KENNEL Threat Detection Boxes for First Responder Situational Awareness and Risk Management

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ABSTRACT

KENNEL is a deployable IoT-based system consisting of a network of unattended ground sensors, known as Threat Detection Boxes (TDBs), which may be outfitted with any variety of custom and commercial-off-the-shelf sensors for hazard detection. The KENNEL system fills a technological gap for sensor fusion, interpretation, and real-time alerting via existing information management systems, such as Team Awareness Kit (TAK). First responders face a critical need for improved situational awareness, detection, and response to hazardous events. KENNEL provides a first of its kind, low-cost sensing & data fusion platform that is highly extensible, configurable, and self-sustaining, opening a world of modernization and innovation possibilities across the first responder domain. TDBs may also be statically or ad hoc deployed, improving flexibility, stand-off hazard detection, and resilience in the operational domain. From critical infrastructure monitoring to wearables, the system affords timeliness of critical information for effective risk management and increased personnel safety.

Keywords

Situational Awareness, Hazard Detection, Microsensors, Sensor Fusion, Risk Management.

INTRODUCTION

November 30th, 2018, a magnitude 7.1 earthquake hit Anchorage, Alaska and caused significant damage to critical infrastructure, including roads, railways, runways, and buildings. Joint Base Elmendorf-Richardson (JBER) was among those severely impacted by the event. Barring sensors on some infrastructure, such as fuel lines, and cameras at restricted areas, the situational awareness was heavily reliant on slow, manual processes with little a priori knowledge. Just a few months prior, Hurricane Florence severely damaged infrastructure at Offutt Air Force Base (Figure 1), Nebraska and Tinker Air Force Base, Oklahoma, as it did to many communities in its wake. Despite the significant advancement in commercial-off-the-shelf sensors, Internet-of-Things (IoT) systems, and mobile technologies, situational awareness for First Responders was slow and discontinuous, relying on first-hand knowledge that's often difficult to obtain and efficiently aggregate in such a crisis. Current state of the art technologies are often hand-held devices used by first responders to assess on-the- ground conditions after a catastrophe, such as the Thermofisher's Gemini[1] for assessing chemical spills or the Ludlum[2] for assessing radiation disasters, placing personnel in potentially deadly environments to conduct hazard surveys. Although some ground sensors exist for radiation and chemical hazard detection, these systems are extremely expensive, bulky, and only report on incidents after the fact or with very limited early warning; additionally, these limitations prevent such systems from ubiquitous employment throughout metropolitan areas that are most at risk for large

[1] https://www.thermofisher.com/order/catalog/product/GEMINI
[2] https://ludlums.com/products/all-products/product/model-194

casualty incidents, such as toxic chemical spills. A streamlined, inexpensive, disposable system that ingests and interprets data from any number of deployed sensors, including handheld devices, wearables, mounted and statically deployed ground sensors, and provides real time hazard monitoring and early warning is a critical need for the first responder community.

Figure 1: Flooding at Offutt Air Force Base.

January 2020, a team of Airmen and Air Force Civilians from the Air Force Research Laboratory (AFRL) Information Directorate (RI), Air Mobility Command (AMC), Headquarters Air Force (HAF), and Air Force Installation and Mission Support Center (AF IMSC) completed a technical experiment at JBER that showed the operational needs and benefits of common operating pictures, mobile apps, and sensors for modernizing and innovating the Department of Defense's security posture and mission readiness. At the heart of their experiment was the Android Team Awareness Kit (ATAK), a situational awareness tool that has been deployed significantly over the last decade for military and civilian application.

Figure 2: Operator using ATAK for situational awareness and communication.

ATAK (Figure 2) is a digital Swiss-army knife of plugins that composes a broadly applicable communication and collaboration platform, in conjunction with the greater TAK Ecosystem. This platform and its many variants and integrations has supported everything from military Special Forces Operations to federal agency security at the Super Bowl (Huntington, 2020) and Presidential Inauguration (Draper, 2021) to civilian agency usage for search and rescue, manhunts, and disaster recovery missions (Department of Homeland Security, 2017). The overwhelming success of this initial proof of concept event at JBER identified the applicability of such technical innovations for Aerial Port Operations and ultimately provided the justification for an extensive portfolio of Aerial Port modernization and innovation projects (Wynn, 2021) (Foster, 2021) (JB-CHS, 2021) (Brackin, 2021) as well as the Aerial Port of the Future Joint Capability Technology Demonstration. However, there was still a gap for a common sensing platform that not only leverages COTS IoT components and sensors, but fuses data sources for real-time alerting, monitoring, and prediction; enter KENNEL.

