Materials Today Chemistry 17 (2020) 100306

Contents lists available at ScienceDirect

Materials Today Chemistry

journal homepage: www.journals.elsevier.com/materials-today-chemistry/

Nano-enabled biosensing systems for intelligent healthcare: towards COVID-19 management

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ARTICLE INFO

Article history:
Received 11 May 2020
Received in revised form
28 May 2020
Accepted 30 May 2020
Available online 5 June 2020

Keywords:
Nano-sensors
Smart diagnostics
Point-of-care systems
Disease management
Personalized health care
COVID-19 diagnostics

ABSTRACT

Biosensors are emerging as efficient (sensitive and selective) and affordable analytical diagnostic tools for early-stage disease detection, as required for personalized health wellness management. Low-level detection of a targeted disease biomarker (pM level) has emerged extremely useful to evaluate the progression of disease under therapy. Such collected bioinformatics and its multi-aspects-oriented analytics is in demand to explore the effectiveness of a prescribed treatment, optimize therapy, and correlate biomarker level with disease pathogenesis. Owing to nanotechnology-enabled advancements in sensing unit fabrication, device integration, interfacing, packaging, and sensing performance at point-of-care (POC) has rendered diagnostics according to the requirements of disease management and patient disease profile i.e. in a personalized manner. Efforts are continuously being made to promote the state of art biosensing technology as a next-generation non-invasive disease diagnostics methodology. Keeping this in view, this progressive opinion article describes personalized health care management related analytical tools which can provide access to better health for everyone, with overreaching aim to manage healthy tomorrow timely. Considering accomplishments and predictions, such affordable intelligent diagnostics tools are urgently required to manage COVID-19 pandemic, a life-threatening respiratory infectious disease, where a rapid, selective and sensitive detection of human beta severe acute respiratory system coronavirus (SARS-COoV-2) protein is the key factor.

1. Emergence of nanotechnology-enabled biosensor-based diagnostics

Since the discovery of biosensors, efforts are continuously being made for translating a demonstrated and optimized sensing prototype to an analytical diagnostics tool [1–3] for clinical applications. Considering technological advancements and constant demand raised by experts, the biosensor market is predicted to be reaching up to 28 Billion USD with a compound annual growth rate (CAGR) of 8.4% by the year 2022 [4], as illustrated in Fig. 1A. For developing a biosensor of tunable salient features, all the aspects of nanoscience and nanotechnology have been introduced in the fabrication of next-generation systems that involve functionalized nanostructures, thin films, biocompatible functionalized materials, miniaturized transducers, introduction of microfluidic manifolds, device packaging, etc. (Fig. 1B, C, & D) [1,2].

A surface-enhanced Raman scattering (SERS) phenomena based selective and sensitive geno-sensing of specific neuro biomarker/cDNA (TuJ1) using graphene–Au hybrid nanoarray was investigated, as illustrated in Fig. 1B. In this research, Raman active dye-labelled probe DNA oligonucleotide were conjugated onto the graphene-Au nanoarray which participate in the enhancement of chemical and electromagnetic mechanism (EM) for SERS based biosensing. The plasmonic Au nanostructures participate in the amplification of Raman signal via electromagnetic mechanism whereas graphene simultaneously enhances the signal via chemical mechanism which brings into line the energy level of graphene oxide with the targeted analyte. Such developed efficient hybrid SERS nanoarray system could be useful to explore the cellular phenomena (stem cell differentiation, disease evolution etc.) [5]. A

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https://doi.org/10.1016/j.mtchem.2020.100306
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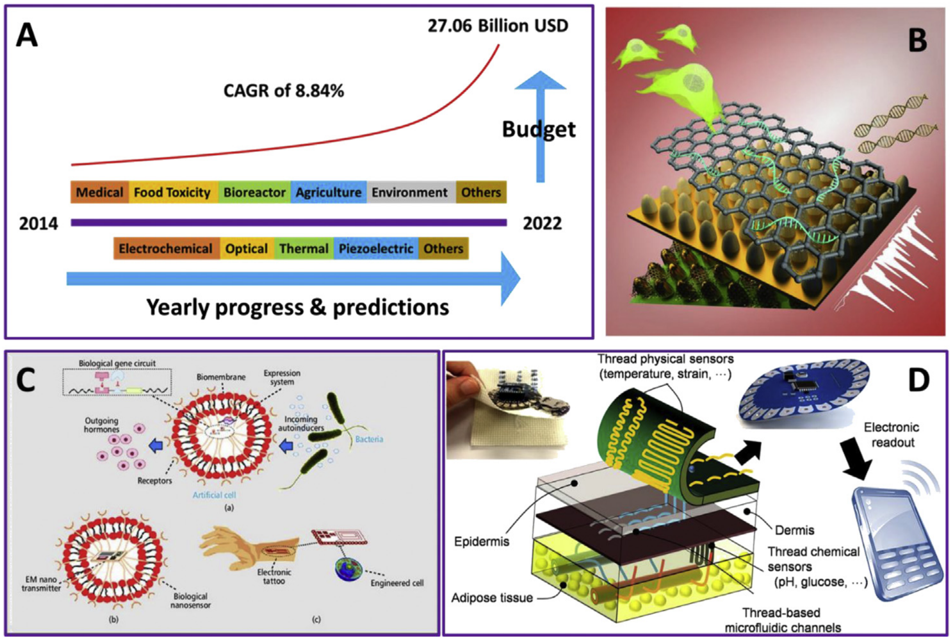

