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SMART DEVICE EVALUATION FOR DEPLOYED OPERATIONS

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UES, Inc.

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14. ABSTRACT Research Development Documents (RDDs) were developed to identify gaps in the Air Force's (AF) capabilities to allow for targeted and focused scientific research and technology development to increase force readiness and human performance. Many of these gaps are open ended and many solutions could apply. A smart device offers a unique solution to these capability gaps due to its size, cost, limited power consumption, and multiplex ability. For this report, the RDDs were evaluated and smart device attachments, applications, and devices were identified. This report briefly discusses the different technologies found to help guide future research and further design, development, testing, and validation for currently available products. Many products are identified to address a single gap, so it is the intent of this report to provide a basic understanding of the technology and guide the selection of products for further development and testing.					
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1.0 INTRODUCTION/BACKGROUND

In the USAF, there are currently many different devices that can be used for detection, monitoring, and prevention purposes. Many of these devices are singleplexed, meaning they only have one purpose or can only test for one agent, are single use, paper-based, or are large devices. This results in a massive strain in space, resources, and energy requirements which can limit transportation and use in deployed environments or the equipment simply cannot be deployed leaving airmen vulnerable to potential threats. While paper-based detection techniques are small and light weight, interpretation can result in error due to varying light conditions due to different environments. A smart device offers a unique solution that can lessen the use of singleplex devices, diminish operation footprint, and reduce paper-based result interpretation error due to varying lighting conditions. This literature review found and evaluated smart devices, applications, and attachments to help guide future research and technology development for a variety of topics and gaps identified in the USAF RDDs.

A smart device (tablet, phone, etc.) can be defined as a context-aware electronic device with the capability to perform autonomous computations and the ability to exchange data to other devices using a wired or wireless connection [55]. These three features separate smart devices from all other devices. Context-awareness allows the device to collect information about an environment or situation using a camera, microphone, or other sensors [134]. This information can be collected actively or passively, depending on the sensors used and the device's battery life. A smart device can then use the context-data to make informed decisions and suggestions to a user [55]. The final and most important feature of a smart device is its ability to share all this information with other devices [134]. These features ensure smart devices are connective (communicate and share information), adaptable (tailored applications for all types of users), and convergent (replace single-purpose devices). Smart devices have advanced at rapid rates and possess increasingly advanced optics, image processing, and computing power. In addition to hardware developments, applications (software) have been developed and improved to replace extraneous lab-based detection devices and more [55]. These hardware and software solutions could allow for rapid through put, decrease equipment footprint, standardize light conditions to lead to less human error, and ultimately help monitor and protect airmen [169].

This report was performed using the data bases National Center for Biotechnology Information PubMed (<https://www.ncbi.nlm.nih.gov/pubmed/>, last accessed September 26, 2020), Franzello Catalog search engine (<https://w95023.eos-intl.net/W95023/OPAC/Index.aspx>, last accessed September 26, 2020), Google (<https://www.google.com/#spf=1579097710281>, last accessed September 26, 2020), Google Scholar (<https://scholar.google.de>, last accessed September 26, 2020), Google Patent (<https://patents.google.com/>, last accessed September 26, 2020), Defense Technical Information Center (<https://www.dtic.mil/>, last accessed September 26, 2020), and Wiley Online Library (<https://onlinelibrary-wiley-com.fal.idm.oclc.org/action/showPublications>, last accessed September 26, 2020) using the key words “smart”, “device”, “phone”, “application”, “software”, “attachments”, “detect”, “monitor”, “predict”, “prevent”, “pathogen”, “chemical”, “radiation”, “Enzyme-Linked Immunosorbent Assay (ELISA)”, “lateral flow”, “reader”, “diagnostic”, “image”, “analysis”, “microscope”, “identification”, and “tracker” in various combinations. The assessment of

relevance for this report was based upon the subjective impression of the authors. This report is divided into three major sections: 1.) Research Development Document for Expeditionary Medicine, 2.) Research Development Document Total Exposure Health, and 3.) Miscellaneous. Each section will address the gaps outlined in Table 1 and Table 2.

2.0 RDD FOR EXPEDITIONARY MEDICINE

Table 1: RDD Expeditionary Medicine priority, gap, and description [87]

Priority	Gap Title	Research Objectives	End State
3	Specialized Pararescue Capabilities	1. Secure, wireless connection with the option of being able to upload information utilizing hardwire connection 2. Define the requirement of what needs to be monitored 3. Define the intervention requirements 4. Identify non-invasive devices to establish clinical outcomes 5. Development of algorithm that predicts patient outcome and need for intervention	• A small, lightweight (band-aid size) solution that can provide all pertinent vital signals that can interface with a device • Continual monitoring and trend/predictive analysis • "Tricorder" • Store locally on the device
4	Tele-mentoring, Tele-medicine, Tele-monitoring	1. Determine the appropriate medical procedures for tele-mentoring 2. Assist the medic in the timeliness/indications of procedure 3. Develop virtual reality using overlaying landmarks 4. Ability to conduct operations with or without connectivity - Impact of connectivity on medic's ability to provide care to patient 5. Determine when clinicians need the visual capability and how beneficial it is 6. Real-time monitoring of multiple patients for remote location (satellite, cyberspace support) 7. Determine the impact of tele-monitoring on patient outcomes 8. Develop Tele-mentoring, tele-medicine, tele-monitoring (TM3) solutions that utilize minimal bandwidth 9. Integrate physiological sensors into TM3 solutions 10. Identify the requirements for variability of support (ability to support various levels of providers) (independent duty medical technician, med tech, nurse, pararescuemen (PJ), etc.)	• Real-time Antivirus capability w/ self-sufficient tutorial that can operate without connection • Transmit real-time video/picture (2-way comms) • Project image on patient • Multi-functional and multi-patient capability technology to keep equipment footprint to a minimum • Data tracking and analysis to determine measures of effect • Network compatible on shared military network • Interoperable with legacy and future patient management equipment • Intuitive for multiple skill sets
9	Drinking Water Sampling	1. Reduce/eliminate the need for an incubation period 2. Kit properly sized to fit Advances Echelon (ADVON) team equipment configuration 3. Develop technology capability similar to Hazardous Air Pollutants On Site (HAPSITE) DOTmLPF-P Change Recommendation 4. Determine viability of pathogens	Rapid drinking water test kit as effective as current methods
12	Emergency Blood Banking Rapid Screening	1. Develop single platform for testing/results 2. Develop ability to test donor for walking blood bank while deployed 3. Include Hepatitis B, Hepatitis C, Human Immunodeficiency Virus (HIV)-1, HIV-2, West Nile, Rapid Plasma Reagin (Syphilis), Cytomegalovirus, Zika Malaria, and Chagas Disease in testing capabilities 4. Explore 6.7 Commercial-off-the-shelf (COTS) modification	Handheld device or cartridge for existing technology to test blood for multiple pathogens

Priority	Gap Title	Research Objectives	End State
13	Rapid Test for Specific Disease Outbreak/Surveillance	1. Develop rapid point of care test with immediate results (less than 24 hours) 2. Utilizing current and emerging technology/science 3. Conduct "Cradle to grave" analysis (i.e. from preconception to human waste)	Simple/specific diagnostic tool (lightweight/rugged) with immediate/near real time results
14	Environmental Testing	1. Reduce/eliminate the requirement for an incubation period 2. Kit properly sized to fit ADVON team equipment configuration 3. Develop technology capability similar to HAPSITE	Rapid environmental (i.e. air, soil) test kit as effective as current methods
19	Hand Held Chemical Screening Analysis	1. Assessment of emerging research technology (total exposure health (TEH)) 2. HAPSITE reliability study 3. On-site results (faster presumptive notification)	Hand held screening device/sensor (Real time monitoring), user friendly for Preventative Aerospace Medicine team and equivalents
22	Rugged Blood Typing Capability	Develop Point-of-care Testing (POCT) blood typing device with these capabilities: 1. High level of accuracy 2. Identify robust chemistry 3. Evaluate environmental factors required for device	• Ability to have blood typing capability able to withstand different environments • Ability to confirm blood type prior to infusion • No power • Portable; handheld • Extended shelf life • No cold chain, no Hazardous Materials
25	Food Testing	1. Develop proactive capability to detect specific pathogens/poisons 2. Identify current thresholds 3. Identify exposure limits 4. Identify clinically relevant biological/chemical contamination/radiological for food 5. Reduce dependence on technology, software, reagent or cold/warm chain management	Capability to test food for pathogens and poisons real-time or near real-time
29	Mosquito Traps/Carrying Pathogen (Specifically Species Identification/Possibly Disease Identification)	1. Ability to trap and test on-site near real time 2. Species identification 3. Disease identification 4. Reduce dependency on training/shipping by automating process 5. Wireless transmission 6. Less dependence on carbon dioxide 7. Monitor current efforts	One device that does both species identification and pathogen detection

2.1 GAP 3: SPECIALIZED PARARESCUE CAPABILITIES

In 1997, the Early Warning Score (EWS) system was developed as a tool to assist caregivers in detecting and predicting physiological changes and clinical deterioration of non-critically ill patients [166]. With advances in technology and a better understanding of human physiology, the EWS was modified and the name changed to Modified Early Warning Score (MEWS). The MEWS monitors and collects systolic blood pressure millimeters of mercury (BP, mmHg), heart rate (HR, beats per minute (bpm)), respiratory rate (breaths per minute), temperature (degrees Celsius, °C), blood oxygen saturation percent (SpO₂, %), amount of administered oxygen liters per minute, and Alert, responsive to Verbal stimulation, response to Painful stimulation, and Unresponsive [166]. Additionally, blood glucose (BG) levels may be monitored in various situations to access further care of patients. Implementation of MEWS has led the use of more rapid response systems, less cardiopulmonary arrest events, lower mortality rates, and improved patient safety and clinical outcomes [97]. While this system has proven to be successful it can be extremely labor intensive and due to the shire size and quantity of devices needed, it is not applicable for use in an austere environment. A small, lightweight, and ruggedized device capable of continually monitoring patient vital signs for MEWS with the option to find trends and predict outcomes would address this identified capability gap. Ideally the information would be stored on the device with the option to securely transmit the information.

2.1.1 KARDIA

Kardia makes a single-lead, four-lead, and six-lead mobile electrocardiogram (ECG) devices, as seen below in Figure 1, compatible with Android and iOS smart devices [6]. Kardia devices utilize high frequency sound to transmit ECG data to its associated application [6]. A visual record of each ECG reading is stored in a Health Insurance Portability and Accountability Act (HIPAA) compliant cloud and can be sent to a medical professional for review [6]. Kardia devices are Food and Drug Administration (FDA) approved, have proven to be highly accurate, and are roughly the size of a business card [6, 68].

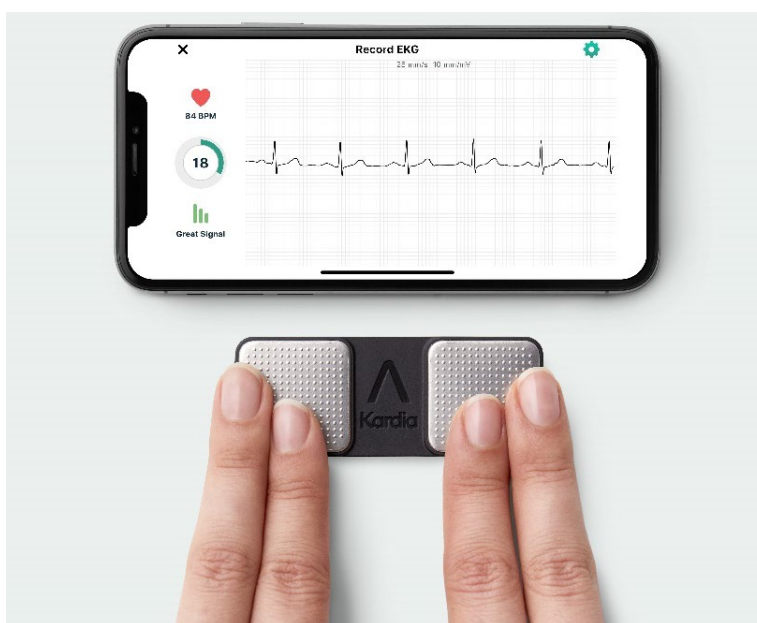


Figure 1: Kardia Mobile Single-Lead ECG [6]

2.1.2 BIOBEAT

BioBeat vital sign sensors are intended for short term use and are placed in a disposable patch fixed to a patient, as seen on the left in Figure 2 [21]. The system is capable of monitoring multiple patients simultaneously and sending alerts for each patient's vital signs [21]. BioBeat sensors record the following parameters: BP, respiratory rate, SpO₂, pulse rate, heart rate variability, stroke volume, cardiac output, cardiac index, pulse pressure, systemic vascular resistance, one lead ECG, mean arterial pressure, sweat level, and skin temperature [21]. Data monitoring is cloud based and any device with a web browser can access the data stream [21]. There are also long term monitoring solutions available from BioBeat which utilize smartwatches, seen on the right in Figure 2 [21]. These smartwatches record all the parameters listed above except, one lead ECG [21]. Data is handled in the same manner for the smartwatch as for the patch-based system [21].



Figure 2: Short term monitoring (left) Long term monitoring (right) [21]

2.1.3 FREESTYLE LIBRE CONTINUOUS GLUCOSE MONITOR

The Freestyle Libre Continuous Glucose Monitor (CGM) is a glucose measuring device, seen in Figure 3 [62]. This device is capable of recording and storing glucose levels for up to eight hours [62]. It relies on a sensor that adheres to the skin and utilizes a thin filament to puncture the skin and measure glucose levels in the interstitial fluid [62]. Readings can be done at any time and are recorded using a handheld scanner that communicates with the adhesive sensor [62]. This device is slower to react to changes in glucose levels than a traditional BG monitors [62]. This is attributed to the difference in the fluid the device measures. As mentioned above, Freestyle Libre Continuous Glucose Monitor measures the glucose level of the interstitial fluid [62]. This is the fluid that bathes the surrounding cells, it take more time for glucose level to rise in this fluid than in the blood, which is the fluid traditional glucose monitors measure. The sensor itself also must be replaced every 14 days [62]. This system does tend to underestimate changes in glucose levels after a meal and reads lower-than-actual values in its lower range [62].



Figure 3: FreeStyle Libre 14-day small automatic glucose monitor [62]

2.1.4 DEXCOM G6 CONTINUOUS GLUCOSE MONITORING SYSTEM

The Dexcom CGM, seen in Figure 4, provides the user with BG readings throughout a 24-hour period while including the estimated speed and direction that the individual's BG levels are heading (either a high BG or lower BG level) [45]. Traditional BG monitors require a finger stick and measure BG level for a single point in time [45]. The Dexcom device can alert users during high and low BG periods, especially during times of exercise or sleep [45]. The Dexcom CGM G6 (the latest model) is capable of connecting to any device that has iOS 10.3 to 11.4.1, and Android OS 6.0 or later operating system [45]. The device pairs with the application CLARITY [45]. In addition, glucose readings, trend arrows, and graphs can be viewed on Apple watches that are connected to any compatible smart phone [45]. This sensor can be worn and used for a duration of 10 days, after which the sensor must be changed [45]. A new sensor must be attached to the arm and recalibrated using a code or finger sticks [45].



Figure 4: Dexcom monitor [45]

2.1.5 BATDOK

Battlefield Assisted Trauma Distribution Kit (BATDOK) is a government off-the-shelf (GOTS) software enabling a single individual to effectively manage multiple patients, record their vital signs in real time, maintain patient records, document injuries, triage, consult with medical colleagues, share patient information, and handoff patients for further treatment all on a single device [127]. It can be used in conjunction with smart device enabled medical sensors to measure a variety of vital signs and is optimized for use by medics, corpsmen, PJs, and other medical practitioners operating in austere environments [127, 140]. BATDOK can also be used in conjunction with Remote Health Solutions' Virtual Exam Room software to enable battlefield telemedicine [127, 140]. BATDOK is currently undergoing testing and further development at the 711th Human Performance Wing [127].

2.1.6 CHECKME PRO HEALTH MONITOR

Checkme Pro Health Monitor is an FDA and European Conformity (CE)-approved all-in-one device capable of measuring (one or two lead) ECG (± 2 bpm or $\pm 2\%$, whichever is greater), body temperature, HR, SpO₂, and non-invasive BP in less than 25 seconds [166, 167]. Before measurements are taken, a personal profile is established using an individual's sex, age, weight, and height [166, 167]. Next, the device is calibrated by simultaneously measuring systolic BP on the Checkme Pro monitor and a reference device [166, 167]. SpO₂ (80-100%: $\pm 2\%$, 70-79%: $\pm 3\%$), pulse rate (± 2 bpm or $\pm 2\%$, whichever is greater), and perfusion index can be measure by placing the right index finger under the lid on the top of the device and the right thumb on the metal plate as seen is in Figure 5 [167].



Figure 5: SpO₂, PR, and PI measurement [65]

Systolic and diastolic BP (± 3 mmHg) and pulse rate (± 2 bpm) can be measured using the Air BP Wireless Blood Pressure Monitor as seen in Figure 6 [167].



Figure 6: Systolic and diastolic blood pressure and PR measurement [167]

Temperature can be measured by pressing the thermometer in the device against the forehead as seen in Figure 7 [167].



Figure 7: Temperature monitor [167]

Checkme Pro can also be used to monitor ECG and SpO₂ simulations on an individual, as seen in Figure 8 [167].

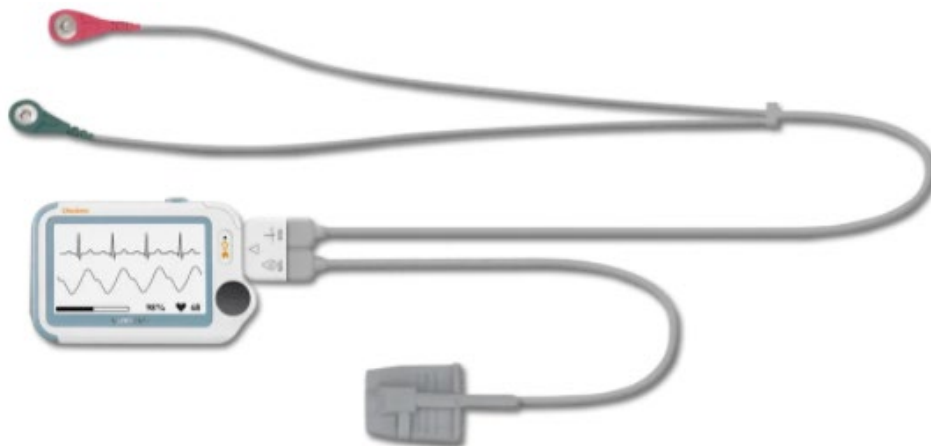


Figure 8: ECG and SpO₂ monitoring [167]

Regardless of the measurements collected, the information can be wirelessly transmitted to the associated application on an iOS, Android, or personal computer (PC) using Bluetooth [167].

2.1.7 WELLUE O2RING

The Wellue O2Ring, seen in Figure 9, is an FDA approved ring that monitors SpO₂ and HR. This ring monitors oxygen levels in the blood and sends an alert when the levels are below the user-set accepted level [168]. Additionally, the device monitors HR and sends an alert if HR becomes too high or low [168]. This device is capable of connecting to the associated application on an iOS or Android device, or PC for further analysis [168]. It can generate high resolution trend charts containing four second interval data [168].



Figure 9: Wellue O2Ring [168]

2.2 GAP 4: TELE-MENTORING, TELE-MEDICINE, AND TELE-MONITORING

Telehealth and telemedicine systems have shown to be valuable component to the healthcare of military members both stateside and in deployed settings [10, 107]. The austere environment of many deployed settings has proven to be a bottleneck in some of the treatment and care given to service members [10]. Much of the telemedicine and mentoring technology is used to improve the treatment and care of injured service members and to help provide aid and communication between physicians and combat medics, in order to optimize the management and improve the overall outcome of care [10, 107]. The types of smart devices discussed below provide healthcare workers with visual and audio tools to assess a patient and guide a medic, diagnose patients, provide consultation services based upon patient statistics, and more. Ruggedized devices capable of completing everyday medical procedures, diagnostics, and that allow for collaboration between experts and remote military members would drastically improve patient outcome.

2.2.1 BUTTERFLY NETWORK iQ

The iQ is a handheld, smart device enabled ultrasound probe, seen in Figure 10, suitable for full-body use [25]. It utilizes an array of capacitive micro-machined ultrasound transducers (CMUTs) instead of piezoelectric crystals [25]. This allows the generation and reception of a wider frequency bandwidth than traditional ultrasound machines, thus allowing a single probe to be used for full-body applications [25]. All data are encrypted and can be stored in the cloud. Also, the device settings can also be controlled remotely in real time for telemedicine purposes [25]. The device costs about \$2,000 and there is an additional annual membership fee of \$420 [25].

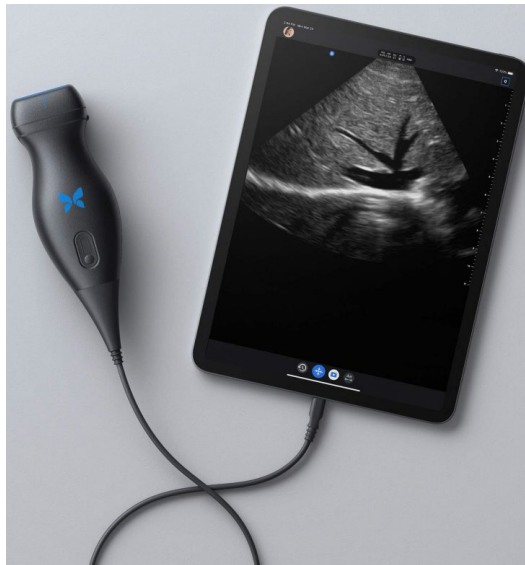


Figure 10: Handheld Butterfly iQ unit [25]

2.2.2 ENDOSCOPE ATTACHMENT

A variety of Universal Serial Bus (USB)-powered flexible endoscope attachments are available for use with smart devices. These devices are typically inexpensive and some can be found with articulating cameras. These devices are generally powered via USB connection to the smart device and require no external power supply except for the smart device they are attached to. This makes the devices suitable for use in austere environments. These devices are typically marketed towards plumbing or mechanical work and thus are typically not made from medical grade materials. However, these attachments provide a proof of concept for future developments.