KENNEL is a research and development effort from the Air Force Research Laboratory (AFRL), Information Directorate (RI), Warfighter Integration Branch (RISD) in partnership with the Florida Institute for Human and Machine Cognition (IHMC). Inspired by the broad capabilities of TAK, backed by several reports and strategic guidance, and with the support of operational mission, KENNEL began designing a platform that would provide a capability for general situational awareness, perimeter security of critical infrastructure, event reporting, and predictive modeling. As prototypes were developed, KENNEL's applicability and alignment to the mission sets of United States Special Operations Command (USSOCOM), Defense Threat Reduction Agency (DTRA), Joint Personnel Recovery Agency (JPRA), among others, became evident and led to operational experiments in expanding the sensor array to Chemical, Radiological, and weather. All these capabilities also align with the mission of the first responder community at all levels. KENNEL's ability to be low-cost, highly configurable, and integrate complex data for real time alerts via ATAK makes it an ideal candidate to provide increased efficiency, effectiveness, awareness, and safety.

TECHNOLOGY CONCEPT

KENNEL (Figure 3) is a tailorable and deployable multi-sensor platform of Threat Detection Boxes (TDBs) that consolidates real-time hazard monitoring via TAK, improving situational awareness for first responders in a variety of scenarios. KENNEL prototypes are equipped with custom-modified Passive Infrared (PIR) motion, commercial-off-the-shelf thermal, custom radiological, and custom paper-based chemical detection sensors, which may serve as early warning for hazardous events and real-time interpretation of incidents. The open-platform also allows for integration and configuration additional COTS, government-off-the-shelf (GOTS), or proprietary sensors. If those sensors follow the available connection specification, they could even be hot-swappable for on-the-fly modularity and configurability. Current interest and support from agencies in the chemical, biological, radiological, nuclear, and explosive (CBRNE) community has focused development and testing of the TDBs for specific hazard monitoring.

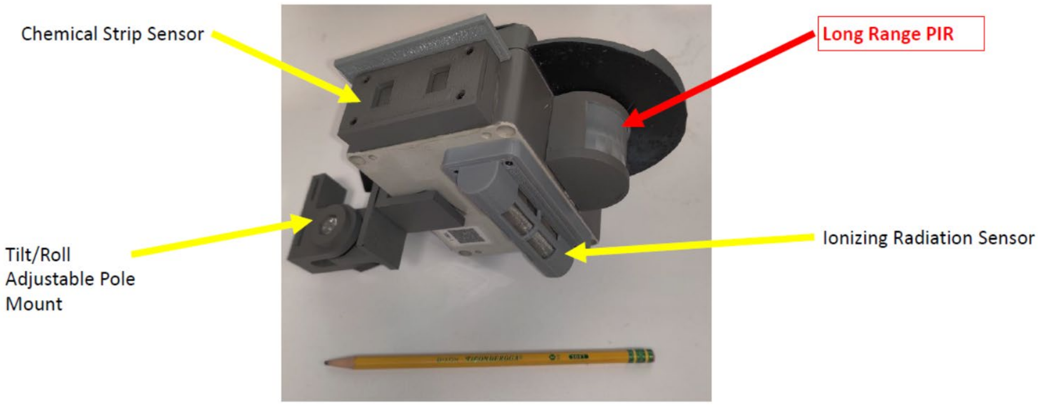

Figure 3: KENNEL configured with PIR, chemical, and radiation sensors.

Existing KENNEL prototypes have CBRNE sensing tailorable for use with existing and emerging COTS sensors. For motion monitoring, long range (130-200ft) passive infrared of inexpensive (~$1-$2) COTS sensors are achieved through a custom designed Fresnel lens. Coupled with vibration detectors or GPS/GNSS, motion detection as well as tamper detection can further enhance what is achieved by the PIR. Integrated with TAK and with additional integration easily tenable, data fusion, ML/AI modeling and prediction, map-based application for remote monitoring and management are all features that are included but could be further broadened or refined. The mini-TDBs (Figure 5) provide small and lightweight capabilities that fit in the palm of your hand and weigh less than 1lb with cost anticipated to be less than $50.00 per box (sensor dependent) and self-sustaining through optimized power usage (extremely low voltage, 3.7V), internal battery, and external solar panel.

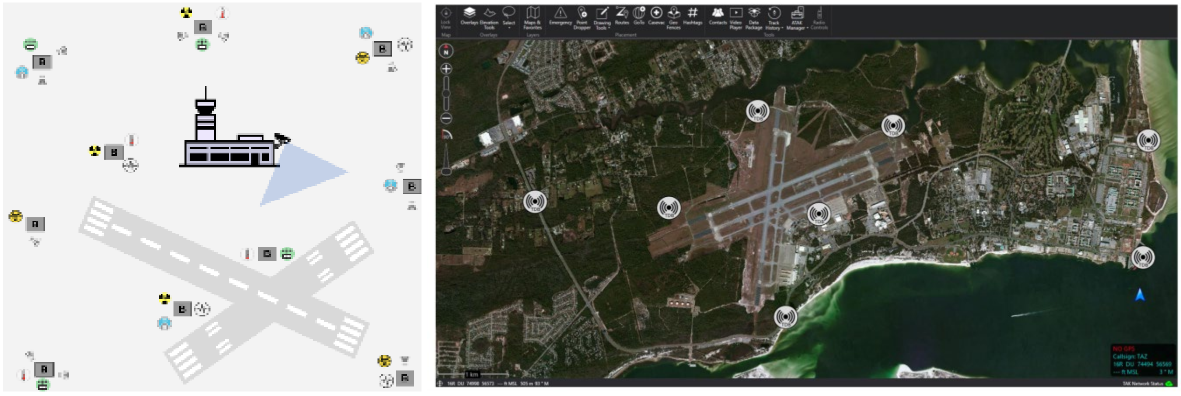

Figure 4: KENNEL deployment concept to prototype display.