Fig. 1. A) Biosensor market analysis in the USA. This prediction is based on the various applications and types of biosensors [4]. B) smart ultrathin graphene layer fabricated on Au substrate integrated with Raman spectrophotometer for genetic (RNA, extracted from stem cell) materials detection [5]. C) Exploring artificial cells for the nano-bio interface-based networking. This approach of nanosensor development is an optimized combination and interfacing of artificial cells, nano-transmitter, bio-cyber interface, and electronic tattoo [6]. D) presentation of a transdermal health monitoring toolkit fabricated using thread-based chemical and physical sensors, microfluidic channels, and interconnects for the realization of a thread-based diagnostic device [7].

concept of Internet of Bio-Nano Things (IoBNT) was proposed by Akyildiz et al. for investigating nanoscale devices (Fig. 1C) to perform intra body sensing, environmental control for toxic substances and the pollution. The IoBNT is capable to transfer health informatics from inside the body to the external health provider via internet which has potential to evaluate drug delivery and efficacy. Further, electronic artificial tattoos are being designed for bio-cyber interface. In this direction, the biocyber interface is a set of process to translate biochemical information of IoBNT to the internet cyber domain via electromagnetic communications and vice versa as portrayed (Fig. 1C). Artificial cells are another successful nanotechnology tool applied for gene therapy, drug delivery, and artificial blood cell production. Therefore, IoBNT is a new technology which could be potentially explored for various health related issues [6]. A 3D analytical biosensing platform based on thread was fabricated by Mostafalu et al. (Fig. 1D). These threads acted 3D microfluidic channels for sensors and electronics needed for health monitoring. This group developed combination of physical and chemical sensors integrated within the microfluidic network. The microfluidic platform was developed via hydrophilic threads decorated onto the hydrophobic fabric (as illustrated in Fig. 1C). The treads serve as microfluidic channel for the controlled delivery of body fluids to the sensing platform. Nanomaterial based conductive threads were used as electrodes for measurements of pH, temperature, glucose and strain. The output of the sensing platform was connected to electronic readout for wireless communication and signal processing to a smart phone or computers. These thread-based devices could be used as implantable devices in the body for health monitoring [7].

Most importantly, cost-effective, miniaturized, easy to operate sensing devices are getting considerable attention in academia, laboratories, and industries to promote smart (highly sensitive and selective) biosensors as smart (keeping desired and physiological range in view) diagnostic systems [3–7].

As of now, developed sensing products, either wearable or non-wearable biosensors, based on electrochemical, optical, thermal and piezoelectric transduction technology, have shown remarkable performance, especially in the testing of blood glucose, cholesterol, triglycerides, pregnancy testing, infectious diseases, drug discovery, blood gas analysis, etc. [8–11]. Despite significant progress, efforts are being continuously made to improve the state of art sensing technology using more efficient and updated technologies to achieve sensing at a low level, especially picomolar (pM) level. However, the need for detecting a targeted biomarker at femtomolar (fM) is also emerging for infectious diseases management which raised the scope to develop smart biosensor i.e. more sensitive and selective. It has been reported that smart bio-sensing materials (selected to immobilized bio-active compounds involve enzyme, DNA, RNA, and antibody), based biosensing prototype chip integrated with a miniaturized potentiostat (M-P) fabricated using micro/nanoelectronics) is getting attention for performing diagnostics at POC applications (Fig. 2). Further, the interfacing M-P with a smartphone to operate M-P and to manage data for data storage and timely informatics analysis is commonly used practice to develop a biosensor of high performance and reliability [19,20].

2. Towards point-of-care diagnostics for personalized health wellness

Modern material science has facilitated the preparation and fabrication of nano-enabled smart sensing substrates (Fig. 1B) such as biopolymers, conducting polymers, metal oxides, gold, carbon nanotubes, graphene, quantum dots, composites, and hybrids [21,22]. The need to achieve high loading of biomolecules to achieve wide detection range and signal amplification to achieve sensing at a low level of biomarker raised the demand of exploring novel electro-active surface-functionalized nanostructures (Fig. 1C). Such nano-systems have also been successfully fabricated onto interdigitated microelectrodes (IDμE) for the development of a biosensor which can detect targeted biomarkers at a very low level (pM and fM). Such a low-level detection limit of a biosensor is very important to detect a disease-specific biomarker at an early stage

