Science and Engineering, pp. 621–627, 2007.
31. H. B. Liu and H. Q. Gong, "Templateless prototyping of polydimethylsiloxane microfluidic structures using a pulsed CO2 laser," J. Micromech. Microeng., vol. 19, no. 3, p. 037002, 2009.
32. A. Eatemadi, H. Daraee, H. Karimkhanloo et al., "Carbon nanotubes: Properties, synthesis, purification, and medical applications," Nanoscale Res. Lett., vol. 9, no. 1, p. 393, 2014.
33. N. G. Sahoo, S. Rana, J. W. Cho et al., "Polymer nanocomposites based on functionalized carbon nanotubes," Prog. Polym. Sci.,, vol. 35, no. 7, pp. 837–867, 2010.
34. C. X. Liu and J. W. Choi, "Improved dispersion of carbon nanotubes in polymers at high concentrations," Nanomaterials, vol. 2, no. 4, pp. 329–347, 2012.
35. H. C. Jung et al., "CNT/PDMS composite flexible dry electrodesfor long-term ECG monitoring," IEEE Trans. Biomed. Eng., vol. 59, no. 5, pp. 1472–1479, May 2012.
36. "ISO standards for CO2 laser cutters." [Online]. Accessed on Apr. 14, 2017.
37. "PLS user guide." [Online]. Accessed on Apr. 14, 2017.
38. "Laser cutter classes." [Online]. Accessed on Apr. 14, 2017.
39. "Universal laser systems." [Online]. Accessed on Apr. 14, 2017.
40. "Class 4 conversion module." [Online]. Accessed on Apr. 14, 2017.
41. A. Nag, S. C. Mukhopadhyay, and J. Kosel, "Tactile sensing from laser-ablated metallized PET films," IEEE Sens. J., vol. 17, no. 1, pp. 7–13, Jan. 2016.
42. "Laser cutting and engraving of PET." [Online]. Accessed on Apr. 14, 2017.
43. "Cutting PET with CO2 laser." [Online].
44. A. de la Escosura-Muñiz, M. Espinoza-Castañeda, M. Hasegawa et al., "Nanoparticles-based nanochannels assembled on a plastic flexible substrate for label-free immunosensing," Nano Res., vol. 8, no. 4, pp. 1180–1188, Apr. 2015.
45. "Aluminium: Advantages and properties of aluminium." [Online]. Accessed on Apr. 14, 2017.
46. J. Lin, Z. Peng, Y. Liu et al., "Laser-induced porous graphene films from commercial polymers," Nat. Commun., vol. 5, 2014.
47. "Laser cutting of polyimide." [Online]. Accessed on Apr. 14, 2017.
48. "Processing plastics with CO2 lasers." [Online]. Accessed on Apr. 14, 2017.
49. G. B. Collins, "Laser processing of polyimide on copper," M.S. thesis, Dept. Elect. Eng. Virginia Polytech. Inst. and State Univ., Blacksburg, 2001.
50. M. S. A. Rahman, S. C. Mukhopadhyay, and P. L. Yu, "Novel planar interdigital sensors," in Novel Sensors for Food Inspection: Modelling, Fabrication and Experimentation. Cham, CH: Springer Int., 2014. pp. 11–35.
51. R. D. P. Wong, J. D. Posner, and V. J. Santos, "Flexible microfluidic normal force sensor skin for tactile feedback," Sens. Actuators A-Phys., vol. 179, pp. 62–69, 2012.
52. J. Engel, J. Chen, and C. Liu, "Development of polyimide flexible tactile sensor skin," J. Micromech. Microeng., vol. 13, no. 3, pp. 359–366, 2003.
53. R. S. Dahiya et al., "Towards tactile sensing system on chip for robotic applications," IEEE Sens. J., vol. 11, no. 12, pp. 3216–3226, June 2011.
54. R. S. Dahiya, G. Metta, M. Valle, and G. Sandini, "Tactile sensing—from humans to humanoids," IEEE Trans. Robot., vol. 26, no. 1, pp. 1–20, Feb. 2010.