KENNEL is a scalable system (Figure 4) that supports thousands of TDBs simultaneously per gateway and may be outfitted with various sensors per the first responder's needs. KENNEL is also indoor and outdoor capable, with TDBs offering a variety of mounting options, including magnet, zip tie, ground stake, or bracket for deployment to doorways, light poles, UAVs/UGVs, or chain link fencing. However, the boxes can also be customized for a variety of mission criteria from camouflaging as common environmental objects to specific form-factors, such as DropPucks. Moreover, TDBs require no user training; simply turn on the system and it automatically communicates via TAK. Ease and efficient set-up is important in time-sensitive scenarios that involve people with a range of training and skill sets. To operate and deploy a TDB, just turn on the box, register the device using a QR code with the TAK device, and deploy. The RF footprint is extremely small (<0.2mW per transmission) with the box remaining inactive 90% of the time; only activating periodically or when a detection is performed. Boxes are IP67 rating, allowing exposure to water and other outdoor elements.

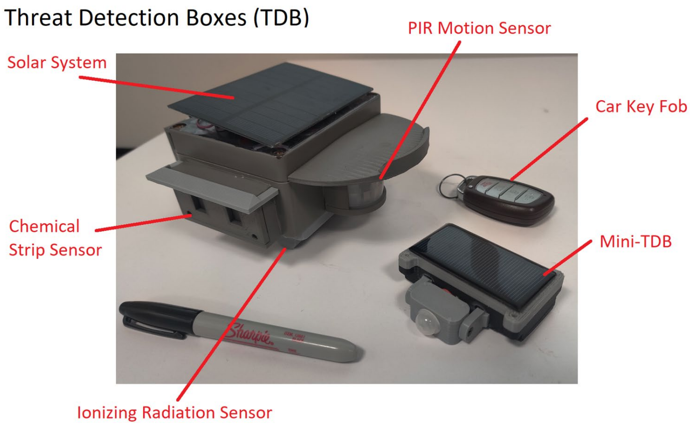

Figure 5: Size comparison of various TDB, mini-TDB, and common items.

First responders could use KENNEL to monitor perimeters and critical infrastructure, such as power plants or fuel reserves, for threats to include natural disasters or CBRNE, fire watch, or intrusion alerts. Chemical spills, for instance, could be assessed and monitored via a fully integrated system with future prototypes incorporating hazard prediction and assessment capabilities (HPAC), improving safety alerts via TAK for first responders potentially downwind from a deadly spill. Future TDB prototypes are under development as miniaturized as wearable devices for radiation, chemical hazard, and motion detection, as well as more ruggedized versions that could be launched into contaminated environments, such as radiation incidents. In addition, stand-off detection tests for onboard, custom radiation and chemical sensors are under way, along with the integration of additional COTS sensors and HPAC plume modeling, which could improve first responders' ability to respond to and mitigate chemical or biological disasters events.

KENNEL provides first responders with a spectrum of options for whole-picture, real-time threat monitoring, warnings, and modeling with built-in data fusion & interpretation, and the ability to integrate at the operational level via a common operating picture. KENNEL TDBs may be statically deployed at critical infrastructure locations, autonomously mounted on existing UAV or UAS platforms for threat investigation, or clipped on the belt of first responders for radiation or chemical hazard monitoring and improved personal safety, Future systems are being developed to include HPAC modeling built into a system of networked TDBs that detect toxic gasses or aerosols and provide real-time modeling of plume direction, increasing situational awareness and hazard assessments. Emerging and existing COTS sensors may also be integrated into the TDBs with future prototypes expanding into biosensing technologies.

Resilient, Reliable Communication

KENNEL TDBs communicate via Long Range (LoRa) radio bands to a gateway (Figure 6) or network of gateways. This overcomes some significant network challenges present in disaster or constrained environments, such as cellular congestion during catastrophic events, as well as degraded or limited infrastructure. It also provides relatively large coverage areas compared to setting up typical local area networks (LANs). There is also added security from both 128-bit AES end-to-end encryption as well as difficulty in intercepting and injecting messages (Sǿndrol et al., 2018). Gateways can be larger, all-weather indoor/outdoor gateways that are permanently or temporarily mounted, or they can be portable, packable gateways that are roughly the size of a Raspberry Pi. To deploy KENNEL, only TDBs, a gateway and a small portable server is needed. Deployment can take place in under 10 minutes. Communication between TDBs and the gateway is bi-directional. Reach-back or further federation of the data from the TDBs can be transmitted through any number of communication networks and protocols from the gateway, such as cellular, military radio, Wi-Fi, ethernet, IRIDIUM, Starlink. This provides flexibility and resiliency to the networking accessibility that is available in any given scenario.