Fig. 2. The potential application of POC testing. An optimized smart POC diagnostics tool can detect the desired biomarker. Such of informatics can be analyzed for personalized health wellness.

i.e. onset of disease and to monitor a disease's progression under a prescribed therapy. Such of biosensors are recommended for the management of the diseases of infectious diseases causes by virus e.g. Zika and Ebola outbreak. In those diseases, the virus replicates in low concertation which is not detectable using polymerase chain reaction (PCR) and enzyme-linked immunosorbent assay (ELISA) but nano-enabled IDμE based biosensors are efficient to perform this task. This approach is also highly recommended to manage several other diseases (such as cancers and stress) along with environmental, agriculture, and food security-related aspects. More towards advancements sides, the IDμE-based bio-sensing chips are being integrated with M-P to promote bio-sensing applications from laboratory to field [4]. This micro/nano electronics-based approach is useful to design and develop portable biosensors of reduced form factors which is the foundation of diagnostics at POC application (Fig. 2) to perform personalized diagnostics [3,8,23–25].

Biosensors facilitate rapid sensing of a targeted biomarker, thereby it is possible to carry out the biomarker detection (or diseases diagnostics) multiple times in a day or a real-time manner. These features project such biosensors to generate enough of bio-informatics to understand the symptom variation and optimize timely therapeutics. Another sensing approach that is being explored to manage disease diagnostics in a real-time manner is MEMS/BioMEMS based bio-sensing. BioMEMS bio-sensing devices based on the pressure sensor, accelerometer, microfluidics, microphones, and ultrasonic sensors are in demand for health management due to automated handling and precise measurement (Fig. 1D). Due to the involvement of major players like Google, Apple, Amazon, etc., and the proven multiple benefits, the market business of BioMEMS based sensing devices will be around 6.9 Billion USD in 2023 with CAGR of 14.9% from 2017 to 2023, as proposed by Yole Development Inc [4]. However, a well-recommended focus towards exploring novel sensing methodologies such as capacitive/piezoelectric ultrasound detection, a cell-phone mobile-based health care wherein smartphone enables easy operation and data recording, and internet of medical things (IoMT) [26,27] for efficient data analysis and data sharing have been suggested by experts as E (electronics) - health to I (intelligent) – health [28]. The E-health includes smartphone-assisted sensing and personalized electronics for rapid bio-informatics collection along with real-time patient care monitoring, diagnostics at certain internal, and self-aware based diagnostics performance. In this era, the smartphone is very common electronic people keep this most of the time everywhere. This common practice can be useful to design a well-planned diagnostics or bio-informatics collection, where the differences of ecology, race, gender, age, etc., are important points of consideration to manage a targeted disease. Such of the intelligent use of electronic devices-based diagnostics in medical practice refers as I-health [29].

On applying fundamental of nano-biosensor technology, our research has also proposed development of smart miniaturized biosensing platform to detect a targeted biomarker such as Ebola, beta-amyloid, cortisol, and Zika-virus protein at low level (10 pM) needed to establish methodologies of rapid diagnostics at early-stage and disease progression monitoring with/without therapy [1–3,12–21]. These salient features enable diseases diagnostics and per requirement and generate bioinformatics to decide therapy timely and establishing a correlation between diseases progression and pathogenesis. Our established sensing prototypes are suitable for POC application [1–3,12,17]. For example, we have fabricated an electrochemical biosensor using IDEs modified using an appropriate self-assembled monolayer (SAM) to detect cortisol [15,16], a psychological stress biomarker at 10 pM within 40 min (Fig. 3A). The SAM based biosensor was tested using saliva collected from farmworker and plasma of HIV infected patients, and sensing outcomes were validated using ELISA [16]. This miniaturized IDE based cortisol immune-sensor was integrated with a microfluidic manifold for automated sampling of 10 μL and customized M-P (LMP 9100, Texas instrumentation) for fabricating a potable cortisol biosensor. As planned this fabricated sensing device was very useful to perform cortisol sensing at POC [20]. As Zika-virus infection declared as international health emergency due its association with microcephaly, a significant attention was made to develop miniaturized electrochemical biosensors to detect zika-virus protein at very low level to achieve early stage diagnostics [3,19]. To achieve this task, Kaushik et al. developed an electrochemical zika virus immunosensor (Fig. 3B) using a SAM functionalized IDEs to detect envelop virus protein at 10 pM selectively (in comparison of dengue and malaria). Such Zika sensor was interfaced with a M-P which can be operated using a smartphone to perform POC diagnostics and easy data management. The integration of IDE based efficient sensor with smartphone make user friendly (easy to use) and performance according to the need of clinical such as rapid sharing and analytics [19]. In order to explore smart electro-active sensing platforms, our groups explored the alternated of ELISA, needed to evaluate diseases progression and efficacy of a therapy. In this research, a chip based electrochemical system was developed to monitor electrophysiology of targeted cells infected with HIV in setting of drug abuse (cocaine) and therapies (Fig. 3C) [23]. It was observed that on infection and treatment selected cell types goes under a distinctive electrophysiology changed which can be monitored using a sensitive electrochemical chip-based technology. Outcomes of this research confirmed that such chip-based sensing system are suitable for