2.2.3 EYEQUE PERSONAL VISION TRACKER (PVT)

The EyeQue PVT utilizes a smartphone application in conjunction with a manually adjustable prismatic eyepiece to calculate and record vision prescriptions [57]. The application walks the user through a step-by-step process of multiple vision tests to determine a prescription [57]. Information is stored in a HIPAA-compliant cloud, and an account is required to record or access the data [57]. EyeQue offers other devices as seen in Figure 11, including an automated version of the PVT called the VisionCheck which also measures pupillary distance, a visual acuity tester, and the PDCheck pupillary distance measuring device [57]. All devices are priced under \$100 and require an annual subscription fee of \$4.99 [57].



Figure 11: VisionCheck Refractive Eye Test (left), Personal Vision Tracker Refractive Eye Test (middle), and EyeQue Insight Vision Screener (right) [57]

2.2.4 BIOBEAT

[See RDD EM gap 3.](#)

2.2.5 NUVOAIR AIR MD

NuvoAir smart spirometry technology, seen in Figure 12, uses a turbine mechanism with disposable single-use nozzles to measure spirometry data [112]. The NuvoAir device calculates spirometry measurements from the rotation speed of the turbine [112]. The instrument connects to a smart device through the audio jack and uses an associated application to analyze the collected data [112]. Age, sex, and height must be entered into the application to enable accurate calculation [112]. Forced expiratory volume in one second and forced vital capacity values are calculated based on The Third National Health and Nutrition Examination Survey values [74, 112]. One of NuvoAir's products, the Air Next spirometer, has been cleared by the FDA [112]. Data points are stored in a cloud, enabling doctors to view the patient's spirometry records remotely [112].



Figure 12: NuvoAire Spirometer [112]

2.2.6 CELL SCOPE

Cell Scope University of California (UC), Berkeley developed optic, illumination, and hardware attachments for smartphones, seen in Figure 13, to allow the camera to capture microscopic images for diagnostic solutions and identification [159]. The attachments currently developed for the Cell Scope are capable of brightfield and fluorescence imaging, can achieve sub-micron spatial resolution, and the attachments have even been modified for otoscopy [159]. The devices have been used to diagnose tuberculosis, malaria, parasitic worms, and ocular diseases, identify ocean wildlife, water quality, and agriculture [159]. Cell Scope UC Berkeley has developed software to accompany the device. The software allows for image collection, annotation, data management, web connection, and automated image analysis [159].



Figure 13: Cell Scope UC Berkeley mobile microscope (left), Cell Scope, Inc. Otoscopy (right) [159]

2.2.7 THINKLABS ONE

The ThinkLabs One digital stethoscope, seen in Figure 14, is capable of more than 100x amplification and can be used for all standard stethoscope procedures [155]. It can be used in conjunction with any smart device equipped with a headphone jack or when an adapter is used [155]. The stethoscope is capable of supporting Bluetooth audio recordings [155]. Additionally, standard recording software or ThinkLabs' application can be used to record sounds which can then be shared over the internet, allowing quick worldwide collaboration [155]. The ThinkLabs One digital stethoscope sells for \$499 [155].



Figure 14: Thinklabs Digital Stethoscope [155]

2.2.8 HORUS SCOPE

The Amwell Horus Scope is a handheld telemedicine-capable viewing device with multiple interchangeable lens attachments including a general viewing lens, an otoscope attachment, a surface lens, a dental lens, a fundus/ophthalmoscope lens, an anterior chamber lens, and an endoscope interface lens, seen in Figure 15 [9]. Although the device has its own screen, it can be used in conjunction with a smart device via USB [9]. Data can be shared via HIPAA-compliant medical record sharing applications [9].



Figure 15: Amwell Horus HD Digital Scope System [9]

2.2.9 LONESTAR VOLATILE ORGANIC COMPOUND (VOC) ANALYZER

The Owlstone Lonestar VOC Analyzer, seen in Figure 16, is not strictly speaking a smart device attachment, but does utilize a tablet computer in its construction. It is a portable Field-Asymmetric Ion Mobility Spectrometer (FAIMS) device used to identify VOCs that are biomarkers of known conditions such as asthma, tuberculosis, and colorectal cancer [118]. The Lonestar weighs 7.8 kilograms and is 38x26x20 centimeter (cm) in size making it light weight, compactable, and highly portable [118].

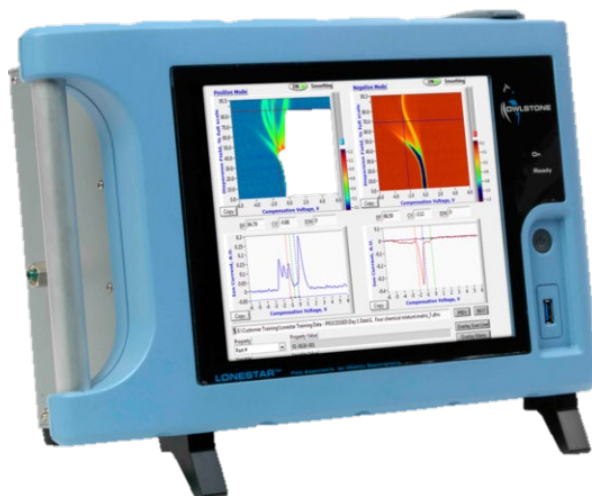


Figure 16: Owlstone Medial Lonestar VOC Analyzer [118]

2.2.10 BATDOK

[See RDD EM gap 3.](#)

2.2.11 REMOTE HEALTH SOLUTIONS (RHS) USA VIRTUAL EXAM ROOM (VER)

The RHS USA VER is a smart-device based telemedicine platform available in configurations optimized for situations from home use to extended field hospital service and in-field medic/emergency medical service [128]. The VER platform is BATDOK-compatible and all versions except one are self-contained in a single pelican case, seen in Figure 17 [128]. Versions optimized for field use are powered by a rechargeable battery and come with a variety of medical devices, depending on the purpose they are optimized for [128]. All self-contained versions are roughly the size of a briefcase and weigh around 15 pounds [128].



Figure 17: Remote Health Solutions VER-Medic System [128]

2.2.12 CHECKME PRO HEALTH MONITOR

[See RDD EM gap 3.](#)

2.2.13 KARDIA

[See RDD EM gap 3.](#)

2.2.14 WELLUE O2 RING

[See RDD EM gap 3.](#)

2.2.15 HEALTHY.IO

Healthy.io is a company that has developed a platform that utilizes the camera of a smartphone to capture images of a wound or Healthy.io testing kit [73]. Healthy.io has developed many dipstick testing kits including MinuteFul-10, MinuteFul-UTI, MinuteFul-Wound, and MinuteFul-Kidney [73]. These testing kits are capable of measuring 10 parameters including multiple infections, pregnancy-related complications, and chronic illnesses [73]. The testing kit or wound images are analyzed using computer vision algorithms and unique calibration methods to arrive at laboratory-accurate results [73]. Test results are stored in a HIPAA and general data protection regulation-compliant cloud for use by medical professionals [73]. This device is FDA cleared and CE marked [73].

2.3 GAP 9: DRINKING WATER SAMPLING

Water is one of the most essential nutrients and it allows the body to maintain homeostasis. In many situations, hydration plays a significant role in a person's ability to maintain peak performance. The ability to test drinking water for a variety of conditions such as bacteria, parasites, viruses, chemicals, metals, and more is important for maintaining the health and safety of military personnel [12, 164]. But many, if not all, bases located in austere environments will lack laboratory capabilities needed to test drinking water quality [12, 164]. This is due to equipment size, electrical consumption, and the need for incubation [12]. Reducing sample incubation times or eliminating the need for incubation all together would help ensure quick sample turnaround to allow for faster and more precise water treatment plans and provide reassurance to military members that the water is safe for consumption. Additional hurdles are faced when in low resource environments and potable water is not an available land resource [164]. Most of the smart devices discussed below address testing potable water, specifically for biological agents or reading paper-based testing techniques.

2.3.1 TRINAMIX INFRARED (IR) DETECTORS AND NEAR INFRARED (NIR) SPECTROSCOPY + APP

TrinamiX NIR spectrometer, seen in Figure 18, is a handheld instrument compatible with various smart devices [156]. They utilize a proprietary IR sensor that can sense wavelengths of one to three microns [156]. It can scan a sample in less than five seconds and can utilize Quick Response codes and barcodes to generate sample names, providing a “point-and-click” spectrometry solution [156]. Colorimetric assays can be utilized to access quality and quantity of a particular component in a sample and spectrophotometry allows for a standardized, objective, fool-proof process of assessing the assay. Results of spectrometry scan are displayed in the associated smart device application and data is encrypted on the device, in the cloud, and during the transfer between the two [156].



Figure 18: Trinamix Mobile NIR Spectroscopy [156]

2.3.2 COLORIMETRIX APP

The Colorimetrix application utilizes a smart device's camera and mathematical algorithms to enable a smart device to be used as a spectrophotometer and a fool-proof means of assessing any colorimetric assay in real-time [38]. This app can be used on any high-end smart device and provides comparable accuracy to commercially available spectrophotometers [38].

2.3.3 OMNIVIS

OmniVis is a portable, lightweight, and durable smartphone attachment, seen in Figure 19, which utilizes a fluorescence detector and a phone's camera to detect cholera microbes in a sample [35, 116]. The device utilizes Loop-Mediated Isothermal Amplification (LAMP) and fluorescence to identify *Vibrio cholerae* [35, 116]. It has proven to be capable of in-situ detection of *Vibrio Cholerae* in under 30 minutes [35]. Currently, the technology is singleplex, but the technology can be modified to identify other biological pathogens.



Figure 19: OmniVis Device [35]

2.3.4 NUMEN SENSORICS A/S

Numen Sensorics A/S utilizes electrochemical detection to identify *Escherichia coli* (*E. coli*) in water samples. The system works by adding magnetic beads modified with specific antibodies/aptamers to capture *E. coli* in water samples [111]. A second antibody/aptamer is added to form a complex that can be applied to carbon printed electrode with an isolating layer and loaded into the electrochemical cell designed by Numen Sensorics [111]. The cell can be read by any potentiostat which can then be connected to any smartphone or smart device [111]. If *E. coli* is present, it will form an antibody-antigen complex in the sample which is capable of digesting the isolating layer on the electrochemical cell [111]. If there is no *E. coli* present in the sample, no antibody-antigen complex will be produced and the isolating layer on the electrochemical cell will remain untouched and therefore no change in electrochemical signal will result. This results in a direct comparison of *E. coli* concentration and electrochemical signal [111]. This technology has shown to be capable of detecting the electrochemical signal produced by a single bacterial cell/1 milliliter (mL) - 5 mL [111]. However, it is of note that this product is in the development phase and the product is a proof-of-concept prototype. The company is currently looking for investors to move forward with product development and further validation studies.

2.3.5 LUMINOSTICS

The Luminostics sensor uses glow-in-the-dark nanoparticles, a clip-on smartphone attachment, seen in Figure 20, and an associated application to perform lateral flow assays for bacteria, viruses, proteins, and hormones from swabs, saliva, urine, and blood [93]. Luminostics has developed highly stable and sensitive glow-in-the-dark nanoparticles capable of detection

using the flash and camera of a smartphone [93]. The system works like standard lateral flow assays and uses an antibody-antigen complex to determine the presence or absence of the intended target. Lateral flow test strips can be prepared with the Luminostic nanoparticle and in the presence of the target the test line will glow when excited by the flash on a smartphone [93]. This glow can then be captured using the camera on the smartphone [93]. Luminostics' device can detect bacteria levels at 100 to 1,000 cells per mL and molecules at femtomolar levels [93].



Figure 20: Luminostics Hardware [93]

2.3.6 SMART MICROOPTICS DIPLE

A variety of microscope attachments are available for smart devices. These attachments vary widely in their complexity, magnification, and other capabilities, from simple clip-on magnifying attachments for the phone's camera, to complex automated devices with custom-developed software. One of the devices for which the most information is available is DIPLE, seen on the left in Figure 21. DIPLE is a simple but powerful microscope system for a smartphone camera, capable of 150x optical magnification and optical resolution of less than 1 micron [78, 136]. When the optical magnification of the DIPLE lens and the digital magnification of the smart device's camera are combined, magnifications of more than 1000x is possible without pixilation [78, 136]. The device is self-contained and has a light source, stage, and metal plate with an optical system [78, 136]. While no specialized applications are necessary to use DIPLE, this device does require a stable flat surface [78, 136]. DIPLE systems are not currently being shipped [78, 136]. However, they are available for purchase at a price of approximately \$100 [78, 136]. Smart Micro Optics also offers BLIPS magnification lenses, seen in Figure 21 on the right, which are secured to a smart device using an adhesive backing and can be used to achieve magnification of over 150x when used in combination with the camera's digital zoom [137]. BLIPS lenses are offered at an even lower price point than DIPLE but require an external stage for stability and securing slides [137].

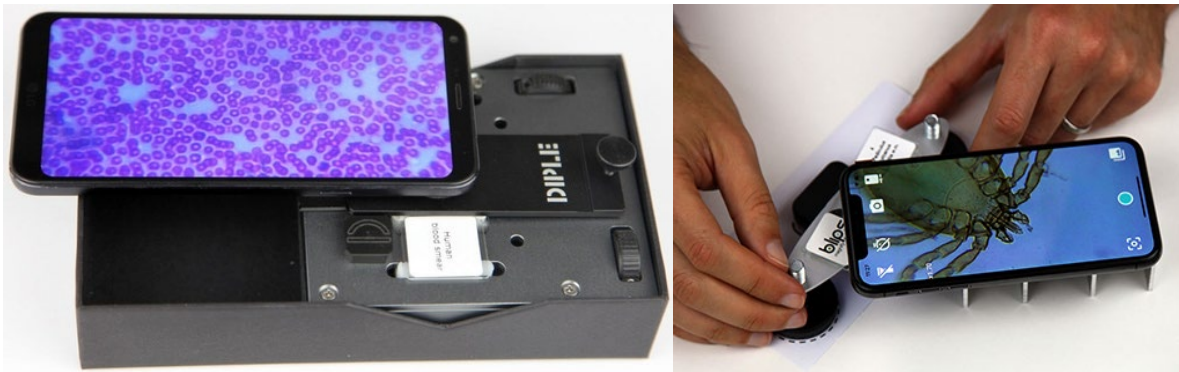


Figure 21: SmartMicroOptics DIPLE (left) [136], SmartMicroOptics BLIPS (right) [137]

2.3.7 CELL SCOPE

[See RDD EM gap 4.](#)

2.3.8 TINYSCOPE AND OTHER SMARTPHONE MICROSCOPES

Tinyscope and other smartphone microscope, seen in Figure 22, are small, lightweight attachments that can be placed over the camera lens of Android, iOS, and other smartphones [85, 170]. The devices use an adhesive sticker that can be reused up to 100 times to attach to the lens of a phone [85, 170]. They are capable of magnifying 20-400x, have a 5mm diameter field of view, and a 2mm optical resolution [85, 170]. While these devices are more commercial and have less scientific backing, they do show that the capability exists and can be fine-tuned.



Figure 22: TINYSCOPE (left) [85], and TI SCOPE (right) [170]

2.4 GAP 12: EMERGENCY BLOOD BANKING RAPID SCREENING

Blood is essential for providing nutrients and oxygen to the tissues in the body [49, 70, 114]. Additionally, blood aids in the removal of toxins from tissues so they can eventually be removed from the body entirely and is essential for maintaining homeostasis [49, 70, 114]. Blood is particularly important when dealing with injuries that result in blood loss. Blood carries the important components and proteins required for clotting and if too much blood loss is sustained, the patient is in danger of the “trauma triad of death” [114]. The “trauma triad of death” is a lethal cascade of hypothermia, acidosis, and impaired coagulation [114]. If an injury is sustained and it leads to hemorrhaging, it is imperative the patient receive proper medical care or severe complications can arise [49, 70, 114]. Hemorrhaging is the leading cause of combat deaths, but an important mitigation tactic is blood transfusions [70, 114]. However, before patients can

receive a transfusion, the donated blood must be screened for possible pathogens to ensure they are not passed to the recipient and cause further complications. A portable, handheld, limited power consumption, and multiplex device that is capable of rapidly screening for commonly occurring pathogens in an austere environment would help address this capability gap. A smart device offers a unique platform capable of meeting many of these requirements and would drastically improve the blood screening process and, therefore, improve patient outcome.

2.4.1 MOBILE-ELISA (MELISA)

This device, seen below in Figure 23, is a smartphone-based enzyme-linked immunosorbent assay (ELISA) or a mobile-ELISA (MELISA) [173]. The MELISA is a low-cost 3D-printed attachment for a smartphone [173]. An ELISA is an important and gold standard technique for diagnosing and monitoring many diseases [173]. The MELISA functions the same as a standard, laboratory-based ELISA and a validation study has reported the same accuracy [44]. The MELISA can use the same types of assays (e.g., direct, indirect, sandwich, and competitive) as traditional laboratory-based ELISAs [1]. The MELISA is currently undergoing tests to determine its functionality in varying temperatures and humidity before gaining FDA approval [1]. ELISA techniques are typically singleplex in nature; however, they can be adapted to perform multiple assays simultaneously. Although, this would increase the potential for human error and increase the time required to prepare and screen the blood samples. For this device, cold chain management is entirely dependent on the ELISA kits used because some kits require temperature-regulated storage while others do not.

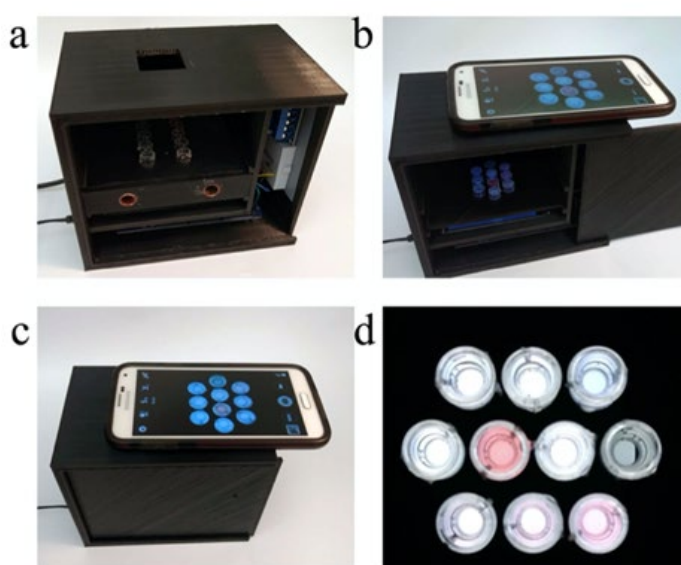


Figure 23: MELISA Prototype [173]

A) Sample incubation mode. B) Loading image capturing tray. C) Image capturing mode. D) A captured image sample using colored dyes for demonstration.

2.4.2 PAPER-BASED VERTICAL FLOW IMMUNOASSAY (VFI)

This immunoassay device, seen below in Figure 24, is attached to the rear-camera of a smartphone and reads the results of paper-based VFI [32]. VFIs utilize a nanoporous nitrocellulose membrane pretreated with capture antibodies for the intended target [32]. The membrane is encapsulated in a stainless-steel filter holder, fixed to the rest of the housing unit,

and then can be attached to the back of a smartphone [32]. This device utilizes the sandwich assay technique to form an antibody-antigen complex that generates a colorimetric signal indicating the presence of the intended target [32]. Preliminary studies have shown that this VFI device is capable of detecting biomarkers for weaponized bioagents, such as *Bacillus anthracis*, the causative agent of anthrax, as well as *Burkholderia pseudomallei*, the causative agent of melioidosis [32]. This VFI devices has performed proof-of-concept testing as a multiplex device and showed the capability to test for multiple biomarkers simultaneously [32].



Figure 24: VFI smartphone attachment with paper membrane assay [138]

2.4.3 MCHIP SMARTPHONE DONGLE

mChip is a microfluidic smartphone attachment that connects to the device through the audio jack, seen below in Figure 25 [89]. The device is capable of testing for infectious diseases in about 15 minutes via a single drop of blood from a finger stick using standard ELISA techniques [13, 89, 130]. Unlike standard ELISAs, mChip uses energy from the connected smartphone to perform the test oppose to requiring an outside power source [89]. mChip is a user-friendly device requiring little to no training and has an easy “positive”, “negative”, or “indeterminate” result display, as seen in Figure 26 [89]. This devices underwent a pilot program in Rwanda where it was used to screen 96 patients at three separate clinics for HIV and syphilis [130]. However, the device has the potential to be adapted to test for other diseases, specifically Lyme Disease [13]. In the Rwanda pilot program, mChip had an accuracy rate of 96% when compared to gold standard laboratory based ELISAs and has a false positive rate of 14% [130]. mChip is currently priced at \$34 which is highly affordable compared to standard laboratory based ELISA equipment [89, 130, 150].

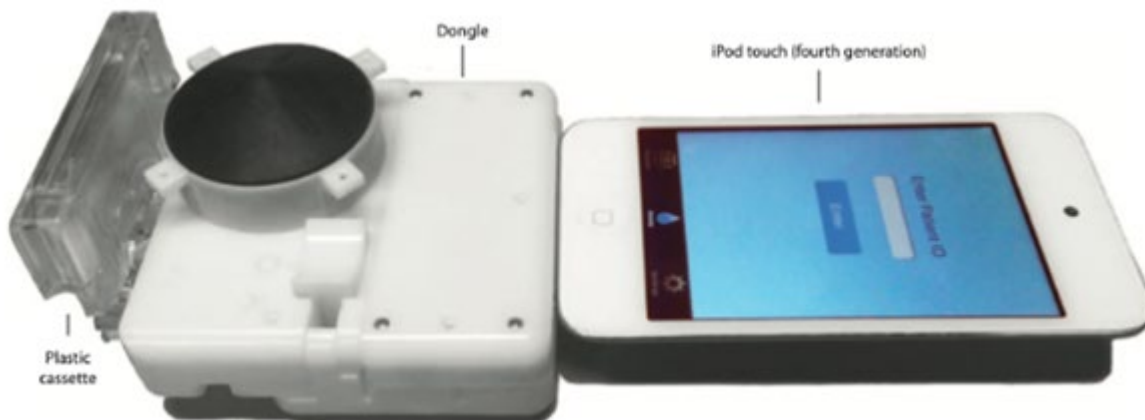


Figure 25: mChip microfluidic cassette attached to a smart device [89]



Figure 26: mChip user interface [89]

2.4.4 SANDIA SMARTLAMP

Sandia National Laboratories developed the SmartLAMP, seen below in Figure 27, a technology readiness level (TRL) 4, real-time (30 minutes), multiplex diagnostic device capable of point-of-care testing (POCT) in resource limited environments [124, 133]. SmartLAMP uses reverse-transcription loop-mediated isothermal amplification (RT-LAMP) techniques based on quenching of unincorporated amplification signal reports to detect viral-ribonucleic acid (RNA) in a sample [124, 125]. SmartLAMP is capable of testing a variety of mediums (e.g., blood, saliva, and urine) [124, 125]. It is currently developed as a multiplex device screening for Zika, Chikungunya, and Dengue viruses and has proven successful at distinguishing between the different serotypes, specifically for Dengue virus [124, 125]. The device works with a custom application, LamptoGo, to analysis the fluorescent signal resulting from the RT-LAMP technique using chromaticity [124, 125]. These signals would typically be undetectable to the naked eye or red, green, blue (RGB) intensity sensors [124, 125]. SmartLAMP is user-friendly, requiring minimal training, and it returns binary, “yes” or “no”, results [124, 125].