Mr. Anindya Nag (anindya1991@gmail.com) has completed his Bachelor of Technology degree on Electronics and Communication from West Bengal Institute of Technology, India in 2013 and received his Master of Engineering (M.E.) degree from Massey University, New Zealand in June 2015. His major during his M.E. degree was Electronics and Computer Systems. His research interests are in the area of Smart Sensors and Sensing Technology for home and environmental monitoring. He is currently pursuing Ph.D. in Faculty of Engineering at Macquarie University, Australia and is working on Printed Flexible Sensors for Human Wellness.

Dr. Subhas Chandra Mukhopadhyay (M’97, SM’02, F’11; Subhas.Mukhopadhyay@mq.edu.au) graduated from the Department of Electrical Engineering, Jadavpur University, Calcutta, India with a Gold medal and received the Master of Electrical Engineering degree from Indian Institute of Science, Bangalore, India. He has Ph.D. (Eng.) degree from Jadavpur University, India and Doctor of Engineering degree from Kanazawa University, Japan. Currently he is working as a Professor of Mechanical/Electronics Engineering with the Department of Engineering, Macquarie University, New South Wales, Australia. He is the Program Leader of the Mechatronics Engineering Degree Program. He has over 26 years of teaching and research experiences. His fields of interest include Smart Sensors and Sensing Technology, Wireless Sensor Networks, Instrumentation and Measurements, Internet of Things, Environmental Measurements, Electromagnetics, Control Engineering, Mechatronics, Magnetic Bearing, Fault Current Limiter, Electrical Machines and numerical field calculation etc. He has authored/co-authored over 400 papers in different international journals, conferences and book chapter. He has edited fifteen conference proceedings. He has also edited seventeen special issues of international journals as lead guest editor and thirty books with Springer-Verlag. He was awarded numerous awards throughout his career and attracted over US$3.0 M on different research projects. He has delivered 296 seminars including keynote, tutorial, invited and special seminars. He is a Fellow of IEEE (USA), a Fellow of IET (UK) and a Fellow of IETE (India). He is a Topical Editor of IEEE Sensors Journal, and an Associate Editor IEEE Transactions on Instrumentation and Measurements. He is in the editorial board of e-Journal on Non-Destructive Testing, Sensors and Transducers, Transactions on Systems, Signals and Devices (TSSD). He is the co-Editor-in-chief of the International Journal on Smart Sensing and Intelligent Systems. He was the Technical Program Chair of ICARA 2004, ICARA 2006, ICARA 2009 and IEEE I2MTC 2016. He was the General chair/co-chair of ICST 2005, ICST 2007, IEEE ROSE 2007, IEEE EPSA 2008, ICST 2008, IEEE Sensors 2008, ICST 2010, IEEE Sensors 2010, ICST 2011, ICST 2012, ICST 2013, ICST 2014, ICST 2015 and ICST 2016. He has organized the IEEE Sensors conference 2009 at Christchurch, New Zealand during October 25 to 28, 2009 as the General Chair. He is currently organizing the 11th ICST in Sydney, Australia during December 4-6, 2017. He is the Ex-Chair of the IEEE Instrumentation and Measurement Society New Zealand Chapter. He is a Distinguished Lecturer of IEEE Sensors Council from 2017-2019.

Consumer Autonomy 'On Purpose'

by Mark Halverson and Leanne Seeto

If you had to pick one, would you rather:

1. see an ad for a consumer device you've looked at beside every web search you do,
2. own a doll that reports recordings of its interactions with your child, or
3. drive a car which could kill the driver to avoid harming others.

At the moment all could be true, but you don't get to vote.

Autonomy is upon us and the sad reality is that while as human beings (and consumers), we are materially impacted by those staging our thinking and intentionally biasing our decisions, we have no insight into the rules by which that Autonomy operates. In this context, Autonomy is any robot or machine (digital or physical) which interacts with a human being based on a set of rules without being operated/piloted in real time by another human being. And while we may dismiss the intrusion as merely marketing, with a higher and higher percentage of our daily experience delivered digitally (and therefore capable of scale impact/manipulation), the greater the need for transparency as to how this Autonomy is making decisions.