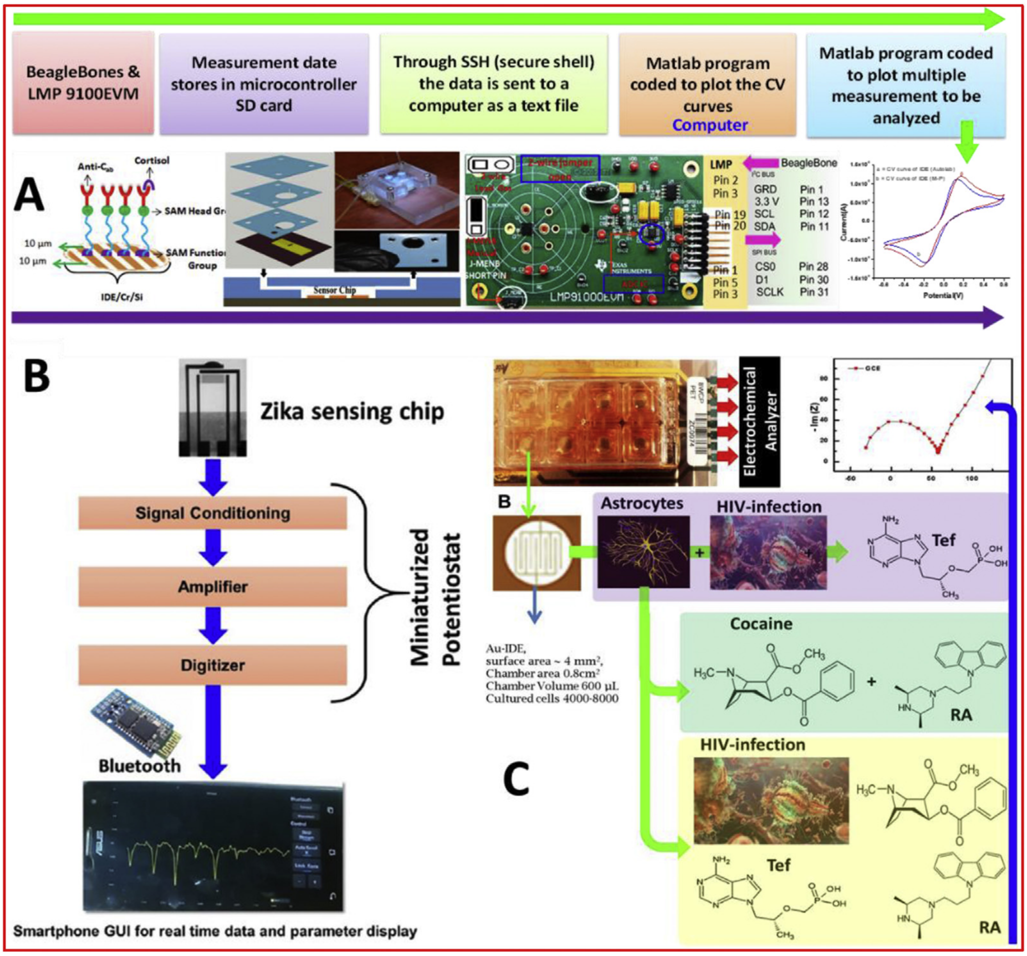

Fig. 3. A) Schematic illustration of SAM/IDE-based electrochemical cortisol immuno-sensor interfaced with a M-P and microfluidic system for cortisol detection at for POC application [20], **B)** fabrication of IDE-based electrochemical Zika immunosensor and its integration with a smartphone to perform POC diagnostics [19], **C)** chip-based electrochemical system to monitor cell electro-physiology of human astrocyte cell on HIV infection in setting with drug abuse (cocaine), with/without FDA recommended drug [23].

rapid to diagnose HIV-infection, monitor efficacy of a therapy, and rapid optimization of a suitable therapy. These affordable and sensitive sensing systems are easy to fabricate and optimize and emerging as an alternate of ELISA and PCR for managing HIV diseases in personalized manner [23].

Wearable electronic micro-sensors are considered as the first generation of smart sensing (the year 2000) [30]. Later, numerous papers and flexible substrate-based sensor prototypes were developed to fabricate efficient wearable biosensors. The interfacial electrical and optical properties of material-targeted biological compounds have been leveraged to develop wireless sensing systems [22,31]. Due to this feature, it is possible to monitor health variation in a real-time manner. Such sensing systems are second-generation (Year from 2010 to 2014) of biosensors which facilitate miniaturization of integrated circuits and low power consumption [32]. The current era, as the third generation of the biosensor, is of non-invasive biosensors (2017–2020) i.e. nanosensor [33]. This generation is emerging with significant advancements in self-powered electronics, bioelectronics, stretchable electronics, and flexible and body compatible materials.