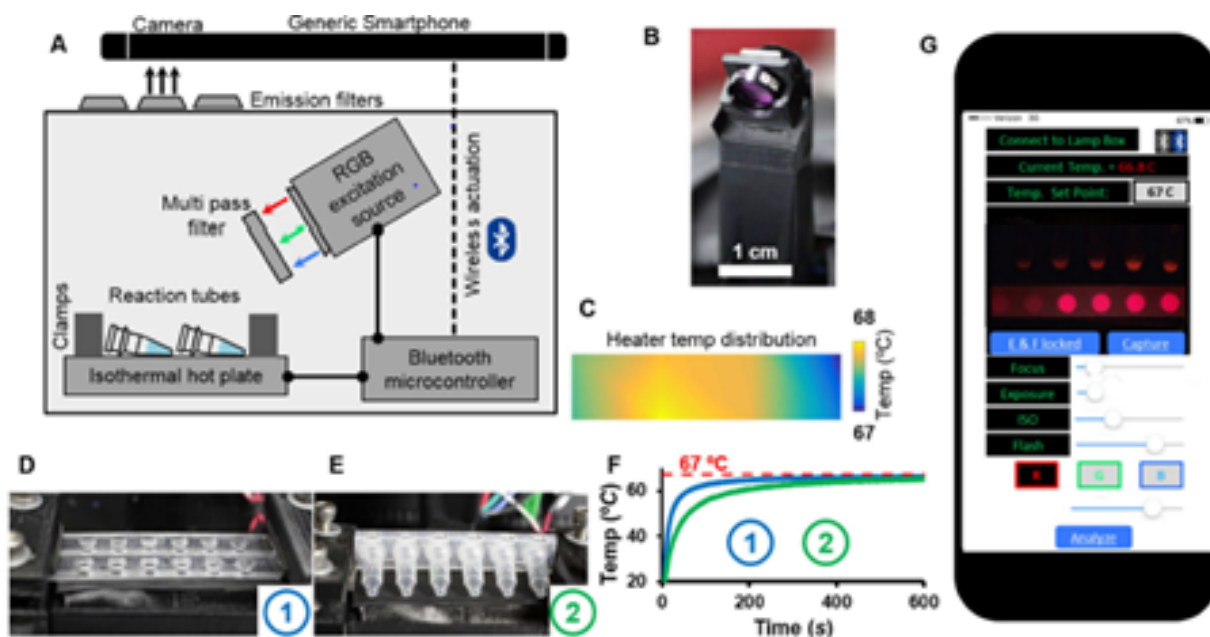


Figure 27: Overview of SmartLAMP testing process [125]

A) Schematic of the RT-LAMP fluorescent detection device, depicting the isothermal heater with reaction tubes, light emitting diode (LED) excitation source, and Bluetooth microcontroller. B) A 3-watt RGB LED coupled with an RGB multi band pass filter. C) The isothermal heater provides a uniform surface temperature distribution within a 1°C variation. The heaters can be loaded with either D) off the shelf PCR polypropylene tubes or E) custom-made laser-cut reaction wells. F) Thermal management and heat ramp rates are greatly improved with custom laser-cut wells. G) The smartphone app.

2.4.5 DISPENSE, DISSOLVE DIFFUSE, DETECT (D4) POCT

The D4 assay, seen in Figure 28 and 29, is a standalone, high-throughput POCT that utilizes sandwich immunoassay to detect pathogens [82]. D4 assay was designed to type and screen blood for point-of-injury care to minimize hemolytic reactions and further complications due to pathogens, as well as measured lactate to allow for hemodynamic monitoring [33]. The device is 3D-printed and consists of a nanoscale non-fouling (protein and cell resistant) poly(oligoethylene glycol methyl ether methacrylate) (POEGMA) brush coated glass chip. The chip has two printed microspots: stable capture antibodies and soluble fluorophore labeled detection antibodies [82]. POEGMA has shown to reduce biomolecular noise and improve femtomolar limits of detection (from protein analytes) in blood, even if dried and stored [82]. In preliminary testing, the D4 assay has shown comparable results to gold standard laboratory based ELISA, table top fluorescent-scanners, has a limit of detection ranging from 6.3 to 113 picograms per milliliter (pg/mL), low false-positive rate, and has the potential to be a multiplex system capable of testing for multiple diseases at the same time [33, 82]. The device is about 185 grams (g); the size of the attachment is 14.5x8.0x7.8 cm [82]. It is of note that the D4 assay is currently undergoing additional testing and research under the Cooperative Agreement W81XWH1720045 (US Army Medical Command); the project is being funded by the Prolonged Field Care Research Award, Funding Level 1, Preclinical Research. Funding was awarded 15 September 2017 and expires 14 September 2021 [66].

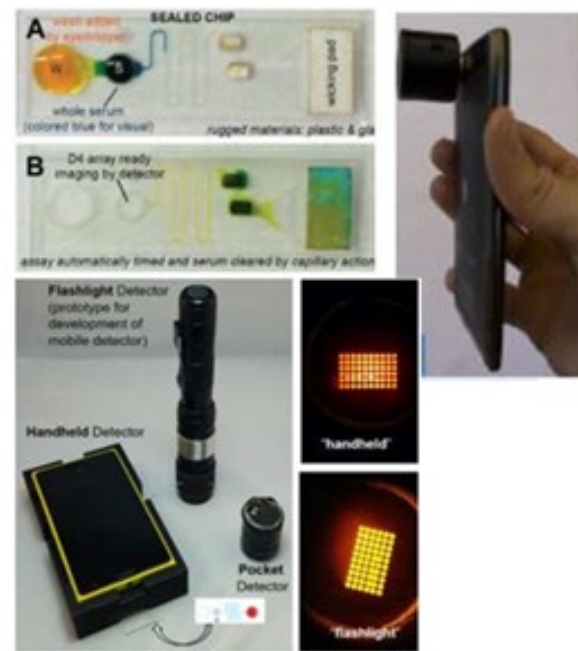


Figure 28: Components of the D4 POCT [34]

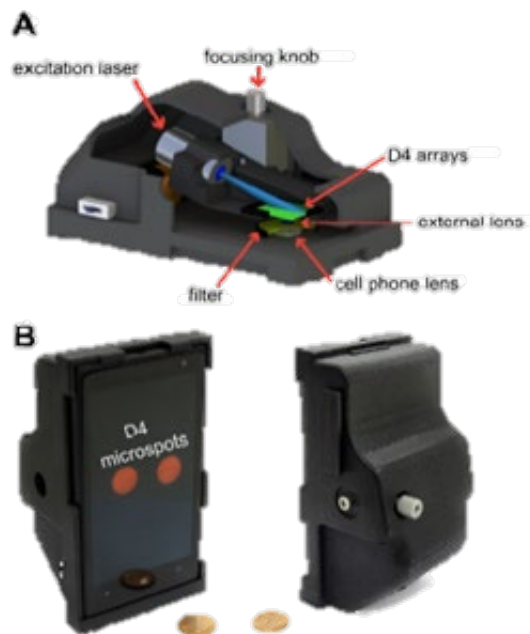


Figure 29: Schematic diagram of mobile phone attachment [82]

A) 3-D illustration of opto-mechanical attachment. B) Mobile phone imaging platform (penny included for scale) D4 microarray spots shown on screen.

2.4.6 LOOP-MEDIATED ISOTHERMAL AMPLIFICATION (LAMP)

This device, seen in Figure 30, utilized LAMP techniques to detect targeted nucleic acid sequences for a specific pathogen in 15-40 minutes [95]. The device consists of three parts a microfluidic chip, chip reader, and smartphone [59, 95]. It has been used in preliminary studies to detect influenza A (InFA, H1N1), Methicillin-resistant staphylococcus aureus, and even used

in agricultural settings to test for *Fusarium* species [59, 95]. The device is capable of connecting to Wi-Fi to transfer and retrieve data, but it still in the development process and requires a relatively lengthy process to prepare samples for testing.

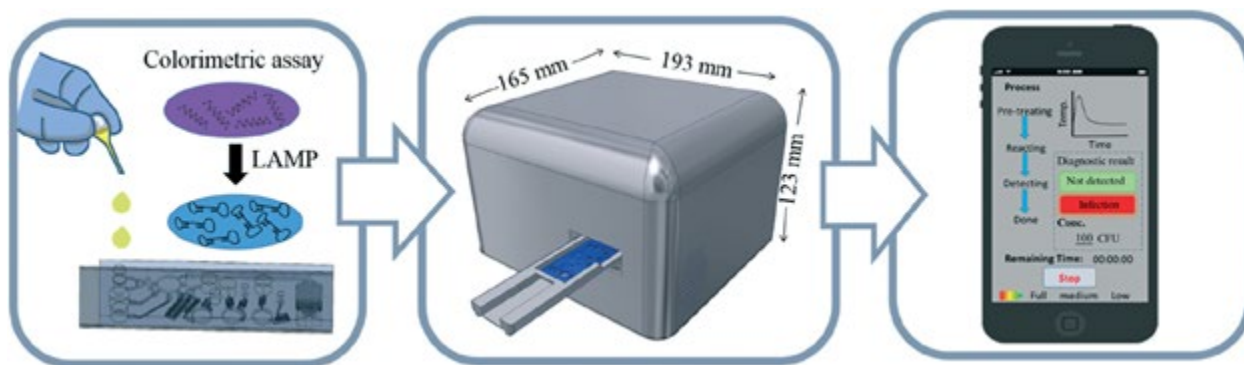


Figure 30: An example of the way LAMP is utilized in sample analysis [95]

2.4.7 MOBILE DIAGNOSTIC RAPID TEST READER (MREADER)

The mReader, seen in Figure 31, is a low-cost, accurate microplate reader that can be used with a smartphone and its associated application to read colorimetric ELISA tests [165]. The mReader consists of a 96 sample well plate and each well can be loaded with a sample from a different individual or test for a different pathogen [165]. Currently, collected blood samples must be prepared before they can be read on the mReader [165]. Sample preparation can take about 25 minutes and requires a portable centrifuge and ELISA kit for the intended pathogen [165]. The mReader takes about 1 minute to process the samples and returns qualitative or quantitative results [165]. The results are captured using the attached smartphone. The phone is mounted to the mReader, captures an image of the 96-well plate, and the associated software analyzes the color changes due to the presence and absence of the targeted pathogen [165]. The system currently costs about \$50 and has been validated against Varicella zoster virus IgG, Cytomegalovirus IgG, Measles virus IgG, Mumps virus IgG, Herpes simplex virus type 1 IgG, Herpes simplex virus type 2 IgG, Epstein Barr virus four antibody test panel– viral capsid antigen IgM and IgG; Epstein-Barr nuclear antigen and early antigen, *Borrelia burgdorferi*, *Helicobacter pylori*, and is capable of identifying 12 common viral and bacterial infections [40, 165].

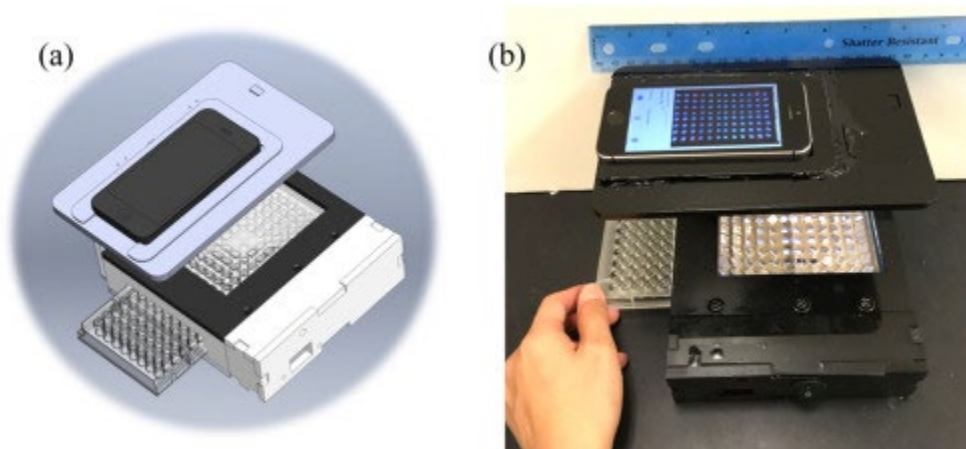


Figure 31: A) 3D model and B) mReader [165]

2.4.8 LAB-ON-A-CHIP

The Optofluidic Lab-On-A-Chip is an accessible, low-cost smartphone attachment, seen in Figure 32, designed to detect infectious pathogens such as *Plasmodium falciparum* directly from diluted (10%) human whole blood samples [145, 146]. The device is made of different lenses and mirrors placed in optofluidic channels angled at 45 degrees to capture Mie scatter (i.e., elastic scattered light due to particles having a similar or larger diameter than the wavelength of the incident light) from different blood samples [145, 146]. The device utilizes anti-histidine-rich protein 2 (HRP-2)-conjugated sub microbeads mixed with HRP-2-infused 10% blood in an immunoagglutination assay lab-on-a-chip device [145, 146]. In the presence of the targeted pathogen, the antibody-conjugated microbeads agglutinate which results in different light absorption and scattering characteristics [145, 146]. This change in light scattering is used to indicate a positive or negative result [145, 146]. The device has a limit of detection of 1 pg/mL in 10% blood samples and takes about 10 minutes to complete the assay, with no requirement for an outside power source [145, 146]. The results are currently interpreted by the user and validation studies have used Photoshop to analyze the results [145, 146]. However, the light source for the images is standardized by using the white LED flash and camera on a smartphone to capture the results.

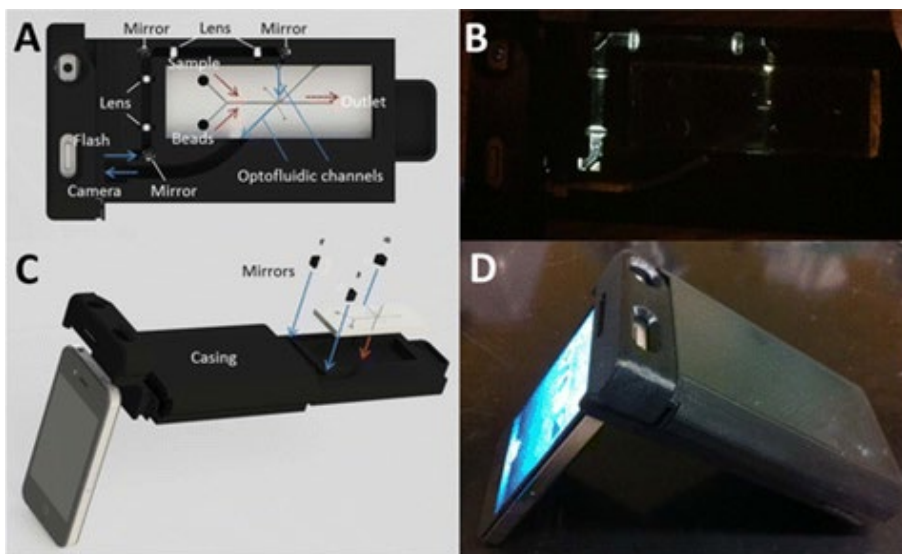


Figure 32: Lab-On-A-Chip Handheld Device [145]

A) Isometric view of the SolidWorks model for the handheld device without the case. B) Top view of the handheld device indicating the path the light travels to reflect through the mirrors and four lenses. C) Exploded SolidWorks model of the entire device including the iPhone 4 adapter, Lab-On-A-Chip adapter, casing, Lab-On-A-Chip tray, optofluidic Lab-On-A-Chip, mirrors for directing the light source, mirror adapters, and lenses for focusing the light after it hits the mirrors. D) Photograph of actual device with an iPhone 4 in the housing.

2.4.9 RAPID-DIAGNOSTIC-TEST (RDT) READER

The RDT reader platform is a low cost, portable smartphone attachment, seen in Figure 33, capable of reading various lateral flow immunochromatographic (LFI) RDTs [103]. The RDT reader platform weighs about 65 g, requires AAA batteries, and is designed for different LFI-RDTs to be inserted and imaged using the reflection or transmission modes on the device [103]. The device uses the LEDs in the system or on the smartphone [103]. An image is captured and the results are analyzed using the associated application [103]. This process takes no more than 5

minutes and the device is currently capable of detecting *P. falciparum*, tuberculosis, and HIV [103].

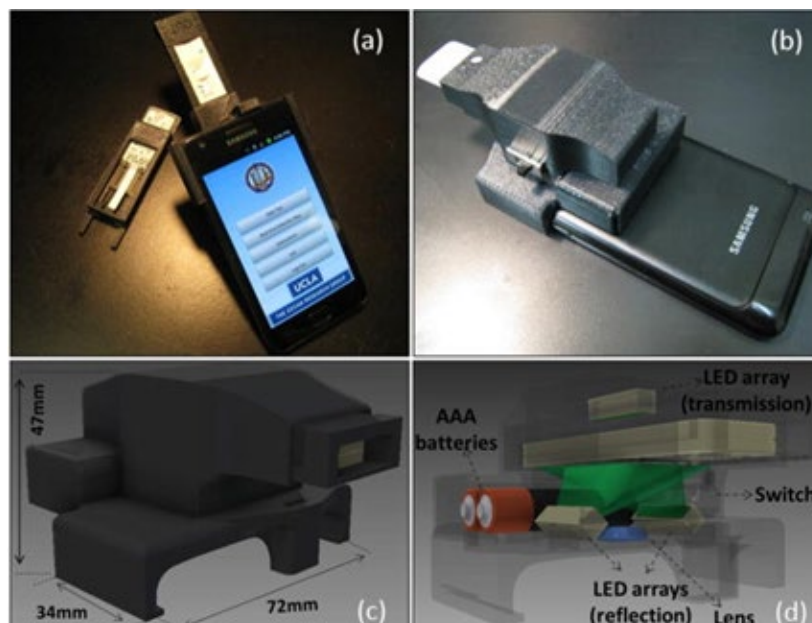


Figure 33: RDT Reader [103]

A) Front view of the RDT reader. B) Back view of the RDT reader. C) Schematic diagram of the external components of the RDT reader. D) Schematic diagram of the internal components of the RDT reader.

2.4.10 RT-LAMP WITH FLUORESCENT LABEL DETECTION

RT-LAMP with fluorescent label detection is a portable smartphone attachment, seen in Figure 34 and 35, that uses RT-LAMP to detect specific RNA segments indicating a pathogen is present [64]. The device consists of an unmodified smartphone, lab-on-a-chip capable of completing RT-LAMP, and a 3D-printed case that houses the electrical and optical components and lithium-ion battery [64]. The lab-on-a-chip portion of the device is dehydrated for storage purposes and requires a rehydration process before testing can begin [64]. The reagents needed for the rehydration process must be stored at -20 °C, but the overall process, seen in Figure 34, from sample collection to results, takes about 30 minutes [64]. As the name indicates, this device uses fluorescent molecules to indicate a positive result and standardizes the image capturing stage using an LED [64]. The data and its analysis are displayed as a visual read-out on the smartphone, seen in Figure 35 [64]. This RT-LAMP with fluorescent label detection device is capable of simultaneous detection of Zika, Chikungunya, and Dengue [64].

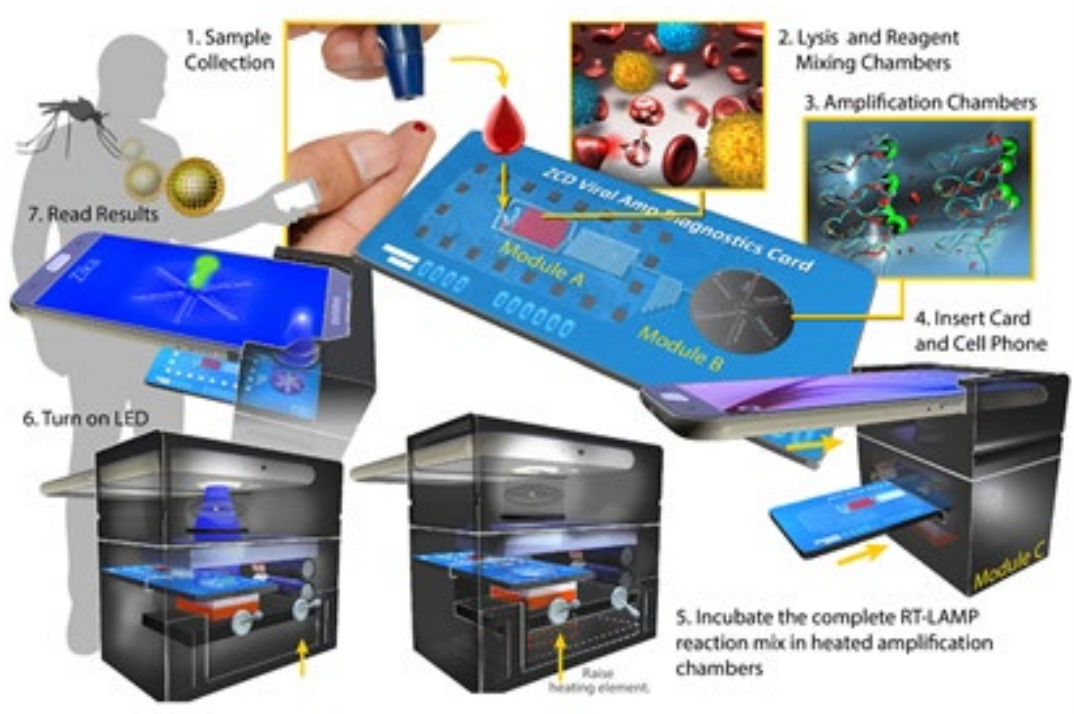


Figure 34: The process for the RT-LAMP with fluorescent label detection device [54]

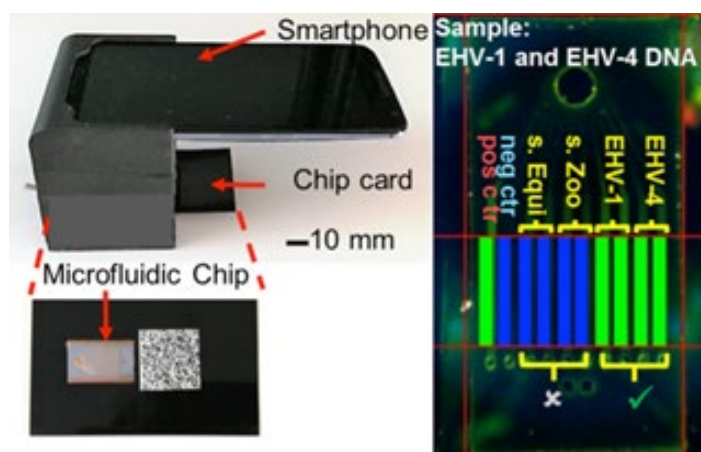


Figure 35: RT-LAMP with Fluorescent Label Detection Device (left) and output display (right) [54]

2.4.11 SMIDGION

SmidgION, seen in Figure 36, is Oxford Nanopore Technologies' third generation portable smartphone deoxyribonucleic acid (DNA) and other biological molecules analysis device [119]. This device is a user-friendly attachment which can rapidly prepare biological samples using barcoding and next generation sequencing techniques [119]. The system takes about 30-40 minutes to complete and requires sample preparation; however, this can be automated using Oxford Nanopore Technologies' Flongle or Voltrax [119].