Figure 6: Packable mini gateway and full-size indoor/outdoor gateway.

Collaborative, Interoperable Incident Management Systems for Command and Control

By integrating with the TAK Ecosystem, KENNEL TDBs become accessible to over a decade's worth of common operational picture development that includes a broad community of over 200,000 users. This includes COPs built for Android (i.e., ATAK) and iPhone (iTAK) mobile operating systems, web browsers (i.e., WebTAK), Windows (i.e., WinTAK) computers, as well as future AR/VR technologies (vTAK/AR-TAK). However, investment in the TAK Ecosystem is not a requirement to use KENNEL. KENNEL is integrated with TAK via Cursor on Target (CoT). For additional management functions it employs a custom ATAK Plugin. It is also compatible with DisService backend system that allows integration connections to TAK Server (TAK Community), PhoenixPrime (AFRL), DSPro (IHMC), or easy integration to any other Information Management System. Likewise, there is a custom web-based KENNEL Dashboard that can be used but the data can be made accessible to any open or proprietary visual interfaces.

In recent testing, we have been able to display alert notifications in TAK and sensor measurements using the TAK KENNEL Plugin. But we have been able to garner even greater capability by leveraging the data connections to other TAK plugins for a variety of automation and data fusion. For example, alerts from KENNEL have been able to task UAS/UGS platforms to further investigate alerts. Discussions are underway for fusing KENNEL chemical and radiological alerts with an existing TAK weather plugin for accurate plume estimations. Another effort within the DOGTAG Portfolio, DINO, is extending TAK's geofence capability with an action/trigger framework that provides support for complex rulesets and broad notification types (e.g., visual alerts, text messages, emails, haptics). Coupling KENNEL with DINO, the TDBs can create digital tripwires in the real world that correlate to geofenced areas of interest (AoI) in the TAK Ecosystem, removing the need to create a priori AoIs within TAK. Furthermore, current TAK geofencing is limited to things that are pushing their location into TAK. It doesn't provide the ability to get alerts when something enters or exits an area that isn't reporting (e.g., wildlife, unauthorized personnel). This capability is made possible using KENNEL.

Sensing and Modeling of Disaster Affected Areas

With the vast array of real-time sensor data available from deployed TDBs as well as data fusion from other accessible data sources or sensors within the network, modeling of disaster areas can be projected and even predicted. For example, if multiple TDBs are deployed around an area with known locations, the order and intensity of readings at various devices can provide plume estimations. If this data is fused with anemometers or other weather sensors, either on-board or in-network, then finer grained accuracy, perhaps even with fewer devices deployed, is attainable. This data can then be displayed on map overlays within TAK clients (Figure 7).

Figure 7: Fire and cloud coverage overlays in ATAK that could be enhanced with KENNEL HPAC data.

Sensor Network Deployment and Data Fusion

As was discussed in the introduction, regarding the TAK Ecosystem, there has been significant usage in event security and disaster response for ATAK. Given the integration that is already completed between KENNEL and TAK, the ability to have TDBs deployed in such scenarios would easily enhance their situational awareness and command and control capabilities during the planning and execution of these mission sets. However, these would still require planned or ad hoc deployment of the system.

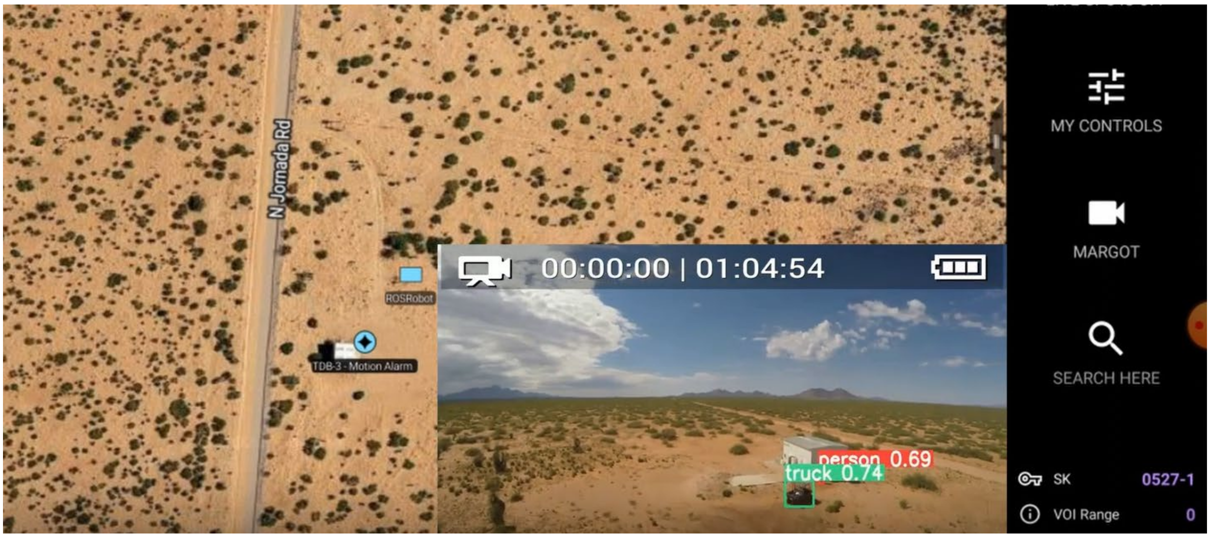

Figure 8: Integration of TDB intrusion alerts tasking UAS for further investigation with ATAK.