It feels easy to dismiss today. A targeted ad for a pair of running shoes showing up alongside a search doesn't seem important. But when digital/autonomous and physical worlds intersect, the risk grows materially. In 2015, when an interactive Barbie doll was launched that recorded the interactions of its users (children), privacy advocates were aghast at the intrusion. And yet every day more and more Google Homes and Amazon Alexas are finding their way into our homes and recording our activities. Another obvious example comes up in the philosophical debate as to whether an autonomous car may choose to kill the driver instead of hitting a school bus or running into a crowd of people.

Every technological breakthrough requires infrastructure supporting its safe integration into society. The horseless carriage would not have achieved ubiquity without infrastructure such as roads, fueling stations, auto insurance, traffic laws and signals, and so many other ecosystem services. Artificial intelligence and Autonomy are in their infancy and currently lack the infrastructure required to be readily adopted by society.

There are multiple initiatives and standards within the IEEE that are seeking to address this issue.

- IEEE P7000™:Model Process for Addressing Ethical Concerns During System Design (Working Group already in process)
- IEEE P7001™: Transparency of Autonomous Systems (Working Group already in process)
- IEEE P7002™: Data Privacy Process (Working Group already in process)

Our challenge now as we move towards an Autonomy economy is how to define the appropriate ethical infrastructure which will enable an entire new class of AI-enhanced jobs, services, and capabilities.

The authors believe an "On Purpose" infrastructure will build trust and offer transparency into the operation of Autonomy. An "On Purpose" infrastructure registers and maintains an overt and specific intention or goal of autonomy, enabling transparency and auditability of autonomous actions against the registered intent.

Standards can play a direct role by establishing a registry of purposes that are clearly defined and to which designers of autonomous systems could subscribe. This structure could be similar to how SIC (Standard Industrial Classification) codes are used across industries today. Such "purpose" categories may include package delivery, marketing, entertainment, self-help, health care, fitness tracking, etc., with a level of granularity under the broad categories allowing for auditability. This type of transparent standard and registry would allow designers, operators, and users to maintain a common expectation for how the systems should operate and therefore flag discrepancies if systems move beyond their stated purpose. Standards of deviation from these purposes should also be established to enable crowdsourced monitoring of autonomous actions and an industry standard reporting mechanism for validating the efficacy of autonomous systems.

Those who study the nature of human decision making may be disappointed by the malleability of the heuristics we use to govern most actions and the inherent bias exhibited in our behavior. Therefore, we should seek a model for Autonomy which enhances human ethical decision making and transparency. Autonomy should act "on purpose" where the full extent of the purpose is clearly articulated and therefore actions (and the associated decision-making process) are auditable against the stated purpose. If your companion robot reached out to hold your hand, wouldn't it be nice to be able to press the "WHY" button and have the machine tell you why it did what it did?

One firm, Precision Autonomy, has begun building this "On Purpose" infrastructure and is applying it to drones/UAVs. At present, drones have an intent that is easily understood and overtly expressed in the form of a mission plan. And they can be tracked in real time to detect any diversion from this mission plan (purpose). This type of transparent operation will continue to build confidence in the adoption of drones while establishing baseline industry infrastructure for more complex Autonomy.

In contrast, much Autonomy has entered our lives and homes without visibility into its purpose and rules for decision making. In the case of the Barbie doll, was it clear that "interactive" meant that it was going to report interactions with children? In the case of Google Home, is it clear that all sounds within a certain proximity can be reported? We need to create transparency for some simple and important concepts by asking the following:

- What is the stated purpose of the Autonomy?
  How do I verify that the Autonomy is following its purpose?
- Who is the beneficiary—what is the customer value proposition?
- Who is the beneficiary—what is the underlying business model?
- Can I opt-in or opt-out with reasonable knowledge of the autonomous actions?

For example, we suspect few people would interact with a service whose stated purpose was to record interactions and sell them to those who manipulate decision-making processes for buying products. May the buyer beware: when the service is free, often **you** are the product.

This is becoming too important to place within a lengthy privacy policy hidden behind an "I Accept" button. It's time that we start contemplating a richer and simpler set of disclosures as well as a registry in which consumer-oriented Autonomy must offer transparency in terms of its overt and covert actions. It's time Autonomy starts operating "on purpose" to unleash the Autonomy economy.