Figure 36: The Oxford Nanopore Technologies SmidgION device [119]

2.4.12 BIOMEME TWO3

The Biomeme two3, seen in Figure 37, is a portable devices capable of performing polymerase chain reaction (PCR), reverse transcription-PCR, quantitative-PCR , and isothermal tests to amplify and identify DNA or RNA samples in very small quantities [19, 22]. The devices is composed of restriction of certain hazardous substances-certified electronic components and assemblies, designed to house an iPhone, and all together weighs about 1 pound [22]. The system is compatible with Biomeme’s M1 Sample Prep (reduces sample preparation time to less than one minute without the need for additional laboratory equipment), Biomeme Go-Strips (2 years with no refrigeration shelf life), Franklin (can test up to 9 samples or 27 targets at once and produces results within one hour), and Biomeme App Suite (customizable thermocycling platform that can run offline and sync data with Biomeme Cloud) [23]. The Biomeme two3 and iPhone, not including the M1 sample Prep, Go-Strips, Franklin, or any fees associated with platform components and training, costs about \$4,000 [174].



Figure 37: Biomeme two3 device [22]

2.4.13 LENS-LESS SMARTPHONE SPECTRUM APPARATUS (LESSA)

The Smartphone LeSSA, seen in Figure 38, is an optical spectrometer smartphone attachment [31]. The device is composed of an iPhone 5S holder, cuvette holder, and two adapters with apertures embedded [31]. LeSSA was designed to test for acute organophosphorus (OP) poisoning in agricultural workers, but the devices functions as a plate reader and could be applied to other ELISA kits for detecting other molecules or pathogens [31]. This device is currently a working prototype and requires incubation; however, it provides a proof of concept for future developments.

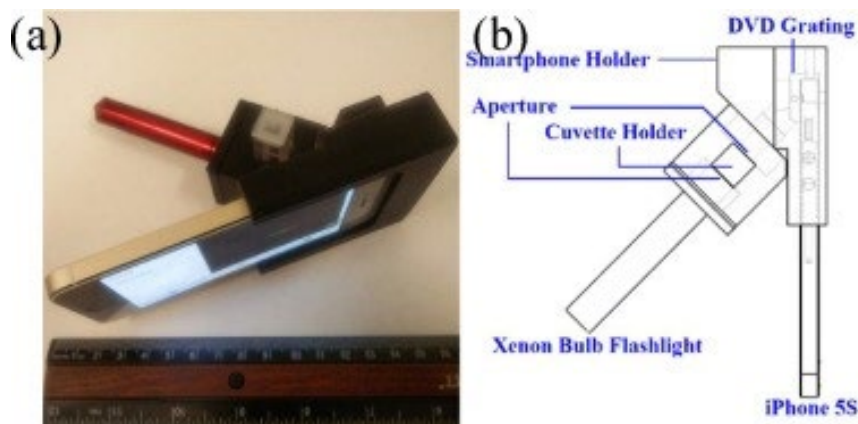


Figure 38: The LeSSA Device with the iPhone 5s (left) schematic structure of the LeSSA (right) [31]

2.4.14 MULTIPLEXED VERTICAL FLOW IMMUNODIAGNOSTIC ASSAY (XVFA)

The xVFA, seen in Figure 39, is a paper-based assay with a smartphone assay reader attachment and associated application for detecting antibodies in human serum [83]. The xVFA colorimetric signal is created by gold nanoparticles captured by specific antigens spatially arranged on a testing membrane to allow for multiplexing [83]. The assay is completed in 20 minutes, and an image is captured using the smartphone reader attachment and smartphone's camera [83]. Using the associated application, the image is sent to a server where it is analyzed and the results are quickly sent back to the user [83]. Currently, xVFA has only been validated against Lyme-specific antibodies in human serum; however, it provides a proof of concept for future developments [83].

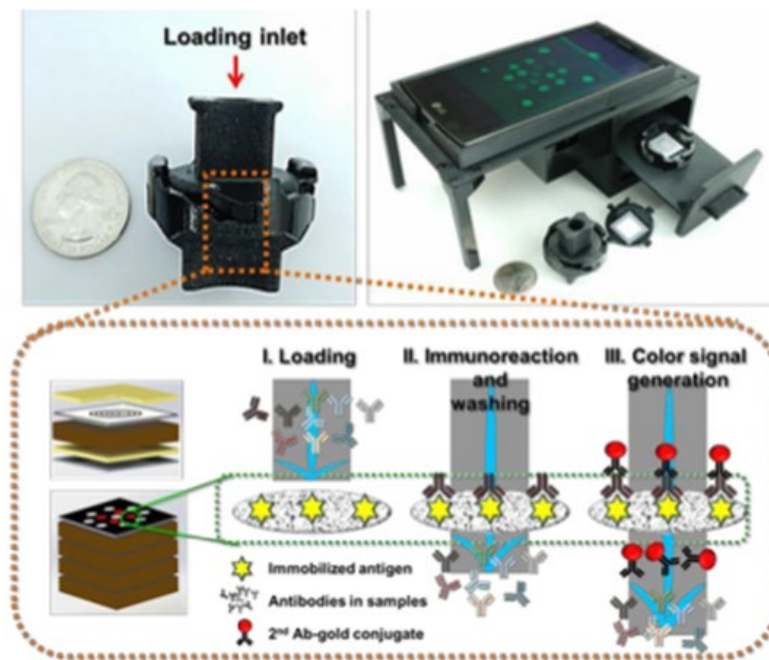


Figure 39: The xVFA Device [83]

2.4.15 SURFACE ACOUSTIC WAVE (SAW) BIOCHIP

The SAW Biochip, seen in Figure 40, is a rapid (within 10 seconds), POCT prototype that utilizes shear horizontal surface acoustic wave technology to detect pathogens in a sample [157]. The device is composed of a disposable biochip, pocket-size control box reader, and mobile smart device to analyze, display, and transmit results [157]. The SAW Biochip uses microfabrication and the piezoelectric effects to generate a shear horizontal surface acoustic wave on a biochip [157]. This wave produces a particle displacement perpendicular to the direction of wave propagation on the surface of the biochip [157]. This allows the biochip to be sensitive to reactions (i.e., antibody-antigen complexes forming) that occur on the surface of the biochip [157]. The SAW Biochip is capable of detecting immunological and virological biomarkers in a sample, but has currently only been validated against HIV [157].

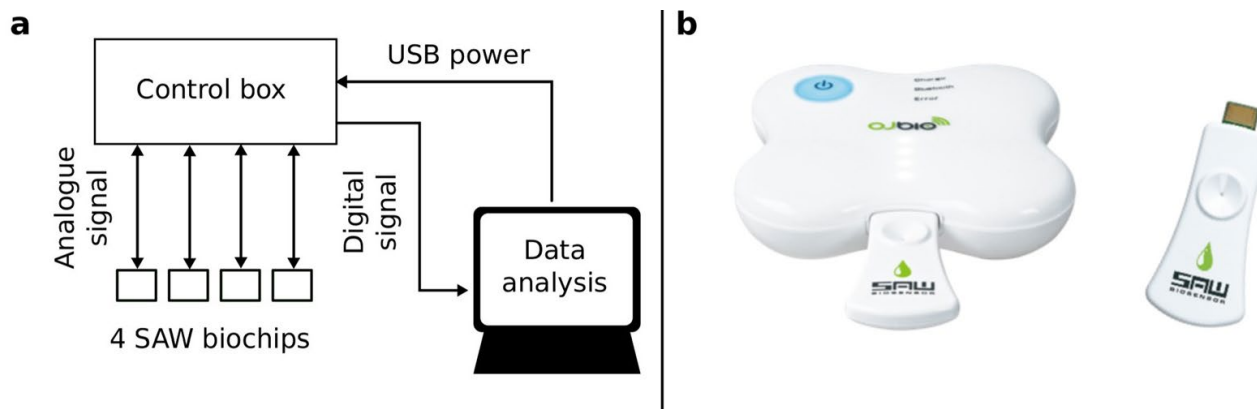


Figure 40: A) schematic for SAW Biochip B) SAW Biochip Prototype [157]

2.4.16 SMARTPHONE-BASED MULTICOLOR BIOLUMINESCENT

The smartphone-based bioluminescent biosensor, seen in Figure 41, is a 3D-printed box-like attachment that utilizes whole-cell biosensors to detect different targets [101]. The system is composed of a 3D-printed box that houses a 3D-printed cartridge enclosing spheroid cells and 3D-printed cartridge holders containing a mirror [101]. This box attaches to the back of a smartphone, which captures images for analysis [101]. This system utilizes whole-cell sensors in a spheroid formation, these cells are modified to respond to specific antigens, antibodies, or molecules and begin the production of green and red-emitting luciferases that can be detected using the camera on a smartphone and indicates the presences of the intended target [101]. Currently, this prototype has only tested for tumor necrosis factor and has provided a limit of detection of 0.15 ± 0.05 nanogram per milliliter [101]. Unfortunately, this device requires an 18-hour incubation process and 40 minutes of vacuuming to remove bubbles prior to testing [101].



Figure 41: Smartphone-Based Multicolor Bioluminescent Device [101]

2.4.17 TRANSMISSION, REFLECTION, AND INTENSITY SPECTRAL (TRI)-ANALYZER

The TRI-Analyzer, seen in Figure 42, is a smartphone-based microplate reader capable of using the camera of a smartphone as a high-resolution spectrometer with the ability to measure colorimetric absorption spectrum, fluorescence emission spectrum, and resonant reflection spectrum from a microfluidic cartridge [92]. The schematic for the TRI-Analyzer can be seen in Figure 43, it is composed of a 3D-printed housing unit that encloses the electrical components, a mirror, a laser, and batteries [92]. A commercially available assay is prepared, placed in the TRI-Analyzer's cartridge, and then inserted into the device [92]. Once inserted, the user uses the smartphone application to select the light source, this could be the LED flash from the smartphone or the green laser diode build into the TRI-Analyzer [92]. The light is gathered using optical fibers and passed through a diffraction grating and then the image can be captured using the camera on the smartphone [92]. Currently, the TRI-Analyzer is a prototype and still requires further validation studies; however, it demonstrates a proof-of-concept that future work can develop further.



Figure 42: The TRI-analyzer in use with an absorption cartridge [92]

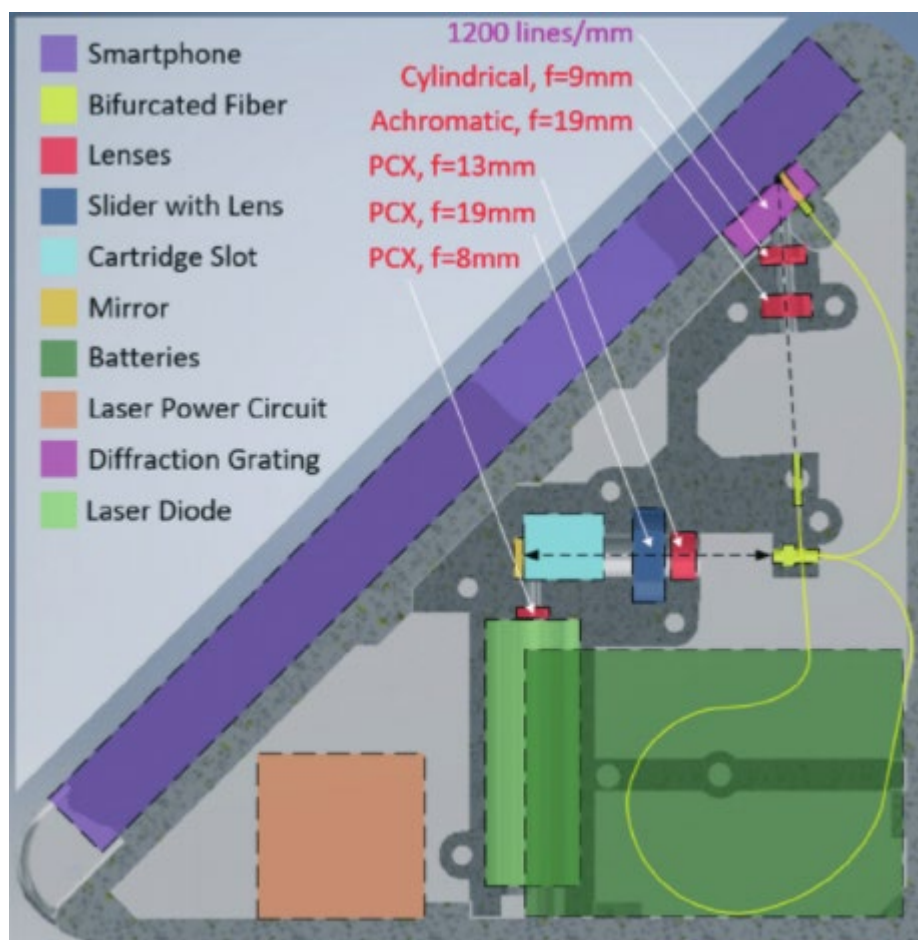


Figure 43: Schamitic of TRI-Analyser [92]

2.5 GAP 13: RAPID TEST FOR SPECIFIC DISEASE OUTBREAK/SURVEILLANCE

Outbreaks of emerging and re-emerging disease can not only impact military operations and training, but also affect local communities and civilian populations that may be receiving aid [76]. Disease outbreak could result from a civilian population spreading a novel disease to the

military population, the military population could bring and spread a novel disease to the civilian community, or disease outbreak could result from biological warfare [76]. The risk of disease outbreak drastically increases when bringing foreign populations together because they both have different pathogens and immunity. This may result in a disease in a population that can be extremely severe in symptoms and can spread extensively. Disease outbreak in a military population can drastically impair operational readiness, increase supply need, and leave the population vulnerable to other pathogens or attacks [76]. Disease outbreak in a civilian population due to military presence can undermine any aid being given and increase supply need [76]. Disease surveillance is an important mitigation technique for avoiding possible infectious outbreaks; however, it can be difficult to do in austere environments due equipment size, power consumption, and available resources. As globalization and infectious disease continue to intertwine, the capability to diagnose and control disease spread will be imperative to operations. A ruggedized and simple device that can rapidly test and monitor gastrointestinal and respiratory disease outbreaks, especially within austere environments would help address this capability gap. The Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) pandemic has highlighted the importance of monitoring disease spread for preparation, back tracing cases, predicting severity, and preventing transmission.

2.5.1 LUMINOSTICS

[See RDD EM gap 3.](#)

2.5.2 VIRUS TEST

The smartphone-based fluorescence detector, seen in Figure 44, is a compact and lightweight 3D-printed attachment for smartphones [171]. The device is composed of a reflective light structure coated with aluminum to improve light reflection, an LED and color filters which can be changed depending on the wavelength needed to excite the fluorophore [171]. This technology is intended to be used with fluorescent lateral flow immunoassay as it provides a dark enclosure for the smartphone camera to excite and detect fluorescence from the assay [171]. This allows for a more standardized lighting condition for the assay which can help eliminate misinterpretation of the results. The detection limit, sensitivity, specificity, and time to receive results (usually about 15 minutes) can all vary depending on the fluorescent lateral flow immunoassay used [171]. When evaluated with avian influenza-infected patients, the device was found to have high sensitivity, high specificity, and low virus titer detection limits [171].

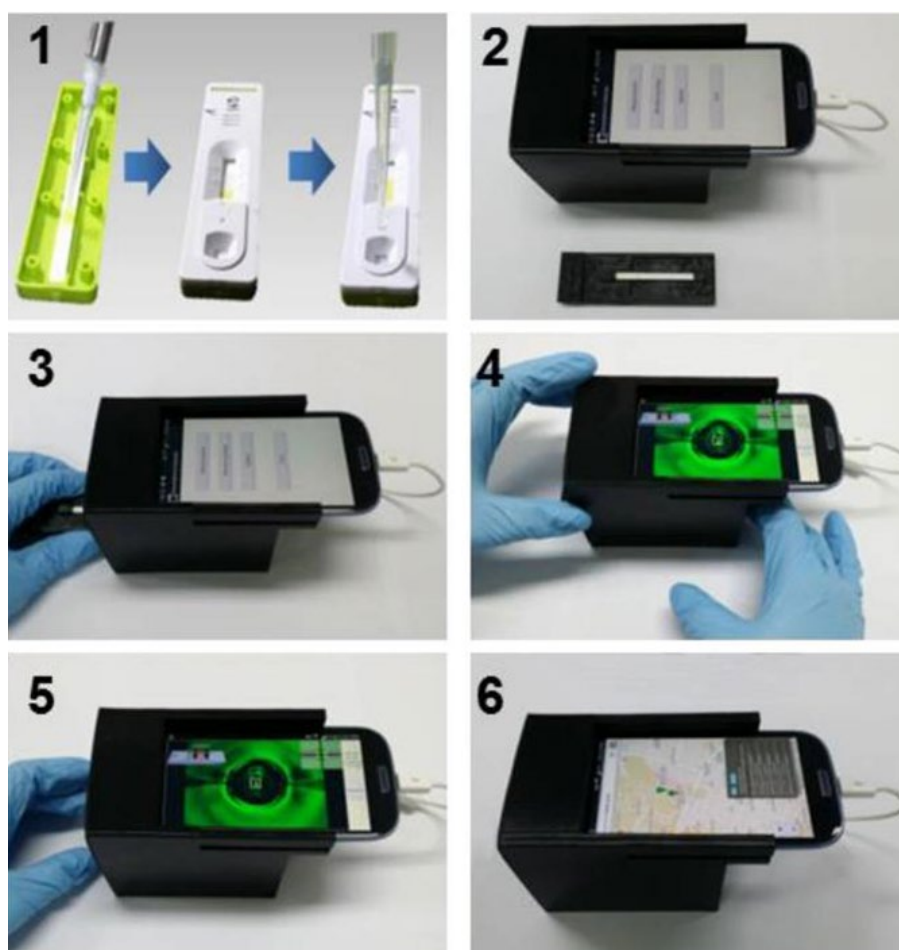


Figure 44: Overview of Smartphone-Based Fluorescence Detector [171]

1) Sample loaded onto the diagnostic strip. 2) After 15 minutes, the strip is placed in the smartphone fluorescence reader. 3 and 4) User starts measurement application on the smartphone and follows prompts. 5) Smartphone displays the results for fluorescence intensity of test line and control line. 6) Test results are displayed on the smartphone and can be wirelessly transmitted to other devices.

2.5.3 MOBILE-ELISA (MELISA)

[See RDD EM gap 12.](#)

2.5.4 PAPER-BASED VERTICAL FLOW IMMUNOASSAY (VFI)

[See RDD EM gap 12.](#)

2.5.5 MCHIP SMARTPHONE DONGLE

[See RDD EM gap 12.](#)

2.5.6 SANDIA SMARTLAMP

[See RDD EM gap 12.](#)

2.5.7 D4 POINT-OF-CARE TEST (POCT)

[See RDD EM gap 12.](#)

2.5.8 LOOP-MEDIATED ISOTHERMAL AMPLIFICATION (LAMP)

[See RDD EM gap 12.](#)

2.5.9 MOBILE DIAGNOSTIC RAPID TEST READER (MREADER)

[See RDD EM gap 12.](#)

2.5.10 LAB-ON-A-CHIP

[See RDD EM gap 12.](#)

2.5.11 RDT READER

[See RDD EM gap 12.](#)

2.5.12 RT-LAMP WITH FLUORESCENT LABEL DETECTION

[See RDD EM gap 12.](#)

2.5.13 SMIDGION

[See RDD EM gap 12.](#)

2.5.14 BIOMEME TWO

[See RDD EM gap 12.](#)

2.5.15 LENS-LESS SMARTPHONE SPECTRUM APPARATUS (LESSA)

[See RDD EM gap 12.](#)

2.5.16 MULTIPLEXED VERTICAL FLOW IMMUNODIAGNOSTIC ASSAY (XVFA)

[See RDD EM gap 12.](#)

2.5.17 SURFACE ACOUSTIC WAVE (SAW) BIOCHIP

[See RDD EM gap 12.](#)

2.5.18 SMARTPHONE-BASED MULTICOLOR BIOLUMINESCENT

[See RDD EM gap 12.](#)

2.5.19 (TRI)-ANALYZER

[See RDD EM gap 12.](#)

2.5.20 CELL SCOPE

[See RDD EM gap 4.](#)

2.5.21 TINYScope AND OTHER SMARTPHONE MICROSCOPES

[See RDD EM gap 9.](#)

2.5.22 SMART MICROOPTICS DIPLE

[See RDD EM gap 9.](#)

2.5.23 LONESTAR VOC ANALYZER

[See RDD EM gap 4.](#)

2.6 GAP 14: ENVIRONMENTAL TESTING

Environmental samples can include air, water, soil, and even sewage [7, 14, 117, 135]. Testing and monitoring the environment can provide important information about pollution, possible contamination, and gives a better understanding of the overall health of that region because environmental health correlates to the health and well-being of the people [7, 14, 117, 135]. Environmental hazards, even if present in small doses, can cause irreversible damage to the plants, animals, and humans inhabiting the area [14]. The ability to screen for environmental changes in any type of environmental sample could allow for the prevention of waterborne ailments, toxicity, and identify early warning sign for future disease outbreaks [7, 14, 117, 135].