Considering the low SWaP-C, self-sufficiency, and scalability, a future state of the system could be embedding TDBs into a greater IoT system as a foundational piece to Smart Cities. TDBs could be deployed at public and private locations that feed additional sensor points into the network. Like at-home weather stations, the growing ubiquitous use of IP-based cameras, and Smart Home sensors, TDBs could be deployed by property owners for private monitoring that could either be shared or subpoenaed during incidents with incentives for installing such devices (e.g., insurance discounts, rebates). Another deployment plan would be embedding into remotely accessible utilities (e.g., electric, natural gas, and water meters) or public infrastructure, such as power lines or streetlights. Since TDBs are highly configurable, multiple sensor arrays could be deployed throughout an area. TDBs at intersections could have PIR, radar-based motion sensors and cameras for traffic management and accident monitoring at significantly reduced cost for areas that don't have the demand and budget of locales with such capabilities, such as Los Angeles County Intelligent Transportation System. Installation at bridges, aqueducts, and levees could be outfitted with seismic and hydrostatic pressure level sensors to monitor potential earthquake or flooding events at critical transportation points or high-risk areas. Installation at the border wall or camouflaged throughout border areas could assist Border Patrol and local agencies with security. Configured with weather sensors (e.g. anemometers, barometers, thermal), air quality monitoring and incidents, such as gas or chemical spills, could save precious time in responding. In urban environments, acoustic sensors could be included and fused with general cross-correlation for trilateration of gunshots and explosions which could even task UAS platforms (Figure 8) autonomously to further investigate an emerging threat situation.

Critical Infrastructure Protection

The first use-case considered for the foundation of the KENNEL project was security and awareness of critical infrastructure of flightlines (Figure 9). With sensors dispersed throughout a flightline, TDBs would provide perimeter intrusion detection from PIR, among other sensors, with advanced detection and validation leveraging cameras and computer vision AI (Figure 8). The models used could assist in classifying wildlife incursions, vehicles, or people with more advanced models identifying risk levels (e.g., hostile forces) or even authorized personnel as demonstrated in Figure 8. This was the primary use case at the onset, but the platform proved flexible enough to be able to expand into other sensor arrays (e.g., chemical, radiological, weather, seismic) for identifying accidental (e.g., fuel spills, fires), environmental (e.g., earthquake, excess rainfall), or kinetic (e.g., explosions, radiological); all increasing impact assessment accuracy and minimizing risk to personnel.

Figure 9: KENNEL TDB providing a variety of sensing at a critical infrastructure location.

Trackables, Wearables, and Ad Hoc Deployables (AHDs)

With the configurable nature of the TDBs allowing flexibility in the SWAP of the platform, a miniaturization effort is underway for a variety of the sensors that shows significant potential in what capabilities could be provided in a wearable form-factor (Figure 10). A current basic capability provides GPS/GNSS-based location awareness of first responders within ATAK at a reduced cost (e.g., reduced data costs compared to LTE cellular reach-back) and longer range than many current systems. There is additional potential in leveraging trilateration techniques for location estimation in areas where additional infrastructure can be set up, either permanently or ad hoc. These location techniques best lend themselves to outdoor application, especially in the case of GPS/GNSS. However, in cases where indoor location is highly important and worth the cost of installing the necessary equipment in a critical infrastructure, then indoor location could be achieved using multiple, miniature gateways with either the trilateration techniques with LoRa or leveraging advancements in Bluetooth Low Energy (BLE) technology. Significant testing would need to be done but there is a hypothesis that a more ad hoc solution could also be attainable through mounting of miniature TDBs with proper configuration.

Figure 10: Mini-TDBs providing wearable and UAS ad hoc deployable sensors.

In addition to the tracking abilities of these miniature, wearable TDBs, miniature versions of chemical, biological, radiological, and visual sensors are also being developed for integration into the mini-TDB platform. This would not only provide a command center additional data on personnel status but could also provide awareness to field team members, via audible, visual, haptic, or ATAK-based altering when exposures occur. These don't just offer a wearable option but an ad-hoc deployable option for monitoring critical infrastructure, objects of interest, or narrow areas of interest. These also offer several deployment options, including magnetic mounting to door jams and cars or DropPuck from UASs enabling increased flexibility in detection and measurement of pathogens or hazardous gasses in indoor or outdoor spaces and at various heights since airborne hazards can concentrate at varying atmospheric levels.