With appropriate "On Purpose" infrastructure in place, the human condition will be enhanced. People will interact and extend themselves with Autonomy in ways that have yet to even be imagined. With new human-centered on purpose capabilities, entire new segments of the economy will form, driving new jobs while enabling the upward march of humanity. IEEE members should be seeking to get involved in initiatives such as P7000 to help shape the categories and definitions of purposes, which can form the basis of a new class of registry such as the Standard Industrial Classification (SIC) structure.

Mark Halverson is the CEO of Precision Autonomy, whose mission is to enable the safe commercial and social integration of autonomous technologies. Precision Autonomy operates at the intersection of artificial intelligence and robotics to allow UAVs and other unmanned vehicles to operate more autonomously. Precision Autonomy has developed an "On Purpose" infrastructure, ensuring machines operate in transparent, predictable, and auditable ways while always keeping human needs at the center.

Mark has over 25 years of consulting experience, working with the world's largest corporations in shaping strategies to embrace innovation and disruption.

Leanne Seeto is a Co-Founder of Precision Autonomy whose mission is to make autonomous IoT services a safe reality. Integrating government, corporates, education and people in the Autonomy Economy. Leanne has over 20 years' experience working in Sydney, London, Tokyo and in the US in startups through to multi-national corporations. She has worked with large corporations developing new market strategies and commercializing disruptive technologies. She has a BSc in Applied Mathematics and Computer Science and is an alumnus of Singularity University. She is the Communications Committees Co-Lead for the IEEE Global Initiative for Ethically Aligned Design of Autonomous Systems.

IEEE P2048 Standards Paving the Road for Virtual Reality and Augmented Reality

by Yu Yuan

IEEE P2048 Working Group is developing twelve standards for virtual reality (VR) and augmented reality (AR). Having attracted participants from over 200 companies and institutions all over the world, the working group now is one of the largest forces dedicated to VR/AR standardization. The working group participants already include device manufacturers, content providers, service providers, technology developers, government agencies and other parties relevant to VR/AR, constituting an excellent mixture for the standards to be widely adopted.

Technology is evolving very fast, especially in VR/AR. Our current being-developed standards only cover a small piece of the VR/AR landscape. We are actively collecting and identifying standardization needs. Some of them could become new projects in the coming months. We welcome interested stakeholders to join our efforts. We seek to provide unique value in the area of VR/AR, based on our depth and breadth of technical expertise. We also are interested in collaborating with other organizations.

The twelve VR/AR standards being developed each focus on a different area of critical work, and include:

IEEE P2048.1 – Standard for Virtual Reality and Augmented Reality: Device Taxonomy and Definitions
This standard specifies the taxonomy and definitions for Virtual Reality (VR) and Augmented Reality (AR) devices. Thanks to the recent technology advances and market growth, more and more companies are producing various VR/AR devices, which include but are not limited to head mounted displays, remote controllers, sensor stations, etc. This project is needed to reduce the emerging confusion in many VR/AR devices that have similar or misleading product names but significantly different functions or performance. By dividing VR/AR devices into different categories and levels, this standard could help end users choose the right devices, facilitate the development of cross-platform content and services, and promote a healthy growth of the VR/AR industry.

IEEE P2048.2 – Standard for Virtual Reality and Augmented Reality: Immersive Video Taxonomy and Quality Metrics
This standard specifies the taxonomy and quality metrics for immersive video. Immersive video is an enabling technology behind many Virtual Reality (VR) applications in various vertical industries (e.g., media, entertainment, education, and tourism). Due to the rapid market growth recently, there have been many variants of immersive video which are different in several aspects: 360 degrees or 180 degrees, stereoscopic or not, view point movable or not, focus adjustable or not, etc. This project is needed to reduce the confusion among these variants as they are often simply called "VR video" in today's market. By dividing immersive video into different categories and levels, this standard could help end users choose the right products, facilitate the development of cross-platform content and services, and promote a healthy growth of the VR industry.