2.6.1 TRINAMIX IR DETECTORS AND NIR SPECTROSCOPY + APP

[See RDD EM gap 9.](#)

2.6.2 COLORIMETRIX APP

[See RDD EM gap 9.](#)

2.6.3 LUMINOSTICS

[See RDD EM gap 9.](#)

2.6.4 CELL SCOPE

[See RDD EM gap 4.](#)

2.6.5 TINYScope AND OTHER SMARTPHONE MICROSCOPES

[See RDD EM gap 9.](#)

2.6.6 SMART MICROOPTICS DIPLE

[See RDD EM gap 9.](#)

2.6.7 SPECIM IQ

Specim Spectral Imaging has developed the Specim IQ, seen in Figure 45. This is a portable hyperspectral imaging camera capable of taking and analyzing images rapidly [143]. Specim IQ uses a 5200mAh Lithium-Ion battery (Type 26650) and has a memory capability of 2 gigabytes (GB), double data rate 3 low voltage random-access memory, and 8GB embedded Multi-Media Controller [143]. Specim Spectral Imaging is a leading supplier for hyperspectral imaging technology. Hyperspectral imaging collects and process information across the whole electromagnetic spectrum, obtaining a spectrum for each pixel of an image oppose to other techniques that use light to analyze an image and then assign a primary color (red, blue, and green) to the pixel [143]. Hyperspectral imaging allows a user to get more information from the image (i.e., material composition) [143]. Hyperspectral imaging has the potential to be used in health and food analysis; however, currently it is mostly used to evaluate environmental conditions such as oil leaks, illegal deposits, and fire risk assessments [143].



Figure 45: Specim IQ Mobile Hyperspectral Camera [\[143\]](#)

2.7 GAP19: HANDHELD CHEMICAL SCREENING ANALYSIS

An important aspect to monitoring the environment is to screen for potential hazardous chemicals [\[14\]](#). Hazardous chemicals could result from accidental spills, runoff from farming pesticides and fertilizers, or the release of a chemical warfare agent. Depending on the chemical, it can be lethal even at small doses, thus the ability to detect different chemical agents is an important mitigation technique [\[151\]](#). A lot of chemical detection equipment is large and not ruggedized, so a handheld portable screening device capable of detecting many different chemical agents in an austere environment would help address this capability gap.

2.7.1 TRINAMIX IR DETECTORS AND NIR SPECTROSCOPY + APP

[See RDD EM gap 9.](#)

2.7.2 COLORIMETRIX APP

[See RDD EM gap 9.](#)

2.7.3 SPECIM IQ

[See RDD EM gap 14.](#)

2.7.4 NERVE AGENT DETECTOR

The Nerve Agent Detector, seen in Figure 46, is a portable (roughly the size of a small car battery) box capable of detecting G and V series nerve agents using fluorescent signals [\[151\]](#). The device consists of an external cell phone, a dark box (made from Legos, in this case), a 96-well plate, and an ultra violet (UV)/visible lamp [\[151\]](#). This device uses a self-propagating cascade that is initiated by the presence of a specific chemical to quantitatively detect the chemical that initiated the reaction [\[151\]](#). In preliminary testing, the device has successfully discriminated between G and V series nerve agents as well as determine accurate concentrations of the agents via colorimetry [\[151\]](#). The results are obtained using the smartphone's camera and color analysis [\[151\]](#).

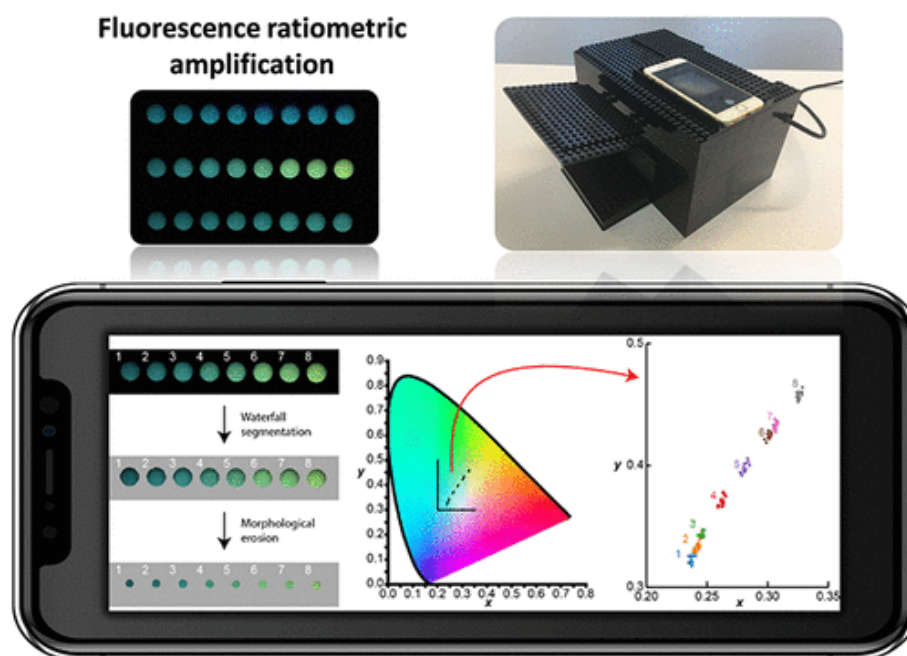


Figure 46: Smartphone fluorescent cascade display and homemade LEGO Dark-Box [151]

2.8 GAP 22: RUGGED BLOOD-TYPING CAPABILITY

As mentioned before, blood is essential for providing nutrients and oxygen, as well as removing toxins from tissues in the body to maintain homeostasis [49, 70, 114]. Prolonged blood loss can lead to hypothermia, acidosis, and impaired coagulation [114]. If an injury is sustained and it leads to hemorrhaging, it is imperative the patient receive proper medical care or severe complications can arise [49, 70, 114]. As stated before, hemorrhaging is the leading cause of combat deaths, but an important mitigation tactic is blood transfusions [70, 114]. As seen in gap 12, it is important that donated blood be screened for possible pathogens to prevent any further complications in a hemorrhaging patient. However, equally important is testing the donated blood ABO blood group type and Rhesus factor to ensure the donor matches the recipient. If the two do not match, the antibodies in the plasma and antigens on the surface of red blood cells will form an antibody-antigen complex that results in agglutination and can lead to death. A portable, powerless, stable blood-typing device that does not require cold-chain management would help address this capability gap.

2.8.1 CRIAM DEVICE

The CRIAM device, seen in Figure 47, utilizes image analysis to determine agglutination level of blood samples in the presence of blood typing antigens [41]. It is portable (roughly the size of a rice cooker), can be used in conjunction with an external smart device or via the integrated touchscreen, and produces results in less than five minutes [41].



Figure 47: CRIAM Device [41]

2.8.2 IMAGE ALGORITHM + BLOOD-TYPING ON A WOVEN CHIP

This device relies on a combination of a silk fabric treated with blood-typing antigens and a smart-device application utilizing image analysis algorithms to determine agglutination levels and return blood type [144]. The treated fabric is adhered to wax printed circles on a paper card similar to standard EldonCard. The results can be interpreted visually, but this can lead to human error and inconsistencies, so it is best interpreted via the application [144]. The algorithm was tested against ten different smartphones and their onboard cameras and was found to correctly identify blood type 93% of the time [144]. The creators of this device determined more fine tuning was necessary and that in-field personnel should perform multiple tests in addition to manual readings [144].

2.8.3 BLOOD TYPE BARCODE

This device is a paper-based card specially printed to contain hydrophilic bar channels treated with anti-A, -B, and -D antibodies hydrophilic channels containing anti-A, anti-B, and anti-D antibodies [69]. The blood sample is introduced to the different channels and blood type can be visually identified from eluting lengths of the bar channels or using the associated smart device application [69]. A picture of the results is taken with the smart device and the application, analogous to scanning a barcode, interprets the results and reports the blood type to the user [69].

2.8.4 BLOOD TYPING BASED ON IMAGE PROCESSING

This device, seen in Figure 48, is a portable automated prototype capable of blood typing an individual using image processing to evaluate agglutination [59]. The device is 30 cm tall with a diameter of 10.5 cm and consists of an alternating current motor (that can be programmed for a specific velocity to ensure mixing or centrifugation), a test plate (containing six testing sites), LEDs (which illuminate the testing field for imaging), and a web camera [59]. Using this prototype, blood and the necessary reagents are placed in a testing site, the speed is selected, the motor is turned on to mix the sample, the motor is turned off, LEDs are turned on, photos are captured, LEDs are turned off, and the images are sent to a tablet or computer for classification using the algorithm developed in C# by the researchers and image acquisition Vision software

[59]. While this device is just a prototype and still in development, it shows promise for not only determining blood type, but also any lab technique that is dependent on centrifugation [59].

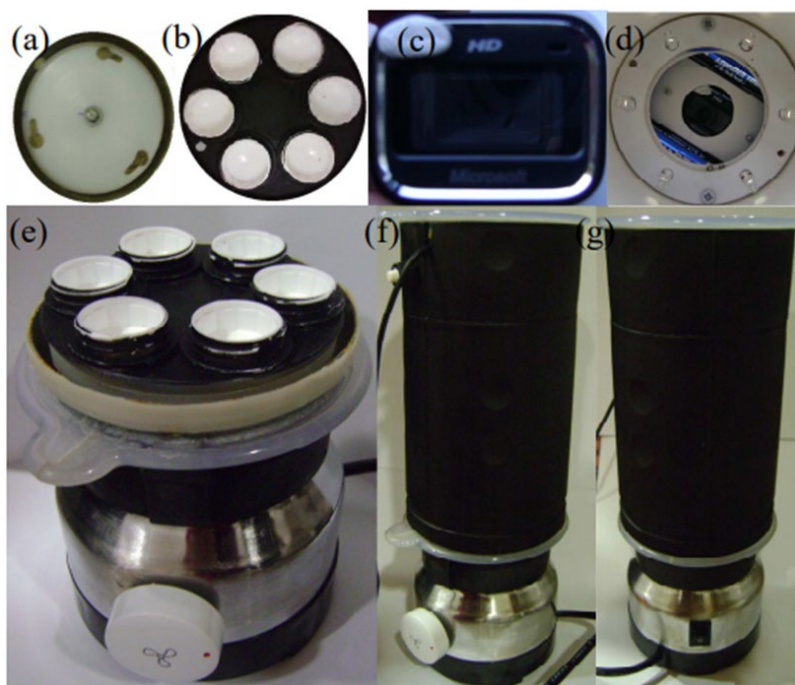


Figure 48: Portable Automated Prototype for Blood Typing [59]

(a) The base of the system. (b) The testing plate with containers for mixing blood and reagents. (c) Web camera for capturing image, (d) LEDs around the web camera lens. (e) The base of the system with mechanism for controlling motor speed. (f) Final system showing speed control. (g) Final system showing on/off control.

2.9 GAP 25: FOOD TESTING

Food is how the body obtains essential nutrients needed to maintain homeostasis. However, food can be easily contaminated due to improper handling, improper storage, and accidental or intentional contamination. This can result in food borne diseases (e.g., *Salmonella* or *Campylobacter*) from biological contaminations or toxicity if the contamination is chemical or biological. It is standard practice to test food for contamination to mitigate risks associated with food borne ailments [139]. Food can be tested using many different techniques from mass spectrometry, ELISA, PCR, cultures, and more; however, many of these techniques must be completed in a laboratory setting and can take anywhere from hours to days to complete [123, 139].

2.9.1 TRINAMIX IR DETECTORS AND NIR SPECTROSCOPY + APP

[See RDD EM gap 9.](#)

2.9.2 COLORMETRIX APP

[See RDD EM gap 9.](#)

2.9.3 LUMINOSTICS

[See RDD EM gap 9.](#)

2.9.4 CELL SCOPE

[See RDD EM gap 4.](#)

2.9.5 TINYSCOPE AND OTHER SMARTPHONE MICROSCOPES

[See RDD EM gap 9.](#)

2.9.6 SMART MICROOPTICS DIPLE

[See RDD EM gap 9.](#)

2.9.7 SPECIM IQ

[See RDD EM gap 14.](#)

2.9.8 SCiO

The SCiO pocket spectrometer, seen in Figure 49, utilizes NIR spectrometry to determine the molecular content of any scanned item or substance [39, 122]. Readouts are shown via an associated smartphone application that compares the measured food item with other cloud-stored measurements of that same item to identify sugar, water, fat content and more [39, 52, 122]. The device and application come with a software tool for creating applets tailored for testing for specific properties of a given substance as well as identifying unknown substances [39]. This device is wireless, roughly the size of a keychain, and costs \$950 [39].



Figure 49: SCiO Scanner [39]

2.9.9 LINKSQUARE

Linksquare is a handheld visible-near-infrared (VIS-NIR) spectrometer, seen in Figure 50, capable of scanning liquids and powders produced by Statio, Incorporated [148]. The Linksquare 1 model measures wavelengths from 400 to 1,000 nanometers (nm) and the Linksquare NIR model measures wavelengths from 700 to 1,050 nm [148]. Both are roughly the size and shape of a stick of butter [148]. Linksquare utilizes a smart-device application to control the device and display results [148]. The results can be evaluated using machine learning and have proven highly accurate at distinguishing salt, sugar, cream, flour, bean, corn, rice, and potato powder [172]. Additionally, the Linksquare system has an artificial intelligence (AI) platform that can be used to develop targeted applets and create databases of samples [148]. The software associated with these devices can display detailed measurements in graphic form as well as export in comma-separated values (CSV) file and binary file types [148].



Figure 50: LinkSquare Portable VIS-NIR Spectrometer [148]

2.10 GAP 29: MOSQUITO TRAPS/CARRYING PATHOGEN (SPECIFICALLY SPECIES IDENTIFICATION/POSSIBLY DISEASE IDENTIFICATION)

Mosquitos are one of the deadliest disease vectors in the world and due to increasing temperatures and environmental changes their population only continues to grow [106]. Mosquito monitoring is a great technique to better understanding the type of diseases in a location because only certain mosquitos can carry specific disease [106, 147]. This can help identify risk levels associated with a base location. However, traditional trapping techniques can be time consuming with complex set ups, collection, and identification techniques.

2.10.1 MOZZWEAR APP

The MozzWear application was developed by researchers at Oxford University. It utilizes a smart device's integrated microphone to detect the flight tone of different species of mosquito [90]. The flight tone is analyzed by an onboard machine learning algorithm (capable of online usage) and the results are quickly returned [90]. Average detection accuracy in preliminary testing was over 80% for aedes and culex species with lower accuracy for anopheles' species [90]. This application, as well as an associated smart acoustic sensor, remains in development by the HumBug project at Oxford University [153].

2.10.2 MOSQUITO BYTE APP

The Michael Reiskind Lab at North Carolina State University runs the Vector Ecology's Mosquito Byte application. This application allows a user to record a mosquito bite in time and space [100]. This record is sent to an online map maintained by Vector Ecology which allows scientists to monitor and track mosquito bite patterns [100]. No personal information is collected in this process and there are many similar applications available [100].

2.10.3 ABUZZ PROJECT

Stanford University's Abuzz Project utilizes smart-device microphones to collect mosquito wingbeat frequencies, time of day, location, and other metadata to identify mosquito species based on species geographic range, diurnal activity cycle, and wingbeat frequencies of known species of mosquitos kept in a laboratory [104]. No application or device is currently available for field use, but recordings can be sent to Stanford University for analysis [104].

2.10.4 VECTECH

VecTech's technology relies on mosquito traps equipped with a camera to capture and identify mosquito species [163]. Images captured are processed through a computer vision algorithm trained by microscopic identifications of mosquito species [163]. The algorithm returns a species identification for a captured mosquito and the pathogen they can carry [163]. VecTech also has a data visualization platform available for working with the results from the algorithm [163].

2.10.5 DO IT YOURSELF (DIY) DIAGNOSTICS (UTA UNDERGRAD RESEARCH COLLECTIVE)

Undergraduate research students at the University of Texas have developed a device utilizing a smart-device camera, a 3D-printed dark-box for fluorescence visualization, and LAMP reactions capable of identify mosquito species [160]. The device, seen in Figure 51, is capable of identify several pathogen-carrying mosquito species using DNA analysis, as well as detect the presence of the Wolbachia parasite (reduces the ability of a mosquito to act as a

disease vector) [20, 160]. This device costs about \$6.50 to construct and is pocket-sized when complete [160].

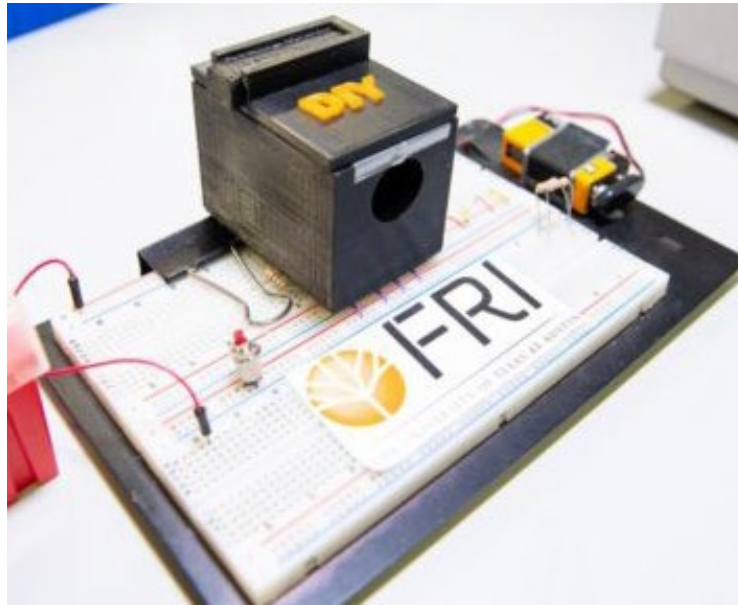


Figure 51: 3D-printed Dark-Box for Fluorescence Visualization [160]

3.0 RDD FOR TOTAL EXPOSURE HEALTH

Table 2: RDD TEH priority, gap, and description [88]

Priority	Gap Title	Research Objectives	End State
1	Real Time Hazard Identification	1. Determine prioritized list of analytes (baseline) 2. Evaluate COTS and GOTS; determine what can be repacked into form factor that supports. Requirements: - Gold standard testing 3. Ensure sensors are effective in operational environment	Ability to continuously monitor exposures to hazards in an operational environment on near real time
2	Detect to Warn	1. Evaluate methods for effective and timely delivery of warning individual in real time of immediate risk 2. Determine appropriate threshold for action (when, what risks, what exposure levels, etc. for exposure, what exactly should someone be altered of?)	Ability to detect and warn individual in near real time of immediate risk for known exposures
6	Epidemiology Analytics	1. Identify relevant databases and rapid detection systems that gather exposure data 2. Develop and evaluate use cases (stakeholders, scenarios, processes) to identify required input and desired output data 3. Identify exposure and disease limits that would warrant an alert in trends 4. Develop algorithms that analyze data and identify reportable trends and threats	Incorporate algorithms into the Military Health Solutions "Comprehensive Health Surveillance" system that alerts end users in real time of exposure trends, threats or changes in baseline that require attention
24	Near Real Time Occupational Exposure Monitoring	1. Determine (or adopt) universal data and communication requirements for sensors 2. Investigate optimal data networking process 3. Determine occupational exposures requiring monitoring 4. Evaluate COTS and GOTS, determine what can be repacked into form factor that supports requirements - gold standard testing 5. Determine what categories of analytes can be combined into one sensor 6. Combine multiple analytes into one sensor (leverage) 7. Miniaturize sensors (leverage)	Low profile, universal networked sensor(s) that collect and analyze multiple analytes in near real time (optimal sensor suite/analyte suite) at the individual level
48	Physiological Parameters and Biomarkers	1. Evaluate the delta between what biomarkers exist and which do not explore biomarkers of interest for incorporation in future monitors 2. Determine prioritized list of physiological parameters and biomarkers of exposures. 3. Evaluate COTS and GOTS, determine what can be repacked into form factor that supports requirements - gold standard testing. 4. Develop noninvasive capability to monitor biomarkers	Noninvasive low profile, near real time monitoring capability to measure physiological parameters. Noninvasive low profile, near real time monitoring capability to measure biomarkers of exposure.
55	Stress Exposure	1. Investigate quantifiable metrics that indicate level of stress 2. Determine prioritized list of stress indications 3. Investigate alternative methods of identifying biomarkers that indicate or correlate to stress levels 4. Develop and test toll/mechanism (prototype) that monitors stress levels	Individual sensor that monitors stress levels in relation to exposure susceptibility

Priority	Gap Title	Research Objectives	End State
57	Substance Abuse	1. Investigate feasibility of utilizing commercial purchases to determine nutritional intake (leading indicators) 2. Determine prioritized list of alcohol, drugs, and tobacco intake profiles 3. Investigate off the shelf applications that monitor/measure intake (self-reporting applications) 4. Investigate alternative methods of identifying biomarkers that indicate or correlate to alcohol, drugs, and tobacco use 5. Develop and test tool/mechanism (prototype) that monitors relevant alcohol, drugs, and tobacco intake parameters	Ability to objectively and accurately monitor actual substance abuse
62	Radiation	1. Determine prioritized list of radiation monitoring parameters 2. Evaluate COTS and GOTS; determine what can be repacked into form factor that supports. Requirements gold standard testing 3. Develop wearable radiation sensor and improve miniaturization	Low profile radiation monitoring at the individual level
68	Nutritional Intake	1. Investigate feasibility of utilizing commercial purchases to determine nutritional intake 2. Determine prioritized list of nutritional intake profiles. 3. Investigate off the shelf applications that monitor/measure intake (self-reporting applications) 4. Investigate biomarkers that indicate or correlate to nutritional intake 5. Develop and test tool/mechanism (prototype) that monitors relevant nutritional intake parameters	Ability to monitor nutritional intake at an individual level
70	Activity Monitoring	1. Assess ability/usefulness of current digital media sources in order to complete exposure assessment 2. Identify what data can be monitored, analyzed and turned into actionable insights 3. Develop taxonomies and ontologies of what we need to listen to 4. Build algorithms that process data into actionable insight 5. Investigate how and what population trends can be individualized	Tools that monitors (24/7 and in real time) and identifies trends and patterns in digital media that supports population and individual exposure surveillance

3.1 GAP 1: REAL TIME HAZARD IDENTIFICATION

As mentioned above, the ability to test the environment and screen for hazardous or toxic chemicals is not only a tool for maintaining a safe working environment, but can also give information about the health and wellbeing of the plants, animals, and human inhabiting the area [7, 14, 117, 135]. While rapid, handheld environmental and chemical screening devices are helpful when there is a concern for a contamination or for occasional testing, it is not ideal for continuous monitoring. Using devices like this for continuous monitoring would result in a lot of waste, space to carry the sheer volume of testing kits required, and time regardless of how quick the device works because testing would be active and require user input. More passive and continuous monitoring devices offer a better picture of what is happening, as well as can act as a warning method when an unknown contamination occurs. Hazards can include high noise levels, radiation, biological, or chemical exposures. The ability to identify and monitor hazards in real time would allow for more informed operational decisions to be made.