Search and Rescue Operations

Through the LandSAR effort developed in collaboration between Joint Personnel Recovery Agency (JPRA), AFRL, Raytheon BBN Technologies, and tested with El Paso County Search and Rescue in Colorado, a search and rescue estimation plugin is available for the TAK Ecosystem. LandSAR provides suggested search areas (Figure 11) based on a variety of criteria Last Known Location to geographical terrain data and algorithms on physical/mental status of the lost person (Soule et al., 2020). The technology even considers if the search party is on foot or leveraging UAS platforms. KENNEL could provide additional search capabilities by extending the sensor arrays on the UAS platforms. Another potential usage would be through scattered deployment from such platforms in the highest probability areas with PIR or tampering acting as a digital flare from the lost parties.

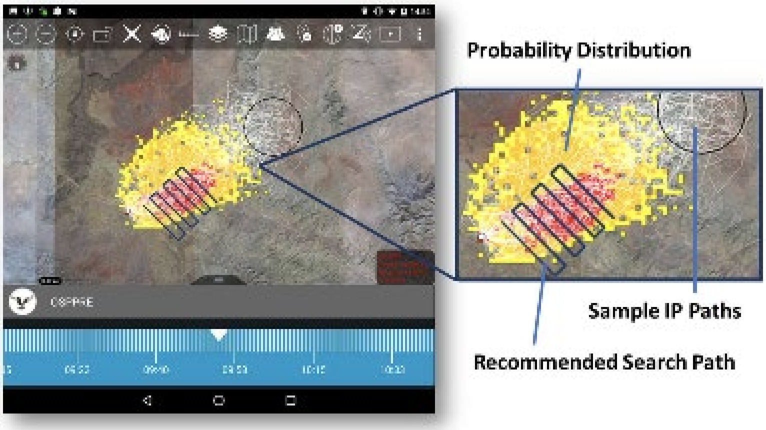

Figure 11: LandSAR Probability Distribution Visualization in ATAK that could be fused with TDB data.

Developmental Testing for System Telemetry and Self-Diagnostics

TDBs gather a wealth of information that affects situational awareness in great measure. Figure 12 shows day/night cycles, temperatures, battery voltage, and run time during a 48-hour deployment. It can be observed that there is a minimal battery discharge overnight. Furthermore, in the morning hours it takes about an hour of sunlight exposure to recover any lost charge overnight. TDBs employ a 5:1 charging ratio only needing a few hours to fully charge the onboard battery.

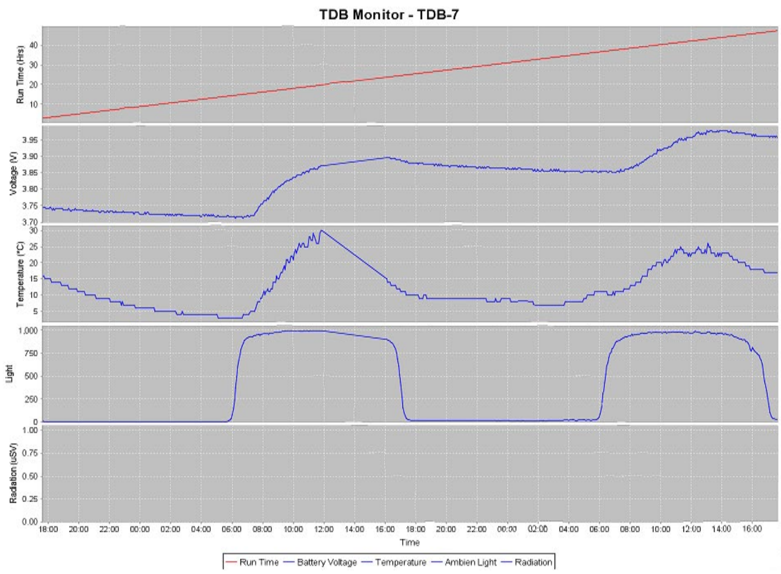

Figure 12: TDB 7 performance during day-night cycle.

Wrinkles on the graphed data (Figure 12) are indicative of external disturbances that contribute to improved situational awareness. For example, short-lived disturbances in the light measurements typically indicate people or vehicles passing near or loitering temporarily by the TDB. Longer disturbances correlate to slow moving clouds. Inverted disturbances (i.e., graph spikes during night time) indicate artificial lights approaching the TDB (e.g., flash lights and vehicle headlights). Figure 13 shows a 24-hour cycle for a TDB that has been running non-stop for 1,220 hours (51 days) while retaining an average battery of 97%.

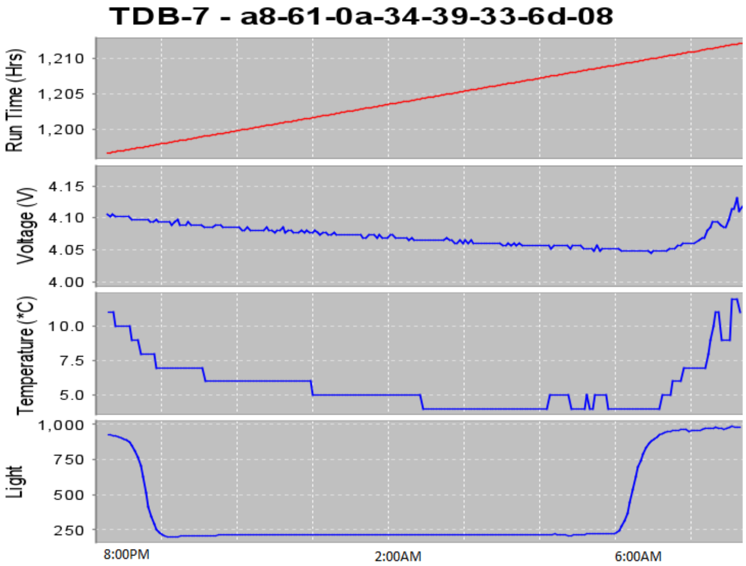

Figure 13: TDB 7 performance during 24 hour cycle.