3. Artificial intelligent supported POC diagnostics for intelligent healthcare

Innovations in biomedical devices are continuously making health care delivery easy, timely, affordable, manageable, and user friendly. As an outcome, the investigation and introduction of new non-invasive approaches of reduced form factor features have made health monitoring more personalized. However, the right analysis of generated bio-informatics has raised the demand for smart deep learning towards artifical intelligence (AI), an approach to mimic human condition by a computer, which can analyze the data efficiently by considering demands and potential challenges in mind. This huge data analysis and data management is needed to understand targeted diseases/symptoms monitoring, correlation of targeted biomarker level with disease variation, efficacy monitoring, and disease management. To categorize data concerning health parameter preferences, a new tool that can digitalize diagnostics systemically for a patient profile is urgently in demand. This can be completely manageable if the IoT methodology associates with the AI-based approach. The IoT approach is capable of digitalizing every possible information intelligently by using the cyber-physical smart passive framework. This feature can filter bio-informatics analysis using AI to optimize the parameter according to the patient profile. Such an AI-assisted IoT based bio-informatics is very crucial to manage targeted diseases in a personalized manner.

At present, system development is emerging as a key factor for developing an efficient diagnostics device of reduced form factor and capable to perform at POC applications (Fig. 2). This has raised the demand for exploring internet of medical things (IoMT), a hardware-based approach involving a smartphone [34]. Although both IoT and IoMT have a lot of similarities but the connecting devices for biomedical application in the health care industry is growing under IoMT. Recently, the IoMT is emerging rapidly in biomedical research because of rapid data sharing and analysis. It has been predicted that AI-IoMT assisted diagnostic will be a focus to develop the next generation of bio-sensing systems [27–29,35]. Such systems are predicted more reliable due to easy calibration because of portability, as a well-packaged miniaturized sensing technology. Future biosensors will enable patient care at home in a real-time manner and will provide diagnostics information to clinicians/health experts to know about disease progression and medication. To achieve such claims and tasks, a systematic step-by-step approach is recommended by experts as illustrated in Fig. 4.

Despite recent developments in biosensing systems, several challenges such as affordability, sensitivity, portability, stability, compatibility with bio-active molecules, etc., are yet to be overcome to achieve disease diagnostics at home, POC or both. Developing novel electro-active biomaterials (especially biopolymer such as chitosan, scaffolds, etc.) exhibiting absolute immune compatibility and desired interfacing with the human body will be one of the major concerns in sensor development. The investigation of M-P operated by a smartphone will also be a key component to achieve diagnostics at POC required for disease management at the epidemic site in a real-time manner. Bio-sensing based on MEMS seems to be a game-changing approach to investigate nano-toxicity aspects of nanomaterials, cell physiology on the exposure of external factors for example inhalation of pollutants particles, viruses, transmitted diseases, etc. Such sensors which are based on advanced chip technology will be very useful to optimize a dose of various nanoparticle selected for biomedical applications, evaluate drug efficacy, and therapy efficacy assessment [36–39]. The outcomes of such of sensing strategy will provide desired informatics to optimize a product to everyday use and drug/vaccine therapy to provide better treatment, as illustrated in Fig. 5.

4. Viewpoint and suggested approaches for intelligent healthcare

In today's world, where time is precious, people, the working class especially, spend most of the day shuttling between various tasks and tend to ignore their health and fitness. Even a simple appointment with a doctor in a clinic can require several tests set for diagnosis, prescription, and finally treatment, which can take a lot of time [40]. Therefore, many patients only go to a clinic when they are suffering from a serious illness. Hence, many people are seeking an alternative, such as a device that can be worn on the body, which would not only continuously monitor the user's health in real-time but also provide timely insights on various health parameters to the user as well as his or her physician. Rural health care [41] is one of the biggest challenges in the world, especially in developing countries where over 55% of people live in rural areas [42]. Thus, the Internet of Things is considered very useful. Data Transfer and Automation (IoT) is the fastest growing technology [43,44] using the Internet of Things. This includes sensors, cyber systems - IoT, and cloud computing [45]. Web systems collaborate at every stage of the web to reach the right people in real-time. In rural areas, the patient must take the medication on time. The IoT can be very useful for those who suffer from the disease [46]. Keeping this in view, IoT users are also focusing on some authentication improvements. The IoT is a device that connects multiple devices locally, including electronics, software, sensors, actuators, and networks [47]. Various applications of the IoT include smart healthcare, smart cities, automation in industries, agriculture, and transportation decision making [48]. They convert the radio-frequency energy emitted by the reader device into a few feet transmitted signals. Given the huge shortage of trained manpower and the high cost of setting up government facilities, it is often impossible to provide proper health care services in rural and remote areas [49].