3.1.1 SPECIM IQ

[SEE RDD EM gap 14.](#)

3.1.2 CLOUDMINDS XI

The Cloudminds XI, seen in Figure 52, is a compact and ruggedized smartphone-integrated Raman spectrometer [36]. Raman spectroscopy is a technique that uses scattered light to determine the vibrational modes of molecules and is commonly used to provide structural fingerprints that can be used to identify molecules. Cloudminds XI uses a 785 nm laser to excite scanned substances and reads a spectral range of 200 – 1,800 cm^{-1} [36]. The device can recognize mixtures of substances and identifies substances by comparing measurements with a cloud-based database of known substances [36]. Cloudminds XI can analyze a sample in three seconds in a wide range of operating temperatures [36].



Figure 52: A1 Smartphone, Raman Module, and Ruggedized Case [36]

3.1.3 BAYSPEC BREEZE

The Bayspec Breeze, seen in Figure 53, is a handheld chemical analyzer utilizing spectrometry to identify substance composition [18]. It comes in a short-wave infrared (SWIR) model having a wavelength range of 900 – 1,700 nm, VIS-NIR (400 – 1,000 nm), VIS-NIR-SWIR (400 – 1,700 nm), and long-wavelength (1,350 – 2,500 nm) variations [18]. It communicates with Android and iOS smart devices via Bluetooth but can also be shared using a USB and utilizes a proprietary application for data analysis [18]. Chemical identification is accomplished through comparing measurements with a library of measurements from known substances [18]. Bayspec Breeze is capable of performing quantitative and qualitative analysis of plastics, illicit drugs, pharmaceuticals, explosives, biological warfare agents, medicine, food, and more [18]. Users can also create their own data libraries to compare scans against [18].



Figure 53: Breeze models with a coin for size references [18]

3.1.4 FLIR ONE G3

The FLIR ONE G3, in Figure 54, is a thermal imaging attachment for smart devices [61]. It accurately measures temperatures from 5 to 120 °C and utilizes an associated application for data capture [61]. The device is similar in size to a cigarette lighter and costs \$199.99 [61].



Figure 54: FLIR ONE Gen 3 [61]

3.1.5 NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (NIOSH) SOUND LEVEL METER APP

The NIOSH Sound Level Meter application, seen in Figure 55, is a GOTS solution for identifying safe or hazardous noise levels using either the smart device's internal microphone or an attached external microphone [29]. It provides metrics including equivalent continuous sound pressure level, time-weighted average sound level, max and peak levels, noise dose, and projected dose according to Occupational Safety and Health Administration and NIOSH standards as well as A, C, and Z weighting networks [29]. This application is free to download and use, but is designed only for use with iOS devices, as their audio hardware and software are more standardized than in Android devices [29].



Figure 55: NOISH Sound Level Meter [29]

3.1.6 SMART GEIGER PRO

The Smart Geiger Pro, seen in Figure 56, is a smart device attachment that plugs into the audio jack of the device [28]. It measures gamma and x-ray radiation within 15% accuracy from 0.05 to 200 microsieverts per hour [28]. It is the size of a flash drive and costs roughly \$70 [28]. Other similar devices are available.



Figure 56: Smart Geiger Pro [28]

3.1.7 COMPLEMENTARY METAL-OXIDE SEMICONDUCTOR (CMOS) GEIGER COUNTER APPS FOR SMART DEVICES

Geiger counter applications utilize a smart device camera's CMOS sensor to measure ionizing radiation [162]. CMOSs photodiodes are designed for detecting visible light photons but are also sensitive to x-ray and gamma photons [162]. By blocking dominating visible light the CMOS sensor can measure x-ray and gamma photons [162]. This can be accomplished by placing several layers of black tape on the lens of the smart device camera [162]. The images can then be analyzed using various Geiger counter application. These applications can be useful for personal dose assessment but are not necessarily accurate, especially because camera quality can vary [162]. Additionally, these applications are not expedient to use, as calibration procedures differ, and the applications require a long stabilization time to integrate the results over [162]. The most accurate Geiger counter application out of six tested was the Radioactivity Counter [162]. This application is available in the application store and cost \$4.49 [162]. Several other similar applications are also available.

3.1.8 DIGISENSE MINI PARTICLE COUNTER

The DigiSense mini particle counter, in Figure 57, interfaces with a smart device via Bluetooth and an associated application [37]. It is a particulate matter counter measuring from 0 to 2,000 micrograms per cubic meter of particle matter (PM) size 2.5 and PM 10 [37]. The Bluetooth functionality enables measurements to be viewed in real time at a distance from the polluted area, thus improving safety for the technician [37]. Results are automatically stored and can be saved as a CSV file [37]. This device costs \$395 and is similar in size to a smartphone [37].



Figure 57: DigiSense Mini Particle Counter [37]

3.1.9 CUSTOMIZED ANDROID APPLICATION

Global positioning system (GPS) and Wi-Fi locating technology in a smartphone was used to track construction workers at a work site [81]. A customized Android application was developed to allow for monitoring and communication between construction workers at a work site and management [81]. This system utilizes state-of-the-art computers and communication technology to determine different safety states due to the relative position between the worker and the hazard [81]. The application provided real-time safety risk information to the managers and could send alerts to the workers and site supervisors [81].

3.2 GAP 2: DETECT TO WARN

Surprise is a highly valuable military tactic, but it is important to have the capability to counter act surprise attacked [42]. Many hazards do not have a color, odor, or irritation factor associated to their presence. This makes it difficult to know if a hazard is present until after infection or damage has occurred to the individuals exposed. Release of these types of agents can be accidental or intentional; however, detect to warn type devices are a key mitigation technique.

3.2.1 AIRTHINGS RADON DETECTOR

Airthings radon detector, the Corentium Plus Device, seen in Figure 58, offers a cloud-based real-time monitoring solution for interior radon levels [5]. Measurements are viewed in a smart-device application and can be accessed from anywhere at any time, making remote assessments of radon levels possible [5]. Available devices range from handhelds to professional-grade home inspection solutions [5]. Several Airthings devices also detect VOC levels, temperature, and humidity [5]. An enterprise application programming interface data analysis platform is also available for more thorough monitoring of a location or a set of locations [5].



Figure 58: Airthings' Corentium Plus Device [5]

3.2.2 VARIOUS SOCIAL DISTANCING APPS

There are many social distancing applications for smart devices. Many of these applications operate using Bluetooth or global online services to indicate proximity to an infected individual and then provide a warning or alert to the user. With applications like this, privacy and security considerations are critical to evaluate prior to use of the application because it could easily be used to collect personal information even if the user is not directly identified. Due to the recent climate with SARS-CoV-2 pandemic there has been a proliferation of social distancing application, but not all of these are effective or secure. If a social distancing application is used it is recommended that the developer be vetted and the methods of information gathering, and user notification be investigated prior to installation or adoption.

3.2.3 FLIR ONE G3

[See RDD TEH gap 1.](#)

3.2.4 ATMOTUBE PRO

The AtmoTube Pro, seen in Figure 59, is a portable, Bluetooth-enabled, keychain-sized air quality sensor that exports data to smart devices [15]. Real-time data is displayed in the associated application [15]. Parameters sensed include PM1, PM2.5, PM10, Total VOC concentration, atmospheric pressure, temperature, and humidity [15]. The battery is rechargeable and lasts up to ten days [15]. The AtmoTube Pro is currently available for \$179 [15].



Figure 59: Atmotube PRO [15]

3.2.5 NIOSH SOUND METER APP

[See RDD TEH gap 1.](#)

3.2.6 SMART GEIGER PRO

[See RDD TEH gap 1.](#)

3.2.7 CMOS GEIGER COUNTER APPS FOR SMART DEVICES

[See RDD TEH gap 1.](#)

3.2.8 DIGISENSE MINI PARTICLE COUNTER

[See RDD TEH gap 1.](#)

3.2.9 CUSTOMIZED ANDROID APPLICATION

[See RDD TEH gap 1.](#)

3.2.10 SPECIM IQ

[See RDD EM gap 14.](#)

3.2.11 CLOUDMINDS XI

[See RDD TEH gap 1.](#)

3.2.12 BAYSPEC BREEZE

[See RDD TEH gap 1.](#)

3.2.13 SMART GIEGER PRO

[See RDD TEH gap 1.](#)

3.2.14 CMOS GEIGER COUNTER APPS FOR SMART DEVICES

[See RDD TEH gap 1.](#)

3.2.15 DIGISENSE MINI PARTICLE COUNTER

[See RDD TEH gap 1.](#)

3.3 GAP 6: EPIDEMIOLOGY ANALYTICS

Due to the current climate of the SARS-CoV-2 pandemic the importance of disease surveillance to expose trends, threats, changes to the threat, and slow the spread of disease is crucial. Epidemiology analytical tools allow for back tracing to determine where a disease started to better understand who was exposed and may need medical treatment or quarantined [72]. They also allow contact tracing to better anticipate and potentially prevent future outbreaks [72]. This becomes increasingly important when in new environments that has pathogens that military forces have no previous immunity to.

3.3.1 CENTER FOR DISEASE CONTROL AND PREVENTION (CDC) EPI INFO APP

Epi Info is a suite of software products including windows, mobile application, and web/cloud-based versions [30]. These programs are freely available from the CDC and provide a solution for data collection, form creation, data analysis, and data visualization for any size of epidemiological research projects [30]. Both mobile applications and the web/cloud-based version function as extensions of the windows version [30]. The windows version is used to develop survey forms and create databases as well as for data analysis and geographic data displays [30]. The mobile application is designed for use as a data collection platform, implementing surveys developed in the windows version and automatically syncs data to the cloud when internet is available [30]. Cloud-based data storage also allows for real time updates and data analysis by every member of a team [30]. The web/cloud-based version is designed for the creation of live dashboards and real-time data analysis including risk ratios, epi curves, and geographical analysis in the field by multiple users [30].

3.3.2 ARCGIS FOR PUBLIC HEALTH

ArcGIS Mobile and ArcGIS Survey123 can be used together to provide an integrated solution similar to the CDC Epi Info application but focused on geographic data analysis [152]. Survey123 allows survey creation and for surveys to be filled out with the geographic location attached to the answers [152]. The survey data is integrated into an online geodatabase for use in ArcGIS mapping and spatial data analysis software [152]. ArcGIS software is available for desktop and mobile applications and can be used for a multitude of data recording and analysis purposes, particularly geographic analysis [152].

3.3.3 SARS-COV-2 SURVEILLANCE APPLICATIONS

Due to the SARS-CoV-2 pandemic many companies including Apple and Google have developed applications that provide near real time contact tracing [11, 51, 71]. The applications use Bluetooth wireless signals to anonymously detect the time spent and the proximity of two phones [11]. The application can also alert users if another application user in the proximity tests positive without revealing the user's name, location, or any other identifying information [11]. However, these applications are state regulated and therefore availability depends on each state's public health authority [11]. Additionally, accuracy depends on the users [11].

3.3.4 ATMOTUBE PRO

[See RDD TEH gap 2.](#)

3.3.5 FLIR ONE G3

[See RDD TEH gap 1.](#)

3.3.6 NIOSH SOUND LEVEL METER APP

[See RDD TEH gap 1.](#)

3.4 GAP 24: NEAR REAL TIME OCCUPATIONAL EXPOSURE MONITORING

Occupational hazards are a concern for many professions and many of those fields have mitigation tools in place (e.g., ear plugs, radiation dose limits, hard helmets, etc.) to reduce these risks. The military can possess many different occupational hazards from exposure to asbestos, radiation, vibrations, noise, biological agents, chemical agents, etc. in their day-to-day duties [161]. To maintain operational readiness, as well as the health and safety of military members, it is important to have the ability to monitor, in near real time, the noise, vibration, radiation, chemical, biological, etc. exposure events.

3.4.1 SPECIM IQ

[See RDD EM gap 14.](#)

3.4.2 ATMOTUBE PRO

[See RDD TEH gap 3.](#)

3.4.3 FLIR ONE G3

[See RDD TEH gap 1.](#)

3.4.4 NIOSH SOUND LEVEL METER APP

[See RDD TEH gap 1.](#)

3.4.5 AIRTHINGS WAVE PLUS

[See RDD TEH gap 2.](#)

3.4.6 CMOS GEIGER COUNTER APPS FOR SMART DEVICES

[See RDD TEH gap 1.](#)

3.4.7 DIGISENSE MINI PARTICLE COUNTER

[See RDD TEH gap 1.](#)

3.4.8 CUSTOMIZED ANDROID APPLICATION

[See RDD TEH gap 1.](#)

3.5 GAP 48: PHYSIOLOGICAL PARAMETERS AND BIOMARKERS

Physiological biomarkers can be used to predict and indicate heart, renal, and pancreas failure, dehydration, hypoxia and many more potentially life threatening conditions [60, 79]. Biomarkers can offer insight to the success of a treatment, progression of a disease, and even offer early warning signs for certain conditions [60, 79]. This can be helpful for monitoring a patient's status and allow for earlier intervention for a condition to result in a more positive outcome [60, 79].

3.5.1 HEALTHY.IO URINALYSIS

[See RDD EM gap 4.](#)

3.5.2 BIOBEAT

[See RDD TEH gap 3.](#)

3.5.3 NUVOAIR AIR MD

[See RDD EM gap 4.](#)

3.5.4 ARMADA-UV

Galileo Group, Inc. modified a smartphone to create ARMADA-UV, which utilizes fluorescence imaging to observe oil production as well as keratinocytes and porphyrin shedding on the human face [63]. These biomarkers allow professionals to characterize and pinpoint locations of inflammation and bacterial colonization, as well as monitor administered treatments for the skin [63]. The ARMADA smartphone/tablet-based LED emitter array technology has been optimized for spectral ranges (visible, near-infrared, and violet/UV-A) with customizable band configurations and its own calibrated light source to adjust and change for ambient lighting conditions to ensure accuracy and reliability in different environments [63]. ARMADA utilizes mass market deployed mobile devices to collect images, upload to a backend server, and apply a more advanced algorithm and state-of-the-art artificial intelligence (AI) techniques to rapidly provides a report back to the consumer [63]. Image characterization accuracy can be improved over time by using AI and big data sets [63].

3.5.5 LONESTAR VOC ANALYZER

[See RDD EM gap 4.](#)

3.5.6 BATDOK

[See RDD EM gap 3.](#)

3.5.7 KARDIA

[See RDD EM gap 3.](#)

3.5.8 FREESTYLE LIBRE CONTINUOUS GLUCOSE MONITOR

[See RDD EM gap 3.](#)

3.5.9 DEXCOM G6 CONTINUOUS GLUCOSE MONITORING SYSTEM

[See RDD EM gap 3.](#)

3.5.10 CHECKME PRO HEALTH MONITOR

[See RDD EM gap 3.](#)

3.5.11 WELLUE O2RING

[See RDD EM gap 3.](#)

3.6 GAP 55: STRESS EXPOSURE

Stress is one of the most significant health issues in the world, stress is a response to change, a challenge, or demand [132, 149]. Stress can be beneficial in short bursts; however, if stress lasts for extended periods of time it can be damaging and lead to disease [132, 149]. Stress can result in body aches, tension, back pain, headaches, heartburn, digestive tract issues, and overall physiological over-arousal [132]. If the stressor is not removed and becomes chronic stress, it can lead to serious physiological damage [132]. To maintain health and operational readiness, it is important to monitor stress levels in military members and chronic stress can be avoided by responding to the initial symptom onset [132]. Electrodermal activity, heart rate, and accelerometry are the most widely used measurements to indicate stress level [131, 132].

3.6.1 MINDSTRONG APP

Mindstrong is an application that communicates with an individual's health insurance company and health care providers to offer users virtual therapy and psychiatric care [8, 102]. The founder of the company has a background in cybersecurity and was interested in finding a new method to identify hackers through their digital fingerprint, using how they type opposed to traditional methods using Internet Protocol (IP) address and username [8]. This idea was further developed into a tool that could potentially be used in healthcare [8, 102]. In addition to providing counseling, Mindstrong can also track how an individual uses their phone (e.g., typing, swiping, and scrolling) [8, 102]. This digital fingerprint is tracked over time and delays in response time or changes can be used as a biomarker to measure and determine stress, mental health symptoms, and well-being [8, 102]. Mindstrong has taken thousands of people's digital fingerprints and is currently trying to validate the results using gold standard reference tools (e.g., phq-9, Hamilton depression score, neurocognitive battery) [8, 102].

3.6.2 HEART RATE VARIABILITY (HRV) APPS

HRV is the measurement of the variation that occurs between each heartbeat [27]. This variation is controlled by the autonomic nervous system which is responsible for the fight-or-flight mechanism and relaxation response [27]. When a body is in fight-or-flight there is less variation in the time between heartbeats; however, when the body is in relaxation there is more variation and therefore a higher HRV [27]. This means the healthier the autonomic nervous system, the faster an individual can switch between fight-or-flight and relaxation, meaning the individual has an overall higher HRV and is more resilient and flexible with a more fit cardiovascular system [27]. Studies have found a relationship between low HRV and worsening depression or anxiety [27]. HRV has also been associated with an increased risk of death and cardiovascular disease [27]. This makes HRV a possible tool that can help determine stress level in an individual. There are many ways to check and monitor HRV and, additionally, there are many applications on smartphones and smartwatches capable of monitoring HRV (e.g., Apple Health, Welltory, HRV4Training, Elite HRV) [26]. These applications work by collecting data from heart rate monitors or using smartphone cameras to measure blood flow and, therefore, heart rate to determine HRV [26].

3.6.3 MUSE

Muse, seen below in Figure 60, rests on a user's forehead and uses Bluetooth to connect to a smart device [105]. Muse consists of an electroencephalogram (EEG), photoplethysmography (PPG), accelerometer, and a gyroscope to monitor brain activity, heart rate, breathing, and body movement to help monitor and build a consistent meditation practice [105]. The device works by monitoring these physiological signals and relaying the information to a smart device [105]. For meditation purposes, an individual would wear the head piece and headphones, the physiological signals relay to the smart device which are analyzed using machine learning and, depending on the user's mental state, corresponding weather sounds are played (e.g., as a user begins to calm down, so does the storm) [105]. For research purposes, an individual would wear the head piece and the physiological signals would be relayed to a smart device for interpretation by the researcher [105]. This product is about \$350 and is advertised towards helping build a consistent meditation practice; however, it monitors brain activity, heart rate, breathing, and body movement so it could be a great tool for monitoring stress in a military member, if it is made more rugged and has the ability to attach more securely [105].



Figure 60: Muse [105]

3.6.4 EMOTIV EEG HEADSET

EMOTIV produces multiple wireless EEG headsets that measure the small electrical signals produced by the brain to monitor and determine the wearer's cognitive state [53]. The raw data collected from the headset is transmitted to a smart device where it can be translated into meaningful information using a machine learning algorithm developed by the company [53]. The algorithm has been validated and is continually being improved [53]. The algorithm indicates six different cognitive states in real-time: Excitement (Arousal), Interest (Valence), Stress (Frustration), Engagement/Boredom, Attention (Focus) and Meditation (Relaxation) [53]. The headsets range from \$300 - \$2,000 [53].

3.7 GAP 57: SUBSTANCE ABUSE

Substance abuse can be an issue among military members due to the high levels of stress and the stigmas behind receiving help for mental health leading to self-medication [109]. Typically, active duty members have increased rates of binge drinking and nicotine use, while veterans have a higher rate of illicit drug use [109]. The military has several deterrence policies in place to discourage drug use; however, opioid and prescription pain medication abuse is still possible [109]. Substance abuse is a part of a much larger issues because it is used as a coping mechanism for mental health disorders such as post-traumatic stress disorder, depression, and anxiety [109]. In addition to deteriorating mental health, substance abuse can also lead to medical conditions such as seizures, liver disease, and lung or heart disease [109]. For the safety of military members on and off duty, it is important to have the ability to monitor substance abuse and recognize when help is needed.

3.7.1 DETECTACHEM MOBILEDETECT APP

DectaChem developed MobileDetect Pouches a presumptive test capable of detecting opiates, stimulants, synthetics, tetrahydrocannabinol, hallucinogens, and depressants [43]. The pouches allow for trace and bulk detection by using proven colorimetric reagents [43]. Colorimetric reagents work by reacting with the analytes to create certain colors. The substance can be identified by comparing the results to a color reference chart, with the current standard being Munsell color charts [43]. In addition to the MobileDetect Pouches, DectaChem also produced a MobileDetect App, seen in Figure 61, capable of automating the detection process [43]. The application auto adjusts for variations in situational lighting and then captures an image of the MobileDetect Pouch to analyze the reaction and identify the substance [43].



Figure 61: DectaChem MobileDetect Pouches and MobileDetect App [43]

3.7.2 BACTRACK

BACtrack offers a range of breathalyzers from simple keychains to smartphone compatible devices with associated applications [16]. Most BACtrack technology uses fuel cell sensors which measure the electrical signal produced by an oxidation and reduction reaction that occurs in the breathalyzer due to the presence of alcohol. However, there are a few devices that utilize semiconductors which work similarly to fuel cell devices by measuring the oxidation of alcohol in the breath, but tend to be less accurate. BACtrack products are extensively available commercially and are used by professional law enforcement agencies [16]. BACtrack's premier product is the BACtrack Mobile Pro with an associated application, seen in Figure 62 [16]. The BACtrack Mobile Pro integrates with a smart device via Bluetooth and is compatible with both Apple and Android devices [16]. The application records BACtrack measurements, and for Apple products, can be integrated into Apple Health [16]. The application can also predict the amount of time until the user is sober and the BACtrack View version of the application can verify measurements via video recording, as well as record the time, date, and location of the measurement [16]. The BACtrack Mobile Pro breathalyzer costs \$99.99 and the BACtrack View application costs \$79.99 to \$129.99 a month depending on the selected plan, but comes with a free BACtrack Mobile Pro breathalyzer [16].