Figures 14 and 15 show a TDB configured with custom radiation and chemical warfare (CW) sensors. These figures show what it looks like when a TDB is exposed to increased levels of radiation and CW agents. It should be noted that these two figures are indoor bench-tests for developmental purposes. However, they do show radiation spikes that are clearly observable indicating a high radiation dose passing by the TDB. CW alarms are indicated by a number other than 1 in the scale. In Figure 14, it is possible to see three instances of CW detections towards the end of the period (Detection value of 2 in the scale). These correspond to specific CW agents to which the TDB was exposed to during that period. Temperature values are constant and a square shaped light curve indicates the TDB is in an indoor environment with artificial lights being turned on and off. In Figure 15, the smaller smooth curve towards the end of the light measurements shows the sun light during sunrise penetrating the window into the room where the TDB is deployed (smooth curve). PIR motion alarms are indicated by vertical bars in the graphs, just like CW alarms. These show when motion was detected around the TDB.

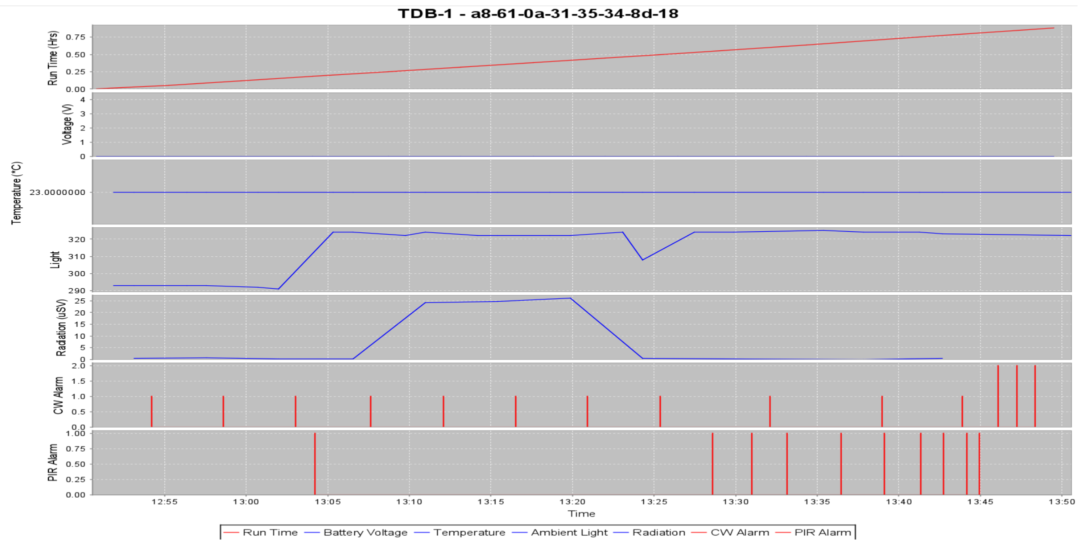

Figure 14: TDB 1 indoor radiological and chemical detections.