IEEE P2048.3 – Standard for Virtual Reality and Augmented Reality: Immersive Video File and Stream Formats
This standard specifies the formats of immersive video files and streams, and the functions and interactions enabled by the formats. Immersive video is an enabling technology behind many Virtual Reality (VR) applications in various vertical industries (e.g., media, entertainment, education, and tourism). Due to the rapid market growth recently, there have been many variants of immersive video which are different in several aspects: 360 degrees or 180 degrees, stereoscopic or not, view point moveable or not, focus adjustable or not, etc. This project is needed to define the immersive video file and stream formats that support all the variants and facilitate the development of cross-platform content and services. This standard identifies existing applicable video coding standards, and defines the integration of these standards into immersive video.

IEEE P2048.4 – Standard for Virtual Reality and Augmented Reality: Person Identity
The standard specifies the requirements and methods for verifying a person's identity in virtual reality. Many of the most important long-term applications for virtual reality, like distance education, e-commerce, work meetings, or simulation and training will rely on maintaining a meaningful representation of yourself that can travel across multiple servers. For example, you might be invited to a meeting at another company where you want to both appear as your chosen appearance (your 'avatar') and also be able to authenticate/prove that you are who you say you are. Similarly, you might want to go to school or go shopping as the same visual avatar. Given that VR will be a very 'social' medium, with many experiences depending on the presence of other people. The standard would allow a virtual reality user to; identify themselves to a site or service through a number of identity authorities; authenticate singular pieces

of information without needing to trust the site with additional information; present themselves with specific visual assets; while having the visualization of their appearance certified.

IEEE P2048.5 – Standard for Virtual Reality and Augmented Reality: Environment Safety
This standard specifies recommendations for workstation and content consumption environment for Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) and all related devices where a digital overlay might interact with the physical world, potentially impacting users' perception. This standard focuses on setting quality assurance and testing standards for qualifying products in said environments, achieving satisfactory safety levels for creation and consumption environment for all or majority of related products available for consumer and commercial purposes. The rise of popularity of digital/analog reality products in consumer electronics, as well as in commercial/industrial fields is requiring a balanced approach to designing a safe environment for developers and consumers. Virtual Reality and Augmented Reality enable new levels of productivity and speed up the training and content creation, yet standardization is necessary in order to provide a safe zone around the device and its operator. Standardization is viewed as the most efficient way to remove obstacles which operators or consumers might encounter, potentially including mandatory detection of objects in close proximity and releasing a warning if the interaction is deemed potentially hazardous. By providing necessary recommendations, we can reduce or eliminate potentially negative impacts which the industry faces.

IEEE P2048.6 – Standard for Virtual Reality and Augmented Reality: Immersive User Interface
This standard specifies the requirements and methods for enabling the immersive user interface in Virtual Reality (VR) applications, and the functions and interactions provided by the immersive user interface. Most of the Virtual Reality (VR) applications are supposed to provide fully immersive experiences, which could be spoiled by non-immersive user interfaces such as the ones enabled by conventional keyboards, mice, and touchscreens. The industry has recognized the necessity of immersive user interfaces in VR applications, and has put lots of efforts in designing and developing various prototypes or component technologies. This project is needed to unite these efforts and specify the baselines of immersive user interfaces in order to help facilitate the development of cross-platform content and services, and promote a healthy growth of the VR industry.

IEEE P2048.7 – Standard for Virtual Reality and Augmented Reality: Map for Virtual Objects in the Real World
This standard specifies the requirements, systems, methods, testing and verification for Augmented Reality (AR) and Mixed Reality (MR) applications to create and use a map for virtual objects in the real world. Augmented Reality (AR) and Mixed Reality (MR) applications add virtual objects on top of the real world. In many scenarios, virtual objects are supposed to be perceived as real objects so that they should have their own coordinates and orientations in the real world like real objects do. This project is needed to specify a unified map for various AR and MR applications to assign coordinates, orientations, and other arguments in the real world to virtual objects. The shared use of virtual objects among different users or even among different applications could be enabled by such a map.

IEEE P2048.8 – Standard for Virtual Reality and Augmented Reality: Interoperability between Virtual Objects and the Real World
This standard specifies the requirements, systems, methods, testing and verification for the interoperability between virtual objects and the real world in Augmented Reality (AR) and Mixed Reality (MR) applications. Augmented Reality (AR) and Mixed Reality (MR) applications add virtual objects on top of the real world. In some scenarios, virtual objects are not only perceivable as real objects, but also supposed to interact with real objects and the real world. This project is needed to define different categories and levels of the interoperability between virtual objects and the real world, and specify the systems and methods that enable these categories and levels.