Figure 62: BACtrack Mobile Pro and BACtrack View App [16]

3.8 GAP 62: RADIATION

Background radiation is everywhere, as the sun, soil, minerals, water, and even our own bodies can act as sources for background radiation [158]. The body is equipped to handle these low levels of radiation; however, high level of radiation can be deadly [158]. Radiation exposure can result from occupational hazards and equipment, but radiation exposure can also result from malicious intent [158]. It is important to have the ability to monitor radiation exposure to ensure dangerous levels are not reached.

3.8.1 RADIOACTIVITY COUNTER APP

Image Insight's GammaPix application utilizes a smart device's camera to detect gamma radiation [50, 77]. Gamma radiation is detected using the CMOS and charge-coupled device chips in the smart device's camera [50]. GammaPix has been tested by Oak Ridge National Laboratory and National Institute of Standards and Technology and was found to detect gamma radiation levels as low as 0.4 milliRoentgens per Hour depending on the lighting conditions and the phone camera being used [50]. It is available for \$4.99 [77].

3.8.2 SMART GEIGER PRO

[See RDD TEH gap 1.](#)

3.8.3 POCKETGEIGER

PocketGeiger, seen in Figure 63, is a smartphone-connected radiation detector with the goal of allowing anyone to monitor and share radiation information through their application [126]. The device contains an X100-7 PIN (p-type, intrinsic, n-type diode) photodiode [126]. These sensors generally are extremely stable, do not have age-related degradation compared to

standard Geiger-Muller tubes or scintillator crystals, and they work by detecting charge changes caused by photons [126]. These sensors are highly reliable and are manufactured by FirstSensor Corporation, which is also a supplier of similar sensors for National Aeronautics and Space Administration's x-ray telescope [126]. PocketGeiger has a measuring time of 2 minutes with a background radiation of 0.05 microSieverts per Hour and costs about \$90 [126].



Figure 63: PocketGeiger [126]

3.9 GAP 68: NUTRITIONAL INTAKE

Like water, food and quality nutrient intake is a key component for overall well-being and can impact mental performance, physical performance, and the wound healing process [75, 80]. Currently in the US, 71% of people between the ages of 17 to 24 do not qualify for military service [154]. Additionally, about two-thirds of active military personnel are overweight or obese [154]. However, it is worth noting that obesity is defined using body mass index, which does not distinguish between excess weight resulting from fat or muscle. Healthy weight maintenance has more to do with consuming the appropriate amount of calories and maintaining a balanced diet than physical activity [154]. Monitoring food consumption can help determine if military members are receiving the proper nutrients to help prevent mental and physical degradation and keep morale boosted [80].

3.9.1 SCIO

[See RDD EM gap 25.](#)

3.9.2 LINKSQUARE

[See RDD EM gap 25.](#)

3.9.3 TOP 10 NUTRITION APPS

There are many calorie and nutrition tracking applications available, but one of the most well-known is Livestrong's MyPlate application [91]. This application utilizes a food database to retrieve nutritional facts for user-entered foods [91]. This application is also capable of retrieving nutritional facts from scanning the barcode on food packaging [91]. The basic version of the application is free to download and use; however, in-app purchases can enable additional features, such as macronutrient analysis and calories burned [91].

3.9.4 DIETSENSOR APP

The DietSensor App utilizes a SCiO handheld spectrometer and a Bluetooth-connected digital scale, seen below in Figure 64, to calculate the exact amount of macronutrients in a given serving of food or in a meal [48]. Meals can be logged to track nutritional goals [48]. Lifetime access to the premium DietSensor application, the digital scale, and the SCiO spectrometer costs \$428.99 [48].



Figure 64: DietSensor App with SCiO handheld spectrometer and digital scale [48]

3.9.5 FREESTYLE LIBRE CONTINUOUS GLUCOSE MONITOR

[See RDD EM gap 3.](#)

3.10 GAP 70: ACTIVITY MONITORING

Social media can offer many benefits, such as allowing family members to stay in contact with deployed military members and providing intel on adversaries; however, it is also a vulnerability concern [96, 110, 141]. Basic personal information such as name, age, address, or location can be of great value to US adversaries and can be used to target individuals or missions [86, 110, 141]. Not only is the amount of information a person may share of concern, but many social media companies share data or have their data for purchase, which can pose a massive threat [86]. In addition to social media, devices like smartwatches and other activity trackers generally use GPS coordinates and this information has shown to be problematic in the past, especially when it comes to heat map activities and barrier markers of military areas [86]. It is important to monitor social media activity to quickly identify, prevent, and respond to possible leaks of sensitive information.

3.10.1 WEARABLE ACTIVITY MONITORS

There are many different companies that make wearable activity monitors (e.g., Polar, FitBit, Garmin, Samsung, Apple, etc.); however, all have the same basic principle to track activity. Wearable activity monitors contain triaxial accelerometers that measure movement in the X, Y, and Z plane [56]. The triaxial acceleration data is feed into a proprietary algorithm to determine type, level, and duration of activity [56]. Depending on the device, they can contain other sensors like optoelectronic sensors (to monitor heart rate and respiratory rate), altimeter, and GPS [56]. Additionally, devices can include user input information (e.g., estimate steps,

distance, physical activity, kilocalories, and sleep) to help the algorithm determine the type, level, and duration of activity [56]. These products have proven to be relatively valid and reliable costing anywhere between \$20 - \$400 depending on the brand and model [56].

3.10.2 SOCIAL MEDIA TRACKER

There are many different applications and controls that can be placed on a smart device to monitor a user's activity (e.g., Bark, mSpy, The Spy Bubble, Hootsuite, etc.) [84, 108]. These products are typically advertised towards parents for monitoring a child's online usage or towards companies for monitoring their brand's image [84, 108]. Most of these applications log the amount of time spent on the device and the individual applications installed, monitor text messages, web history, online messages, social media, media files, other installed application usage, and have GPS tracking [84, 108]. These applications work by using propriety algorithms to monitor for specific words and forward information from incoming calls or text messages [84, 108]. These applications can monitor in real time and can also save information for later review [84, 108]. The applications range from free to costing \$100 per year [84, 108].

4.0 MISCELLANEOUS

With advances in technology, smart devices have been developed and adapted to meet many different needs. Some of these needs align with gaps identified above by the USAF; however, there are many smart devices and applications that could be applicable and helpful in a deployed environment not listed in the RDDs. This section will cover devices subjectively identified by the author's that may prove helpful to the USAF but are not explicitly asked for.

4.1 AGVA INTELLIGENT VENTILATION (AI-VENT) ADVANCE PURE

The Advance Pure from AgVa Healthcare, is a portable, smartphone controlled mechanical ventilator, seen in Figure 65 [4]. This device is capable of volume controlled-continuous mandatory ventilation, volume controlled-synchronized intermittent mandatory ventilation, assist control ventilation, pressure regulated volume control, pressure controlled-continuous mandatory ventilation, pressure controlled-synchronized intermittent mandatory ventilation, pressure support ventilation, continuous positive airway pressure, bi-level positive airway pressure, spontaneous ventilation, and AI-VENT [4]. It is slightly larger than a pint glass and has an onboard 3-hour emergency power supply, making it suitable for field use [4]. This device was developed for in-home use in India, where electricity is not constantly available, and the environment is frequently dusty [4]. The price of an in-home unit is currently approximately \$700 and has proven to be a safe and suitable solution for mechanical ventilation in impoverished patients with neurological diseases [3, 4].



Figure 65: Advance Pure AgVa Intelli Ventilator [4]

4.2 EYE EXAMINATION

In the past it has been found that there is low vision readiness amongst military personnel [24]. Many military members were found to have not had a professional ocular examination within the last two years and of these individuals, many were not deployment ready due to substandard visual acuity or not having the required pairs of glasses or protective inserts [24]. Additionally, there were a few that had undiagnosed ocular diseases [24]. Visual readiness is an important aspect of operational readiness, especially due to the increased sophistication of visual equipment used in the field.

4.2.1 AEye RETINAL SCREENING

Aurora AEye integrates a handheld fundus camera, seen in Figure 66, with an AI software that analyzes images of the patient's retina to diagnose diabetic retinopathy without dilation [2]. The software runs on a secure HIPAA-compliant cloud [2]. The camera can be used with minimal training and results can be received within a minute [2].



Figure 66: Aurora AEye handheld Fundus camera [2]

4.2.2 ODOCS NUN OPHTHALMOSCOPE

The oDocs Nun, seen in Figure 67, is a universally compatible smartphone attachment for retinal photography [113]. The oDocs Nun is applicable for pupils as small as 2 mm, has a wide-angle view, dynamic focus, filter enhancements, and a rechargeable battery [113]. This device can be used to perform ocular health examinations without an office or the immobile medical equipment [113]. The oDocs Nun is best used in conjunction with MedicMind's free-to-use, securely encrypted web-based teleophthalmology platform [98, 113]. This platform enables a live examination to be performed via an online virtual meeting [98] (MedicMind, 2021). The oDocs Nun costs \$1,120 [113]. oDocs also makes 3D-printed plans for a simple fundus viewer attachment available for smartphones, sells lenses for the attachment, and sells slit lamp and dermatoscope attachments for smartphones [113].



Figure 67: oDocs nun attachment [113]

4.2.3 PEEK RETINA

Peek Vision's Peek Retina, seen in Figure 68, is a smart device camera attachment that allows a patient's dilated eye to be viewed and imaged [120]. It requires no infrastructure to use and can therefore be deployed anywhere dilating eye drops can be brought or obtained [120]. This device is intended to be easy to use and comes with a set of retinal images for practice [120]. Peek Retina can be used with any smart device [120]. Multiple journal articles have been published where this device has been tested or reviewed, including articles in The Lancet and PLoS ONE [121].



Figure 68: Peek Retina attachment [120]

4.2.4 D-EYE OPHTHALMOSCOPE

D-Eye, seen in Figure 69, is a digital direct ophthalmoscope that can be used on either dilated (20-degree field of view) or undilated (6-degree field of view) eyes [46]. The D-Eye system is composed of an iPhone camera lens attachment and associated application. The application is capable of recording, editing, and transmitting images and videos of the fundus oculi as well as recording patient information and generating reports [46]. Medical data is saved to HIPAA-compliant cloud storage system [46]. De-identified images can be shared between multiple colleagues for collaborative remote medicine [46]. However, D-Eye can only be used with an iPhone [46]. D-Eye is FDA and CE registered and has been written about in the Open Journal of Ophthalmology and in Nature Scientific Reports [46]. The full D-Eye system costs \$435 [46].



Figure 69: D-Eye [46]

4.2.5 IDX

Digital Diagnostics produced an AI ophthalmologic diagnosis software called IDx-DR. IDx-DR relies on a fundus camera to capture two images of each eye and tests for diabetic retinopathy [48]. These images are then analyzed by the AI, which identifies visible biomarkers for diabetic retinopathy and returns results in less than a minute [48]. The program requires minimal training to use and does not require a physician’s input or supervision, as it issues a diagnosis automatically [48]. Diagnoses are limited to “negative for more-than-mild diabetic retinopathy” and “more-than-mild diabetic retinopathy” [48]. IDx-DR is the first AI diagnostic system to be approved by the FDA [48].

4.2.6 RETINA-AI

Retina-AI is a cloud-based AI platform that diagnoses diseases such as diabetic retinopathy, macular degeneration, and glaucoma from pictures of the retina [113, 129]. Retina-AI combines image analysis with a variable auto-encoder methodology based on patient information such as age, race, and sex, as well as non-retinal eye observations like polyps and drusen [113, 129]. This approach is designed to identify a spectrum of conditions that affect the eyes – including non-ophthalmic conditions, as well as the severity of those conditions [129]. FDA approval is pending [129].

4.3 READING M9 PAPER

M9 chemical detection paper is a coated tape with a mylar-adhesive backing capable of adhering to objects to be used to detect liquid nerve and blistering agents [94]. The paper is treated with a suspension of an agent sensitive red indicator dye that turns pink, red, reddish brown, or reddish purple when exposed to a liquid nerve or blistering agent [94]. The color change observed on M9 paper is due to the dye’s unique reaction due to the acidity of the different agents [94]. M9 paper is not capable of identifying the specific agent but it acts as an indicator for their presence [94]. Detection through color change can be highly subjective and susceptible to human error due to differences in opinion, color blindness, and lighting conditions.

Devices capable of standardizing lighting conditions and detecting color or color changes would drastically help reduce error and increase automation.

4.3.1 GOSPECTRO

The GoSpectro handheld spectrometer, seen in Figure 70, is a system composed of a smart-device attachment and associated application [67]. The system is used in conjunction to characterize the spectra emitted from light sources [67]. This allows the measurement of object color for any object that absorbs light in the visible spectrum [67]. The GoSpectro is approximately the size of an AA battery and costs €390 [67].



Figure 70: GoSpectro Handheld Spectrometer [67]

4.3.2 COLORIMETRIC ANALYSIS APPLICATION

Color Grab (Loomatic), Catch Color Free (CeSnow), and LifeDropper (Bitjutsu Software) are colorimetric analysis applications for smart devices [142]. These systems use patented algorithms that have the user capture a relative white image taken in the same lighting conditions as the color in question [142]. The user captures the image of the relative white sample and then captures an image of the unknown color [142]. The patented algorithms compares the two and returns the results of the unknown color [142].

4.3.3 TRI-ANALYZER (UIUC)

[See RDD EM gap 12.](#)

4.3.4 COLORIMETRIX

[See RDD EM gap 9.](#)

4.4 SMALL UNIT LEADER SITUATIONAL AWARENESS TOOL

The Small Unit Leader Situation Awareness Tool (SULSAT) uses a wirelessly connected tactical robot or small drone control system to allow for real-time video footage to be displayed on a smart device for platoon and squad leadership [99]. The tactical robot is controlled by one person that can receive and send the video footage to leadership [99]. This allows leadership to move through their squad, instead of needing to stand behind the control and look over the user's

shoulder. SULSAT has a range of approximately 20 feet, but it is still in the development phase. It could allow leadership to have an increased situational awareness, maneuverability throughout their squad, and survivability because the robot can check for improvised explosive devices.

4.5 TRANSFORMATIVE APPLICATIONS PROGRAM

The Transformative Applications Program (Trans App) has been working on military mapping with offline satellite imagery, heat maps to show where and how long previous patrols have been, almanac showing local sunrise and sunset times, a blast and fragmentation distance calculator, a weapon and munitions recognition guidebook, high-value target face recognition database, and much more [18]. Trans App's goal is to adapt smartphones for field use to help bridge capability gaps and replace radios, paper maps, and outdated bulky equipment [18].

5.0 RESULTS

Ranking Definition:

- 1 - Meets no/very few needs for that category
- 2 - Meet some needs for that category, but leaves most needs unmet
- 3 - Meets half of the needs for that category
- 4 - Meets most needs for that category
- 5 - Meets all/most of the needs for that category

Design Criteria:

Modifiability: ability to modify the technology to better fit a given scenario or fill additional capability gaps.

Multiplex System: ability to monitor or detect more than one vital sign, pathogen, chemical, etc. Devices only capable of monitoring or detecting one entity will result in a lower score.

Processing Time: time required to prepare the device for usage. A lower score will be given to devices that require extensive prep time or do not provide real-time monitoring or results.

Compatibility: software can be used on multiple operating systems and hardware can adapt for environmental changes (e.g., light).

Durability: rugged, and can withstand the challenges of an austere environment.

Power Source: does not require a power source or can rely on a smart device's power.

Portability: technology has limited components and all are portable. Devices that are large or tedious to setups will be scored lower.

Data Storage: data is stored on a secure server and there is minimal need for cloud-based storage. Devices with solely cloud-based storage and no other method for transmitting data will be scored lower.

Ownership: technology is limited by IP rights, requires purchased services, or licensing/subscription fees. Open-source platforms, hardware and software that can be used on common smart devices (e.g., iPad, tablet, Android) will score higher.

Accuracy: performs with a similar accuracy to gold standard equipment.

Cost Criteria:

Development/Implementation: similar cost to currently used devices or devices that perform similar functions. Higher scores will be given to more cost-effective devices.

Maintenance: costs associated to maintain the hardware/software.

Licensing/Application Fees: limited or no additional cost to integrate and analyze collected data. Devices that require a software purchase in addition to the hardware will receive lower scores.

Consumables: cost of reagents, materials, or replacement parts.

Functionality Criteria:

User Training: training required to perform proficiently with the hardware/software. Devices requiring less training time (hours versus days) and flexible training (online versus in person) will be given higher scores.

Technical Support: help provided to the user. A higher score will be given to technical support that is readily available (e.g., 24 hours/day).

Interpretation and Accessibility of the Data: level of experience needed to operate the system and understand the data. Devices that can be used and interpreted by a lay person are given a higher score.

User Friendliness: easy to navigate the hardware/software. Devices that are not intuitive will receive a lower score.

Potential for User Error: minimal multitasking and user judgement. Higher scores will be given to devices that do not require a user to do multiple tasks at once, have clear instructions, and have clear results (e.g., negative/positive, high/low).

Table 3: Vital Sign Device Comparison

Criteria	BioBeat	Checkme Pro Health Monitor	Wellue O2Ring	Kardia
Design	3.4	3.5	3.1	3.3
Modifiability	1	1	1	1
Multiplex System	5	5	2	1
Processing Time	5	5	5	5
Compatibility	5	5	5	5
Durability	2	2	2	2
Power source	3	3	3	3
Portability	5	5	5	5
Data storage	2	3	2	5
Ownership	1	1	1	1
Accuracy	5	5	5	5
Cost	N/A	5.0	5.0	4.5
Development/Implementation		5	5	5
Maintenance		5	5	5
Licensing Fee/Application Fee		5	5	3
Consumables		5	5	5
Functionality	5.0	4.2	5.0	4.8
User Training	5	4	5	5
Technical Support	5	5	5	5
Interpretation/Accessibility of Data	5	4	5	4
User Friendliness	5	4	5	5
Potential for User Error	5	4	5	5
Overall Average	4.2	4.2	4.4	4.2

Table 4: Glucose Monitoring Device Comparison

Criteria	Freestyle Libre Continuous Glucose Monitor	Dexcom
Design	2.90	2.90
Modifiability	1	1
Multiplex System	1	1
Processing Time	5	5
Compatibility	2	2
Durability	3	3
Power source	4	4
Portability	5	5
Data storage	2	2
Ownership	1	1
Accuracy	5	5
Cost	N/A	N/A
Development/Implementation		
Maintenance		
Licensing Fee/Application Fee		
Consumables		
Functionality	4.6	4.8
User Training	5	5
Technical Support	5	5
Interpretation/Accessibility of Data	3	4
User Friendliness	5	5
Potential for User Error	5	5
Overall Average	3.8	3.9

Table 5: Microscope Attachment Comparison

Criteria	DIPLE	BLIPS	Cell Scope	Tinyscope
Design	3.8	3.9	3.8	3.3
Modifiability	3	3	4	3
Multiplex System	5	5	5	5
Processing Time	5	5	5	5
Compatibility	5	5	5	4
Durability	2	2	2	2
Power source	3	3	3	5
Portability	4	5	5	5
Data storage	5	5	2	2
Ownership	1	1	2	1
Accuracy	5	5	5	1
Cost	4.8	5.0	N/A	5.0
Development/Implementation	4	5		5
Maintenance	5	5		5
Licensing Fee/Application Fee	5	5		5
Consumables	5	5		5
Functionality	2.4	2.4	4.2	2.6
User Training	5	5	5	5
Technical Support	2	2	1	1
Interpretation/Accessibility of Data	1	1	5	1
User Friendliness	3	3	5	5
Potential for User Error	1	1	5	1
Overall Average	3.7	3.8	4.0	3.6

Table 6: ELISA Device Comparison

Criteria	MELISA	mChip Smartphone Dongle
Design	3.8	4.6
Modifiability	4	4
Multiplex System	4	4
Processing Time	1	5
Compatibility	4	5
Durability	4	4
Power source	1	5
Portability	5	5
Data storage	5	4
Ownership	5	
Accuracy	5	5
Cost	3.3	5.0
Development/Implementation	5	5
Maintenance	2	5
Licensing Fee/Application Fee	4	5
Consumables	2	5
Functionality	3.2	5.0
User Training	4	5
Technical Support	2	
Interpretation/Accessibility of Data	4	5
User Friendliness	4	5
Potential for User Error	2	5
Overall Average	3.4	4.9

Table 7: LAMP Device Comparison

Criteria	Sandia SmartLAMP	LAMP	RT-LAMP	DIY Diagnostics
Design	4.4	3.4	3.9	4.3
Modifiability	4	1	5	5
Multiplex System	5	4	5	4
Processing Time	5	3	2	4
Compatibility	5		5	5
Durability	5	4		
Power source	5	2	5	3
Portability	5	3	5	4
Data storage	4	5	2	
Ownership	2		1	
Accuracy	4	5	5	5
Cost	4.3	3.3	2.7	3.3
Development/Implementation	5	4	3	4
Maintenance	4	3	3	4
Licensing Fee/Application Fee				
Consumables	4	3	2	2
Functionality	5.0	4.5	2.0	3.8
User Training	5	4	3	4
Technical Support			1	
Interpretation/Accessibility of Data	5	5	2	3
User Friendliness	5	5	2	4
Potential for User Error	5	4	2	4
Overall Average	4.6	3.7	2.9	3.8

Table 8: Lateral Flow Device Comparison

Criteria	Luminostics	RDT Reader	Paper-Based Vertical Flow Immunoassay
Design	4.0	4.7	4.1
Modifiability	5	5	4
Multiplex System	5	5	5
Processing Time		5	3
Compatibility		5	
Durability	2	4	4
Power source	5	4	3
Portability	5	5	5
Data storage		5	
Ownership	1	5	4
Accuracy	5	4	5
Cost	3.0	3.0	3.0
Development/Implementation	3	3	3
Maintenance			2
Licensing Fee/Application Fee			
Consumables			4
Functionality	4.4	4.4	5.0
User Training	4	5	5
Technical Support	4	5	
Interpretation/Accessibility of Data	5	4	5
User Friendliness	5	5	5
Potential for User Error	4	3	5
Overall Average	3.8	4.0	4.0