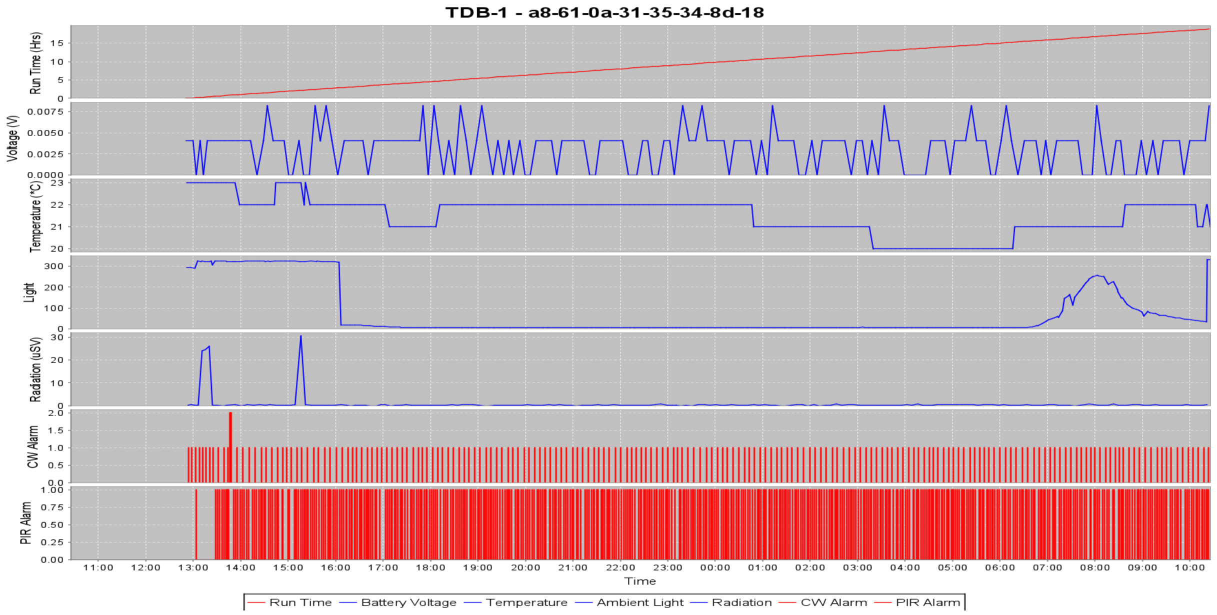

Figure 15: TDB 1 effect of sunlight on PIR sensor detections.

Operational Testing with Community Engagement for User Validation

Several testing and demonstration events have provided insight into the effectiveness and applicability of KENNEL. In Aug 2022, our team demonstrated KENNEL integrated with a UAS to expand operational deployment at White Sands Missile Range. KENNEL was used with TAK and a Group 1 UAS to inspect a TDB motion perimeter alarm (Figure 8). In this experiment the distance between TDB and gateway was 2.04 miles, which was not a maximum range, merely a constraint of the experimentation area. In Oct 2022, our team successfully deployed KENNEL prototypes (Figure 16) at USSOCOM's Dragon Spear CBRN Research, Development, and Acquisition Experiment (RDAX). Static TDBs monitored radiation and motion events during CBRN exercises, and UGV/vehicle-mounted TDBs provided radiation monitoring for first responders. Our efforts provided real time situational awareness via ATAK alarms. These alarms provided teams with improved situational awareness for faster decision making.

Figure 16: TDBs and mini-TDBs mounted to fences, doorways, and trees during operational exercises.

CONCLUSION

In conclusion, KENNEL prototypes have garnered positive feedback from military operators participating in joint CBRN exercises, which highlighted a similar need in the first responder community as a whole for improved situational awareness. KENNEL's highly extensible, modular sensing and data fusion capabilities make the system appropriate for a range of applications including critical infrastructure monitoring and improved personnel protection. Based on the support provided to date from the Air Force, the various organizations and agencies in the joint CBRN community, and a growing list of DoD, Federal, and First Responder agencies from local to state-wide organizations, we look forward to further broadening the applicability and readiness of this technology for deployment.

ACKNOWLEDGMENTS

Special thanks to Mr. Mark Disbrow (DTRA, contractor), Maj Alberto Rios (US Army), CWO Jerrett Davis (USSOCOM), and Mr. Alan Samuels (Army DEVCOM) for their support in testing, networking, and collaboration to further the research and development of KENNEL. We would like to recognize Andreas "AJ" Johansson (Corona Fire), Warren Demarast (JPRA), Ryan McLean (TAK Product Center), Kevin Brown (CMSgt USAF, retired) for their wisdom in applying this sensing platform to First Responder agencies at various levels. We would also like to thank Officer Robert Lindbloom, the Pensacola Police Department, and the City of Pensacola for supporting our research and developmental testing. Lastly, our sincerest gratitude to the first responders and their agencies that selflessly answer the call to protect our families and communities.

ACRONYMS

AFRL	Air Force Research Laboratory
AHD	Ad Hoc Deployable
AI	Artificial Intelligence
AoI	Area of Interest
AR/VR	Augmented Reality / Virtual Reality
ATAK	Android Team Awareness Kit
BLE	Bluetooth Low Energy
BLOS	Beyond Line of Sight
CBOA	Chemical and Biological Operational Analysis
CBRNE	Chemical, Biological, Radiological, Nuclear, Explosive
COP	Common Operational Picture
COTS	Commercial-off-the-Shelf
CR	Contingency Response
CW	Chemical Warfare
DoD	Department of Defense
DTRA	Defense Threat Reduction Agency
GNSS	Global Navigation Satellite System
GOTS	Government-off-the-Shelf
GPS	Global Positioning System
HAF	Headquarters Air Force
HPAC	Hazard Prediction and Assessment Capabilities
IHMC	Institute for Human and Machine Cognition
IoT	Internet of Things
JBER	Joint Base Elmendorf-Richardson
JB-CHS	Joint Base Charleston
JPRA	Joint Personnel Recovery Agency
LAN	Local Area Network
LoRa	Long Range
ML	Machine Learning
PIR	Passive Infrared
QR	Quick Response
RDAX	Research, Development, Acquisition Experiment
SWAP-C	Size, Weight, and Power, & Cost
TAK	Tactical Awareness Kit
TDB	Threat Detection Box
UAS	Unmanned Aerial System
UGS	Unattended Ground Sensor
UGV	Unmanned Ground Vehicle

USSOCOM United States Special Operations Command

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