However, IoT is considered viable [50]. Living as healthy people can lead to economic growth and they are more productive thus, the country grows. Many health monitoring systems have been developed over the years to improve the quality of life by providing better health [51]. The Internet has become an important part of our daily lives. The whole concept of IoT enables users to communicate and access information about sensors, gateways, and wireless networks [52]. The Internet of Things has a role to play in improving quality of life [53]. It is an ever-growing network of smart objects connected using the internet. It can be used to diagnose the disease at home and take appropriate medication [54]. The overview of the healthcare monitoring system is depicted in the below block diagram.

As illustrated in Fig. 6, IoT wearable devices and AI-based healthcare monitoring systems elaborated. Patients' vital parameters such as Heartbeat and the temperature is continuously monitored via medical sensors and periodically stored in cloud service. The system collects real-time data from the patients and delivers an updated patients' status to the medical professionals and the caretakers using a wireless sensing network (WSN). This autonomous system replaced the traditional method to collect the parameters regularly by the nurse. It avoids human errors in collecting the patients' data manually. Data transfer protocol helps to transfer the messages. The observed vital signs of the patients are analyzed and checked against the standard range to detect the abnormal condition of the patients.

The IoT wearable devices and AI-based healthcare monitoring system incorporates IoT Edge and AI technologies to provide predictive capabilities. The IoT Edge technology provides a way to

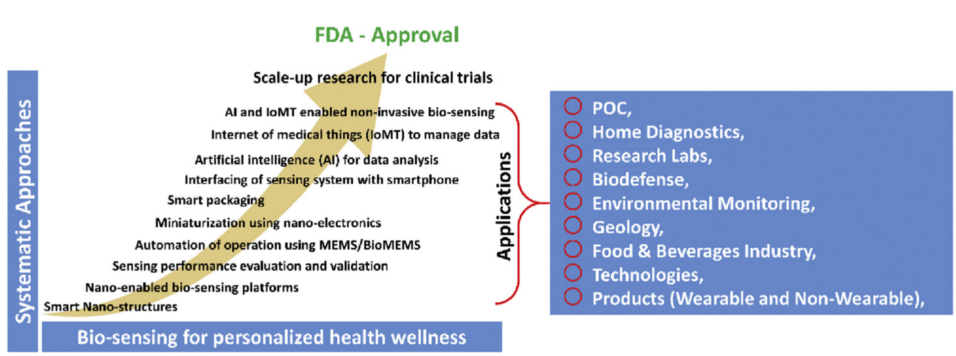

Fig. 4. Illustration of a systematic approach to developing an efficient and affordable biosensor for clinical and POC applications.

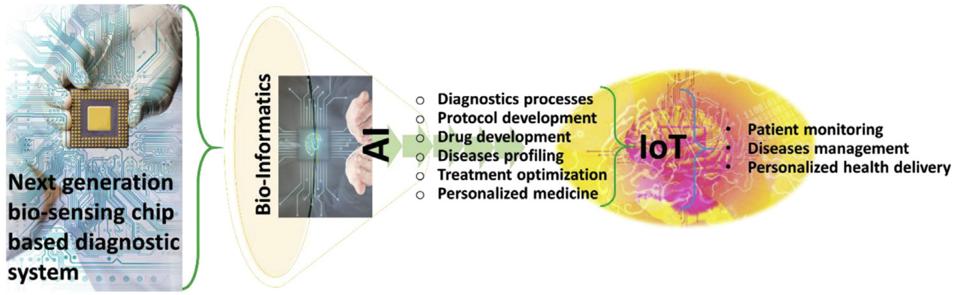

Fig. 5. Illustration of next-generation biosensor-based diagnostics approach for personalized health wellness.

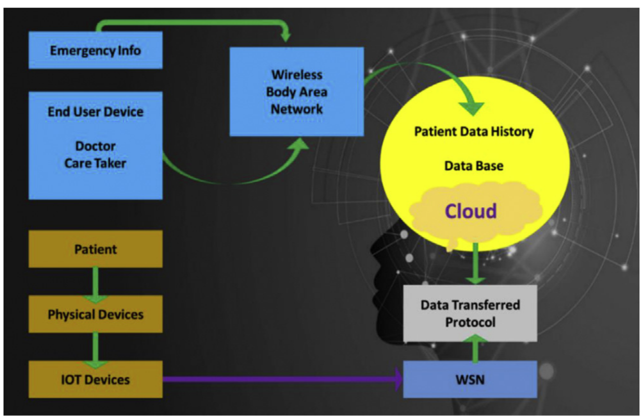

Fig. 6. Deception of IoT wearable devices and AI-based healthcare monitoring system.

package and deploy AI models on the cloud or at the edge itself which reduce tremendous computational power. The healthcare data collection and storage can be done by the smart biosensors discussed in the earlier sections of the paper. After data collection completes, AI infrastructure needs to design and develop AI models which includes machine learning and deep learning algorithm development and enhancement. Once AI models will be ready for the deployment, there are two possible ways to deploy it. First, deploy AI model at IoT device or wearable device and another is to deploy it on IoT edge gate way. The deployment scenario as shown in Fig. 7, a machine learning, deep learning or AI model will be used for deployment at the edge of IoT. It can be done using IoT function container to the data of process retrieved from IoT wearable devices in real time processing. The appropriate action will be taken only after AI model predict anomalies on the streaming data and generate proper actions.