Table 9: HRV App Comparison

Criteria	Apple Heath	Welltory	HRV4Training	Elite HRV
Design	2.9	3.1	3.1	2.9
Modifiability	1	1	1	1
Multiplex System	5	5	5	5
Processing Time	5	5	5	5
Compatibility	1	4	4	2
Durability				
Power source				
Portability				
Data storage	2	1	1	1
Ownership	1	1	1	1
Accuracy	5	5	5	5
Cost	5.0	5.0	2.5	2.0
Development/Implementation	5	5	3	2
Maintenance				
Licensing Fee/Application Fee	5	5	2	2
Consumables				
Functionality	5.0	5.0	5.0	5.0
User Training	5	5	5	5
Technical Support	5	5	5	5
Interpretation/Accessibility of Data	5	5	5	5
User Friendliness	5	5	5	5
Potential for User Error	5	5	5	5
Overall Average	4.3	4.4	3.5	3.3

Table 10: EEG Device Comparison

Criteria	Muse	EMOTIV
Design	3.3	3.1
Modifiability	1	3
Multiplex System	5	3
Processing Time	5	5
Compatibility	4	3
Durability	2	2
Power source	4	3
Portability	5	5
Data storage	1	1
Ownership	1	1
Accuracy	5	5
Cost	2.7	2.0
Development/Implementation	2	2
Maintenance	2	2
Licensing Fee/Application Fee	4	2
Consumables		
Functionality	3.8	3.0
User Training	5	5
Technical Support	5	1
Interpretation/Accessibility of Data	2	2
User Friendliness	5	5
Potential for User Error	2	2
Overall Average	3.3	2.7

Table 11: Spectrophotometry Device Comparison

Criteria	SCiO	LeSSA	VOC Analyzer	Trinamix	(TRI)-Analyzer	Linksquare	Cloudminds XI	DietSensor's SCiO	GoSpectro
Design	3.3	3.4	2.4	3.6	3.4	3.8	3.9	3.1	3.1
Modifiability	2	2	2	2	3	3	2	2	2
Multiplex System	3	3	3	3	3	3	3	2	2
Processing Time	5	2	3	5			5	5	5
Compatibility	3		1	5	4	3	3	3	3
Durability							5		
Power source	4		2	5	4	5	5	5	5
Portability	5	5	4	5	5	5	5	5	5
Data storage				3		4	5	2	2
Ownership	1		1	1	2	3	1	1	1
Accuracy	3	5	3		3	4	5		
Cost	2.0	5.0	3.0	N/A	3.0	3.7	N/A	3.8	4.5
Development/ Implementation	2	5	3		3	3		5	5
Maintenance	2					3		3	4
Licensing Fee/Application Fee	2							2	4
Consumables						5		5	5
Functionality	3.6	2.2	2.8	3.0	2.4	2.8	3.2	3.8	3.8
User Training	3	2	2	3	3	3	3	3	3
Technical Support	3	2	4	3	2	3	3	3	3
Interpretation/ Accessibility of Data	3	2	2	3	2	2	3	4	4
User Friendliness	4	3	3	3	3	3	3	4	4
Potential for User Error	5	2	3	3	2	3	4	5	5
Overall Average	3.0	3.5	2.7	3.3	2.9	3.4	3.6	3.6	3.8

Table 12: Activity Monitoring Devices Comparison

Criteria	Polar	Garmin	Samsung	Apple	FitBit
Design	3.9	3.8	3.7	3.6	3.8
Modifiability	2	2	2	2	2
Multiplex System	5	5	5	5	5
Processing Time	5	5	5	5	5
Compatibility	4	4	4	2	4
Durability	5	5	4	4	5
Power source	5	5	5	5	5
Portability	5	5	5	5	5
Data storage	2	2	2	2	2
Ownership	1	1	1	1	1
Accuracy	5	4	4	5	4
Cost	5.0	5.0	4.7	4.3	5.0
Development/Implementation	5	5	4	3	5
Maintenance	5	5	5	5	5
Licensing Fee/Application Fee	5	5	5	5	5
Consumables					
Functionality	4.8	4.8	4.8	4.8	4.8
User Training	5	5	5	5	5
Technical Support	5	5	5	5	5
Interpretation/Accessibility of Data	5	5	5	5	5
User Friendliness	5	5	5	5	5
Potential for User Error	4	4	4	4	4
Overall Average	4.6	4.5	4.4	4.2	4.5

Table 13: Social Media Tracking App Comparison

Criteria	Bark	mSpy	The Spy Bubble	Hootsuite
Design	2.8	2.8	2.8	2.7
Modifiability	3	3	3	2
Multiplex System	1	1	1	1
Processing Time	5	5	5	5
Compatibility	5	5	5	5
Durability				
Power source				
Portability				
Data storage	2	2	2	2
Ownership	1	1	1	1
Accuracy				
Cost	5.0	5.0	4.7	4.3
Development/Implementation	5	5	4	3
Maintenance	5	5	5	5
Licensing Fee/Application Fee	5	5	5	5
Consumables				
Functionality	5.0	5.0	5.0	5.0
User Training	5	5	5	5
Technical Support	5	5	5	5
Interpretation/Accessibility of Data	5	5	5	5
User Friendliness	5	5	5	5
Potential for User Error	5	5	5	5
Overall Average	4.3	4.3	4.2	4.0

Table 14: Eye Image Analysis Application Comparison

Criteria	AI Retinal Screening	IDx-DR	Retina-AI
Design	2.4	2.2	2.2
Modifiability	2	2	2
Multiplex System	1	1	1
Processing Time	4	5	5
Compatibility	2	2	2
Durability			
Power source			
Portability	5		
Data storage	2	2	2
Ownership	1	1	1
Accuracy			
Cost	N/A	N/A	N/A
Development/Implementation			
Maintenance			
Licensing Fee/Application Fee			
Consumables			
Functionality	4.8	4.8	4.8
User Training	4	4	4
Technical Support	5	5	5
Interpretation/Accessibility of Data	5	5	5
User Friendliness	5	5	5
Potential for User Error	5	5	5
Overall Average	3.6	3.5	3.5

Table 15: Eye Image Capturing Device Comparison

Criteria	oDocs Nun	Peek Retina	D-Eyecare
Design	3.1	3.6	3.0
Modifiability	2	2	2
Multiplex System	1	1	1
Processing Time			
Compatibility	5	5	2
Durability			
Power source	4	5	5
Portability	5	5	5
Data storage	4	2	5
Ownership	1	5	1
Accuracy			
Cost	3.5	N/A	5.0
Development/Implementation	5		5
Maintenance	5		5
Licensing Fee/Application Fee	2		5
Consumables	2		5
Functionality	5.0	5.0	5.0
User Training	5	5	5
Technical Support	5	5	5
Interpretation/Accessibility of Data	5	5	5
User Friendliness	5	5	5
Potential for User Error	5	5	5
Overall Average	3.9	4.3	4.3

6.0 DISCUSSION

Many of the devices and software mentioned above are not discussed in great detail, but instead brief overviews are provided to give an understanding of what the devices are capable of, how they work, pricing, accuracy, and validation information available. Duplicating devices and software were grouped together and graded using the criteria explained above to help guide future validation studies or further device development and implementation. This grading criteria allow one device to be selected for testing or further developing so that all devices do not necessarily need to be tested. It is important to note that one section (e.g., design, cost, or functionality) may be more important for a given situation and thus the overall score may not be the best guide. Additionally, the grading criteria are subjective, and a difference of opinions may

result. This report is intended to provide a list and summary of devices available that could meet USAF gaps, but not without further testing or development.

There are four devices capable of monitoring vital signs: BioBeat, Checkme Pro Health Monitor, Wellue O2Ring, and Kardia. The comparison can be seen in Table 3. For continuous hands-off monitoring of multiple vital signs and multiple patients, the BioBeat devices offers the best solution; however, the Checkme Pro Health Monitor is a close second. The Wellue O2 Ring is highly portable and offers a great solution for monitoring oxygen saturation levels and heart rate for a patient, but it cannot monitor multiple patients simultaneously. Similarly, the Kardia ECG monitor is only capable of recording ECG data for one patient and it is not intended for continuous monitoring.

The Freestyle Libre and Dexcom are capable of monitoring glucose levels, but are intended for individuals with type 1 or 2 diabetes. These devices score almost identically as seen in Table 4; however, one advantage offered by Dexcom is its ability to predict trends and patterns for an individual's glucose levels. This offers a unique ability to help prevent hyper- or hypoglycemia.

As seen in Table 5, there are many attachments for smart devices capable of turning the device into a microscope. The Tinscope and other smartphone attachments scored the lowest due to their lack of validation and potential for automation. Additionally, these devices are intended more as a commercial "toy" for individuals to learn about the microscopic world, opposed to being scientific tools. Smart Micro Optics has developed the DIPLE and the BLIPS, which score slightly higher than the Tinscope. The DIPLE and BLIPS are intended for scientific use; however, results are analyzed by the users. This requires user training and leaves room for human error. The Cell Scope system developed by UC Berkeley scores the highest because it is capable of capturing microscopic images for diagnostic and identification purposes but can also be modified and used for otoscopy. This system also has an associated application that allows for annotation, data management, web connection, and automated image analysis.

ELISA is a great laboratory technique used for identification and detection, and can be used to quantify particular pathogens, proteins, antigens, antibodies, etc., in various samples. Seen in Table 6, there are two attachments, the MELISA and mChip Smartphone Dongle, which make a smart device capable of completing ELISAs. Both are great possible solutions for conducting ELISA in a field setting oppose to a laboratory setting. However, the MELISA scored the lowest because it is entirely dependent on the ELISA kit used, so the processing time can be lengthy, could require cold chain management, and results must be interpreted by the user which can lead to human error. The mChip Smartphone Dongle scored higher than the MELISA due to its quick processing time and easy result readout. It is important to further validate both of these devices against laboratory gold standards and determine how different temperatures and environments impact their performance.

Like ELISA, LAMP laboratory techniques can be used to identify, detect, and quantify particular pathogens in different samples. Seen in Table 6, there are four attachments, Sandia SmartLAMP, LAMP, RT-LAMP with fluorescent labels, and DIY Diagnostics, which all allow a phone to become capable of completing LAMP. RT-LAMP scored the lowest because it requires cold chain management to rehydrate the chip before diagnostics can be completed. The LAMP and the DIY Diagnostics scored very similarly. Both attachments are in the early development phase. The LAMP system scores slightly below the DIY Diagnostics device because it still requires lengthy sample preparation. However, both systems still need additional validation testing. The Sandia SmartLAMP scored the highest. This device is TRL 4, delivers results in 30

minutes, is capable of multiplex testing, requires minimal to no user-training, and returned binary “yes” or “no” results.

A technique similar to ELISA is lateral flow assays. Both techniques use antigen-antibody complexes to identify and detect pathogens, proteins, antigens, antibodies, etc. in a sample. Seen in Table 7, there are three attachments, Luminostics, RDT Reader, and Paper-Based Vertical Flow Immunoassay, for a smart device that help a user read and interpret the results of a lateral flow assay to help minimize user error. The three devices scored similarly with the Luminostics scoring the lowest. Luminostics scored slightly lower than the other devices due to limited information about its processing time and because it uses proprietary nanoparticles which has the possibility to bottleneck research and development. RDT Reader and Paper-Based Vertical Flow Immunoassay overall scored identically; however, the RDT Reader scored higher for design while the Paper-Based Vertical Flow Immunoassay scored higher for functionality. Neither system is currently capable of autonomous analysis. But the RDT Reader is compatible with many different LFI-RDTs developed by various companies while the Paper-Based systems utilizes a nanoporous nitrocellulose membrane pretreated and prepared specifically for the device.

HRV can be a useful measurement for monitoring stress and workload, there are many different devices and applications capable of analyzing HRV but the four in Table 8 were the focus of this report. The Welltory application scored the highest. This system can use a phone’s rear camera for basic real-time measurements or an external heart rate monitor for more precise and monitoring measurements. The application delivers results in a user-friendly interface that breaks HRV into three readouts for performance (total HRV), energy, (parasympathetic nervous system status), and stress (sympathetic nervous system status). Welltory scored higher than Apple Health because it is compatible with many devices and operating systems, while Apple Health has limited compatibility with any operating system other than iOS. Apple Health uses an external heart rate monitor to measure heart rate and then calculates the standard deviation of the NN intervals from the beat-to-beat data. Apple products are known for being highly accurate; however, this application gives limited information about the user’s nervous systems. The application simply gives the user a high (rested) or low (needs rest) read out. HRV4 Training followed Apple Health. This system, similar to Welltory, can use the rear-facing camera of a smart device or an external heart rate monitor. The system is designed for athletes and offers training suggestions based on the past 30 day’s data. This system scored slightly below Welltory and Apple Health due to its cost. Elite HRV scored the lowest of the four applications. Elite HRV uses an external heart rate monitor to analyze HRV. The application can provide biofeedback, guide breathing exercises, and offers a team coaching platform to allow multiple users to link. Despite the scientific backing, this application scored lower than the other systems because of its cost and the limited compatibility with different devices and operating systems.

As seen in Table 9, there are two devices that interface with a smart device to give it the capability to collect EEG data-- the Muse and the EMOTIV. Neither device is intended for continuous passive monitoring, but the Muse scored the highest. This device is designed for guiding and establishing consistent meditation practices for a user; however, it has some research applicability. The Muse scored higher than the EMOTIV because it measures brain activity, heart rate, breathing rate and body movement using PPG, an accelerometer, and a gyroscope. These sensors give Muse the potential to be a multiplex system. The Muse is also more cost effective than the EMOTIV, but neither are ruggedized device and both require a trained professional to interpret and understand the results.

As seen in Table 10, there are many devices that are compatible with, or are attachments for smart devices, allowing the devices to complete spectrometry. These devices were designed with different intents, but can be broken into three types of spectrometers. The first are attachments for the rear camera of smart devices. The GoSpectro, LeSSA, and (TRI)-Analyzer all attach to the rear camera of a smart device to allow the camera to act as a spectrometer. The GoSpectro scored the highest because it is the smallest and is the only fully developed and tested device. The LeSSA scored the next highest. This device is small like the GoSpectro and has showed to be capable of testing for OP compounds as well as pathogens by analyzing the results of ELISA kits. The LeSSA is a proof-of-concept device and requires further development for the device, user interface, data interpretation, and result display as well as requires more validation testing. The (TRI)-Analyzer is the largest of these three devices and is also just a prototype requiring more development of the device, user interface, data interpretation, and result display as well as additional testing. The second type of spectrometer devices are “point-and-click” type devices. The DietSensor’s SCiO, Linksquare, and SCiO fall into this category. These devices are separate hand-held spectrometers that use Bluetooth to connect and transfer data to a smart device. These devices are intended for determining the macronutrients in food for tracking dietary habits or identifying unknown substances (e.g., salt vs sugar, water vs alcohol). For this category, the DietSensor’s SCiO scored the highest because of its cost, user interface, and user-friendliness. The last type of spectrometer are standalone spectrometers. The Cloudminds XI and VOC Analyzer fall into this last type. The VOC Analyzer scored the lowest for this type. It is a tablet sized FAIMS capable of identifying biomarkers for known health conditions. Despite this device’s abilities, it scored lower than the Cloudminds XI because it requires training for use and data interpretation. The Cloudminds XI scored the highest for this type because it is a ruggedized smartphone integrated Raman spectrometer. Cloudminds XI scored the highest due to its size, cost, durability, and user interface. The Cloudminds XI scored second highest overall for spectrometer devices but would be the recommended device for further development and testing because it is the only ruggedized device that has been tested in a range of operating temperatures. This makes the device applicable for field testing in austere environments.

There are five devices outlined in Table 11 that will be discussed for monitoring activity--these are Polar, Garmin, Samsung, Apple, and FitBit. These four devices all scored similarly with the biggest difference being the product’s accuracy, compatibility, and data transparency. Polar scored the highest of these products due to its accuracy, compatibility, and data transparency. Many Polar products are used as gold standards when comparing different activity monitors. Polar is compatible with all operating systems and many different devices. Additionally, Polar is highly transparent with the collected data making it is easy to retrieve the second-by-second data collected compared to other products. Garmin and FitBit scored second highest. These products have slightly lower accuracy but are compatible with all operating systems and allow users to easily retrieve the collected data. Samsung follows closely behind. Again, Samsung is not as accurate as Polar products and it scored lower than Garmin and FitBit because its second-by-second data cannot be retrieved. Samsung activity data is displayed in 15-to-60-minute time intervals with ranges for a given physiological parameter. Apple scored the lowest. Apple products are on par with Polar product’s accuracy; however, they have limited compatibility with non-Apple products and like Samsung give limited transparency for collected data.

With the rise of social media, many applications have been developed to track a user’s activity or monitor specific keywords, hashtags, or locations. As seen in Table 12, four were evaluated Bark, mSpy, The Spy Bubble, and Hootsuite. Bark and mSpy scored the highest of

these applications. Both are intended for parental control and monitoring of social media. Bark and mSpy allow the user to monitor social media activity and restrict access to specific websites. They are both highly cost effective and could be used to ensure sensitive information is not accidentally being leaked online. The Spy Bubble scored the second highest. The Spy Bubble also monitors social media activity but can also provide details about incoming and outgoing calls as well as GPS information. The Spy Bubble scored slightly below Bark and mSpy because the information it collects is more personal and could be a security concern if the software is hacked. Hootsuite scored the lowest of these applications. Hootsuite is intended for monitoring online activity relating to the user's business, industry, or products. It scored slightly lower than the other applications because it is more applicable for monitoring specific topics and industries than individual people.

Retina disease diagnostic tools were the last group of devices and software compared. There are three products, seen in Table 13, that interface with a smart device to allow for diagnosis of retinal diseases: AI Retinal Screening, IDx-DR, and Retina-AI. AI Retinal Screening scored the highest of these devices. AI Retinal Screening is the only product in this group that integrates a handheld fundus camera with the AI software that analyzes the images. The IDx-DR and Retina-AI scores tied for second. Both are standalone AI software that only analyze retinal images and they do not take the images. Devices like oDocs Nun Ophthalmoscope, Peek Retina, or D-Eyecare Ophthalmoscope, seen in Table 14, are capable of capturing images of the retina but not diagnosing retinal diseases. The Peek Retina and D-Eyecare devices scored the highest. The D-Eyecare device uses HIPAA-compliant cloud storage, is FDA and CE registered, and cost effective. However, it is only compatible with iPhones. Peek Retina is compatible with all smart devices and small, but is still in the testing and development phase. The oDocs Nun is larger than the Peek Retina and D-Eyecare and less cost effective, but offers a teleophthalmology platform.

7.0 CONCLUSION

The gaps listed in the RDD documents are open-ended and have room for interpretation. This allows for many devices to meet the identified gaps; however, more information can help guide device selection, design, development, and testing. This report briefly discusses different devices, attachments, and software compatible with smart devices that meet the gaps in the RDDs. Due to the open-ended nature of the gaps in the RDDs, this literature review does not select technologies to address a gap. The intent is to provide an overview of the current technology that can be used to guide the selection of devices for further design, development, testing, and validation.

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LIST OF ABBREVIATIONS AND ACRONYMS

%	percent
ADVON	Advances Echelon
AI	Artificial Intelligence
AI-VENT	AgVa Intelligent Ventilation
BATDOK	Battlefield Assisted Trauma Distribution Kit
BG	Blood Glucose
BP	Blood Pressure
BPM	Beats per Minute
°C	Degrees Celsius
CDC	Center for Disease Control and Prevention
CE	European Conformity
CGM	Continuous Glucose Monitor
cm	Centimeter
CMOS	Complementary Metal-Oxide-Semiconductor
COTS	Commercial Off the Shelf
CSV	Comma-Separated Values
D4	Dispense, Dissolve, Diffuse, Detect Assay
DNA	Deoxyribonucleic Acid
<i>E. coli</i>	<i>Escherichia coli</i>
ECG	Electrocardiogram
EEG	Electroencephalogram
ELISA	Enzyme-Linked Immunosorbent Assay
EWS	Early Warning Score
FAIMS	Field-Asymmetric Ion Mobility Spectrometer
FDA	Food and Drug Administration
g	Gram
GB	Gigabytes
GOTS	Government Off-the-Shelf
GPS	Global Positioning System
HAPSITE	Hazardous Air Pollutants On Site
HIPAA	Health Insurance Portability and Accountability Act
HIV	Human Immunodeficiency Virus
HIV-1	Human Immunodeficiency Virus Type 1
HIV-2	Human Immunodeficiency Virus Type 2
HR	Heart Rate
HRP-2	Histidine-Rich Protein 2
HRV	Heart Rate Variability
iOS	iPhone Operating System
IP	Internet Protocol
IR	Infrared

LAMP	Loop-Mediated Isothermal Amplification
LED	Light Emitting Diode
LeSSA	Lens-Less Smartphone Spectrum Apparatus
LFI	Lateral Flow Immunochromatographic
mAh	Milliamp Hour
MEWS	Modified Early Warning Score
mL	Milliliter
mm	Millimeter
mmHg	Millimeters of Mercury
MELISA	Mobile-Enzyme-Linked Immunosorbent Assay
NIOSH	National Institute for Occupational Safety and Health
NIR	Near Infrared
nm	Nanometers
OP	Organophosphorus
PC	Personal Computer
PCR	Polymerase Chain Reaction
pg/mL	Picograms per milliliter
PJ	Pararescuemen
PM	Particle Matter
POCT	Point-of-Care-Testing
POEGMA	poly(oligoethylene glycol methyl ether methacrylate)
PPG	Photoplethysmography
PVT	Personal Vision Tracker
RGB	Red, Green, Blue
RDD	Research Development Document
RDT	Rapid Diagnostic Test
RHS	Remote Health Solutions
RNA	Ribonucleic Acid
RT-LAMP	Reverse-Transcription Loop-Mediated Isothermal Amplification
SARS-CoV-2	Sever Acute Respiratory Syndrome Coronavirus 2
SAW	Surface Acoustic Wave
SpO ₂	Oxygen Saturation
SULSAT	Small Unit Leader Situation Awareness Tool
SWIR	Short-Wave Infrared
TEH	Total Health Exposure
TM3	Tele-mentoring, tele-medicine, tele-monitoring
TRI	Transmission, Reflection, and Intensity Spectral
TRL	Technology Readiness Level
UC	University of California
USAF	United States Air Force
USB	Universal Serial Bus

UV	Ultra Violet
VER	Virtual Exam Room
VFI	Vertical Flow Immunoassay
VIS-NIR	Visible-Near-Infrared
VOC	Volatile Organic Compound
xVFA	Multiplexed Vertical Flow Immunodiagnostic Assay