IEEE P2048.9 – Standard for Virtual Reality and Augmented Reality: Immersive Audio Taxonomy and Quality Metrics
This standard specifies the taxonomy and quality metrics for immersive audio. Immersive audio is an enabling technology behind many Virtual Reality (VR) applications in various vertical industries (e.g., media, entertainment, education, and tourism). Due to the rapid market growth recently, there have been many variants of immersive audio. This project is needed to reduce the confusion among these variants. By dividing immersive audio into different categories and levels, this standard could help end users choose the right products, facilitate the development of cross-platform content and services, and promote a healthy growth of the VR industry.

IEEE P2048.10 – Standard for Virtual Reality and Augmented Reality: Immersive Audio File and Stream Formats
This standard specifies the formats of immersive audio files and streams, and the functions and interactions enabled by the formats. Immersive audio is an enabling technology behind many Virtual Reality (VR) applications in various vertical industries (e.g., media, entertainment, education, and tourism). Due to the rapid market growth recently, there have been many variants of immersive audio. This project is needed to define the immersive audio file and stream formats that support all the variants and facilitate the development of cross-platform content and services. This standard identifies existing applicable audio coding standards, and defines the integration of these standards into immersive audio.

IEEE P2048.11 – Standard for Virtual Reality and Augmented Reality: In-Vehicle Augmented Reality
This standard defines an overarching framework for Augmented Reality (AR) systems that assist drivers and/or passengers in vehicles. In-vehicle augmented reality has become a new way of providing driving assistance and other infotainment services in vehicles, and is regarded as a promising vertical application of augmented reality. It can be implemented on various devices: Head Up Displays, Smart Glasses, etc. The common point is to make the user interface more friendly while avoiding or minimizing the risk of distracted driving. This project is needed to specify the requirements and methods for applying augmented reality in vehicles, identify existing applicable standards, and define the integration of these standards into a consistent vehicular environment.

IEEE P2048.12 – Standard for Virtual Reality and Augmented Reality: Content Ratings and Descriptors This standard defines the content ratings and descriptors for Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR). The immersive and realistic experiences enabled by Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) enrich people's lives, but some of them have the potential to cause mental or even physical problems (e.g. epileptic seizure). For example, unlike the situation in a theme park in the real world that people could choose not to ride a roller coaster after they see its performance and feel it is too dangerous, usually people are not fully aware of what they are facing before they put on a VR headset and enter a VR game for the first time. Even worse is the fact that people might not have the option to stop or escape when they are forced to ride a virtual roller coaster in a VR game. Hence, in addition to the traditional ratings and descriptors that address the ethical issues such as violence and sexual content, new ratings and descriptors are needed to protect people's health and safety from risky VR/AR/MR content. This project is needed to define a comprehensive set of ratings and descriptors for VR/AR/MR content. Existing applicable standards will be identified and leveraged.

For more details, visit the VRAR – Virtual Reality and Augmented Reality Working Group webpage.

To join the IEEE P2048 Working Group, please contact Dr. Yu Yuan at y.yuan@ieee.org.

Dr. Yu Yuan is currently serving as the Chair of IEEE Digital Senses Initiative, the Standards Chair of IEEE Consumer Electronics Society, the Chair of IEEE Virtual Reality and Augmented Reality Working Group (IEEE P2048 Standards Series), and a Board Member of IEEE Standards Association Standards Board. He is also serving on several TRB Standing Committees and IFAC Technical Committees. As a veteran researcher and practitioner in the areas of Consumer Electronics, Transportation, and Internet of Things, he has filed numerous patents and published extensively in referred conferences and journals. Dr. Yuan founded Senses Global Corporation, a multinational technology company specializing in Virtual Reality, Augmented Reality, Human Augmentation, and Smart Robots. Prior to this he had been working for IBM Research as a research scientist.

Funny Pages

Standard Fare

by Guest Artist