There is also a possibility of AI model deployment at IoT device or wearable device. In that cases, all real-time data processing will be done at the microcontroller level and anomalies will be identified at the wearable device to take appropriate actions based on real-time prediction. There are multiple benefits of proposed AI model deployment on IoT edge and wearable devices. It monitors patient health indicators in real time. It provides secure transmission of data collected by the wearable devices to the cloud. It's also analyzed patient data to prompt urgent actions and provide long-term healthcare guidance with timely emergency notifications. At last, it also provides potential for analysis of aggregated patient data to identify health risk patterns across a population.

5. Intelligent diagnostics for COVID-19 management

A life-threatening respiratory infectious disease known as COVID-19, associated with novel RNA envelope human beta severe acute respiratory syndrome (SARS-CoV-2) virus, strike China in late December 30, 2019. This new infectious disease has affected over 5 million people around globe (30% them belong to the United States of America) and continuing to grow because of easy human to human transmission, no effective of therapeutics, and lacking effective diagnostics systems. Health agencies monitored COVID-19 epidemic sincerely and latter declared it as a pandemic and alert every country to plane joint efforts to combat against this international health emergency. Every country pain serious attention to develop regulatory guidelines, therapies, and diagnostics systems to manage COVID-19 pandemic. But the variation in categories and strains of SARS-CoV-2 virus projected developing high efficacy therapy as an unpredictive and long-term goal [55–57].

This obstacle turned the attention of experts to think about management COVID-19 infectious diseases which bring the need of investigating efficient sensor to detect SARS-CoV-2 selectively and timely as an urgent focus. As demonstrated, SARS-CoV-2 spreads through person-to-person which raised to demand of using precautions like mask [58] and investigating diagnostics at POC without need of labor extensive sophisticated laboratories. To achieve desired diagnostics, we suggested that an optimized compartmentalization approach, as discussed above, could be the best way fabricate a nano-enable miniaturized biosensor for SARS-CoV-2 virus protein detection at site of epidemic [57].

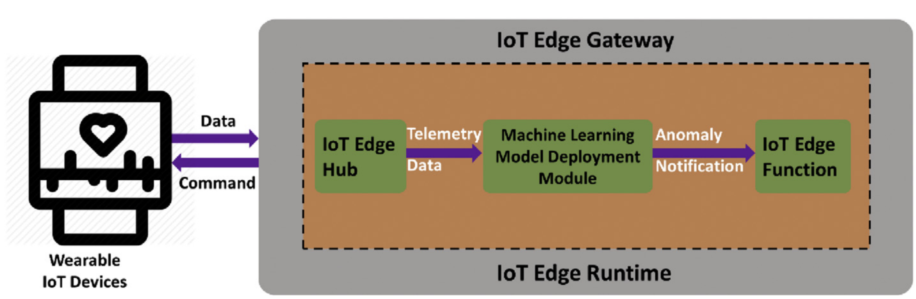

Fig. 7. AI model deployment on IoT edge gateway.

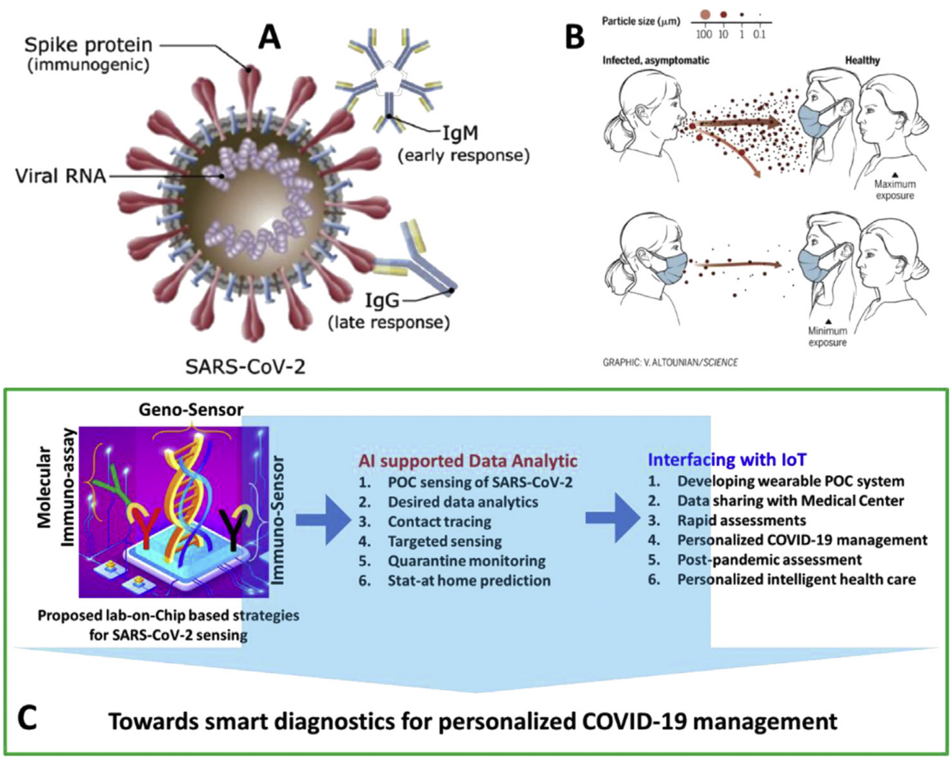

Fig. 8. A) Biological structures of SARS-CoV-2 virus protein [57], B) possibility of human to human transmission and it possibility to avoid spreading using a mask [58], C) Nano-enabled sensing supported by AI and IoT for smart diagnostics of COVID-19, an approach toward personalized COVID-19 management.

Such of desired SARS-CoV-2 sensing supported by AI and IoT is emerging a key factor to manage COVID-19 pandemic management. The need of developing such smart sensing system to COVID-19 pandemic because of asymptomatic carries and hospital discharges patient again got SARS-CoV-2 virus infection. These challenges demand the real-time SARS-CoV-2 detection and tracing to population [59,60]. If such intelligent system implemented, then smart management of COVID-19 pandemic can be achieved successfully (Fig. 8) due to advantages as follows.

- A miniaturized IDE-based SASR-CoV-2 biosensor can be fabricated via selecting specific Anti-SASR-CoV-2 virus protein antibody for selective and sensitive detection within 30—40 min of operation time.
- Such biosensor can be transformed to develop POC analytical devices to perform SASR-CoV-2 at POC needed to manage COVID-19 in personalized manner.
- Such SASR-CoV-2 detection will generate bioinformatic to understand the diseases progression, efficacy of therapy, optimization of a good therapy, and correlating between SASR-CoV-2 level and pathogenesis.
- MEMS based can designed to evaluate the efficacy of a new drug prior to test using animal model.
- Introduction of IoT in SASR-CoV-2 biosensing may be useful to develop wireless system for POC diagnostics.
- AI supported POC diagnostics of COVID-19 will be emerged as breakthrough in big data analytics needed explore.
- An optimized combination of nano-enabled SASR-CoV-2 biosensing, IoT and AI will be a perfect platform to manage COVID-19 pandemic intelligently without errors at personalized level.
- Tunable features and programmable operation will be useful to manage COVOD-19 diagnostics after considering variabilities associated with population, race, gender, and medical history.
- AI-supported algorithm will be useful to optimize a therapy among available drugs, vaccines, and combinations,
- AI-supported analytic can direct expert to plan for targeted testing or where the attention is most required i.e. high risk areas.
- AI-assisted big data analytics will be useful to predict the need and understanding of social/physical distancing.
- AI and IoT supported COVID-19 management strategy is acceptable to evaluate the risk factors, tracing of population, and suggesting option, which are the primary requirement of every county to remove lock down and open business, mainly universities.
- AI and IoT assisted approach will be useful to assess the needs of an individual is there is a factor of neurobehavior alteration and safe work practice.
- AI and IoT supported POC diagnostics can manage COVID-19 pandemic in personalized manner.
- Technology supported intelligent healthcare will be driving force to trace and eradicate COVID-19 pandemic.

6. Viewpoint

As summary, this opinion article explores the state of art bio-sensing technological approaches that have been investigated and are being under investigation for disease diagnostics and management. Keeping capabilities of sensitive and selective diagnostics at POC, the future bio-sensor market projection suggested developments, and related challenges with a viewpoint are also described. This report is oriented as a call to experts for developing advanced analytical bio-sensing devices for disease diagnostics needed for personalized health care and wellness at home and POC. As future research, it is strongly recommended to introduce the concept of miniaturization in biosensors to explore required for POC application. Further, the operation of POC biosensors using a smartphone for useful bio-informatics analysis supported by AI and IoMT (for data storage, sharing, and security) for rapid and essential diagnostics emerged very usefully for timely therapy optimization and personalized diseases diagnostics. This report is a request for investigating AI and IoT supported SARS-CoV-2 detection selectively at low level desired for early-stage COVID-19 diagnostics at POC to manage pandemic successfully, in personalized manner.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgment

Authors acknowledges respective institutions and department for providing facilities and support. AK acknowledges a research grant (GR-2000024) funded by Florida Polytechnic University, Lakeland, FL, USA.

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