Project Report
TIP-190

Remote Sensing Support for Urban Search and Rescue: FY23 Humanitarian Assistance and Disaster Relief Technical Investment Program

C.L. Council
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4 January 2024

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS

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EXECUTIVE SUMMARY

In this report, we have conducted an overview of remote sensing support to Urban Search and Rescue (USAR). To do this, we conducted a literature review to understand the state of the art in R&D as applied to this mission space. To further our understanding of the current operational needs and environment, we also conducted numerous qualitative research interviews with subject matter experts in both USAR and remote sensing.

We found surprisingly few publications specific to remote sensing applied to the USAR mission. However, from the literature related to wilderness search and rescue and disaster relief in general, we were able to glean insights into ongoing R&D efforts that could be applied to the USAR mission.

Our analysis combined the needs identified by interviewees and their expert opinions on previous success of remote sensing and technology in general with our own internal analysis and brainstorming. From these inputs, we outline specific USAR use cases where data derived from remote sensing could provide direct input to USAR decisions and actions. A survey of existing remote sensing resources available to USAR was cataloged, as were the challenges articulated by the interviewees with using those resources effectively.

To guide future research and development, we articulate a development road map that would result in technology providing better decision inputs to USAR mission decisions and actions. This roadmap describes efforts across several categories: foundational technology, fixed wing aircraft and sensors, artificial intelligence and computer vision, small uncrewed aircraft (sUAS), and and decision support software architectures.

We also propose solutions that are a mix of social contract and technology, as USAR could establish a partnership between the population, industry, and remote sensing providers to provide for direct localization and communication of survivors to the search and rescue team.

The prevailing challenges to remote sensing support of USAR reported by interviewees are timing of the remote sensing data, staffing that can support ingestion and analysis of remote sensing data, and policy related to acquiring, using, and distributing data acquired by remote sensing. As future development in this space progresses, we recommend it be done with these challenges in mind. Specifically, consider that a better sensor or algorithm is of no use if the output requires staff with atypical expertise and that output isn’t delivered in time to make a difference.

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1. METHODOLOGY

We explored the domain of remote sensing support for Urban Search and Rescue by performing a literate review, conducting qualitative interviews of subject matter experts in the field, and analyzing the results of each.

1.1 LITERATURE REVIEW

We reviewed a total of fifteen publications released between 2003 and 2022. As the topic is the application of a particular technology (remote sensing) to a very specific domain (urban search and rescue), the publications were focused on one or the other, with the specific article being the cross over between the two domains. While the focus of this research is on the application of remote sensing specifically to urban search and rescue, the relevant literature was sparse, so we expanded the search to search and rescue more broadly to include wilderness search and rescue as well.

1.1.1 How People Search

We first explore how people search for other people or objects at the most foundational level: human vision. According to research, human vision focuses on a point of interest in a scene and the eye rapidly moves to the next point in the scene, but how the brain controls where in the scene to look next is not yet well understood (McClanahan, 2021). Factors that contribute to where in a scene the eye looks include: regions that differ from others in some way, the context of the scene relative to the target of the search, and mental templates of the target being looked for.

McClanahan's research indicates that search targets that are unusual or rarely seen by the searchers are missed more often than targets that are more common. Providing training to people just before being tested for identifying objects reduces the missed object rate by nearly one-half.

When a group of searchers are looking for a specific person or object, they may conduct an exercise to determine how close they need to be in order to reliably identify the person or object. A group of searchers will circle the object to determine their optimal separation to increase the likelihood that the team will be able to pick out the object as the search an area. Referred to as the Northumberland Rain Dance, this technique was pioneered by Dave Perkins and Pete Roberts, of the Northumberland National Park Mountain Rescue Team in the UK.

As searchers traverse uneven terrain or in the case of urban search and rescue, rubble, their attention is split to tracking their foot placement as they walk (Hollands, 2001).

To summarize, searchers carry a mental template of what they are looking for, look for that person or object in places that they are likely to be, and do so by scanning the area as methodically as they can. As they move over rough terrain, the task of searching becomes more difficult as their attention is diverted to walking safely. Before departing on a search, it is helpful for searchers to have a fresh reminder of what they may be searching for.

1.1.2 Mimicking the Human Process with Small Uncrewed Aerial Systems

According to the literature, there is a lot of interest and progress in the application of small Uncrewed Aerial Systems (sUAS) to the search and rescue domain. In many ways, the application of sUAS is working to mimic or augment the general approach taken to search and rescue: by adding cameras and other sensors, the aerial platform is able to scan a much larger area more quickly than a person on foot, and capture that area with enough detail to discern objects within the collected data. The aerial augmentation enables searches over larger areas and areas that are more difficult to access (Bashyam, 2019).

Similar to human based search planning methods, algorithms are being developed to combine wilderness probability of detection maps with specific sUAS flight characteristics in order to develop optimized flight plans (Bashyam, 2019).

Also similar to human-based search and rescue, research has shown that multiple sUAS are required to effectively conduct SAR missions (Alhaqbani, 2021). However, unencumbered by terrain, aerial SAR opens up new opportunities in search patterns. For example, having a single sUAS with sensors to sample, followed by multiple sUAS can approximate fish schooling behavior and has resulted in higher mean rescue times.

1.1.3 Artificial Intelligence and Computer Vision

As artificial intelligence and computer vision progresses, it becomes more likely to automatically detect people in using various remote sensing techniques. In general, being able to reliably identify a person in an image taken from above, at a close range of 1.5 meters, and also detecting signs of life in that person, is well established (Zhang, Yang, & Shen, 2021). However, detecting a person when they are even partially obscured, or from further distances, remains an ongoing area of research to solve.

Combining multiple sensor types and correlating their observations can greatly increase the probability of detecting a person (Goian, 2019). An experiment conducted by (Goian, 2019) used computer vision with color imagery to understand the environment, thermal imagery to detect the presence of a person within that environment, and a third sensing modality such as radio frequency to detect a cell phone as a third indicator that the object of interest was a person.

Combining AI/computer vision detection algorithms to imagery collected by sUAS to facilitate a SAR operation has been proven to reduce search time in multiple cases (Gotovac, 2020).

AI and computer vision requires the processing of the data collected and computation to be performed against that data. In some concepts of operation, the imagery or data is collected during flight, offloaded to a computer, processed, and then evaluated by AI/computer vision. However, as on-board processing becomes more capable, moving the AI/computer vision part of the workflow to the edge, that is running on the sUAS or other platform directly, can increase the speed of detection up to 400% (Li, 2022).

On-board processing may currently be faster, but reduced computation due to compromises made to make processing portable can result in less accurate AI/computer vision results. A hybrid approach with some processing happening on the platform and some computation happening on a companion computer provides improved accuracy with increased speed (Juan Sandino, 2021).

A significant challenge for AI/computer vision development in the disaster or search and rescue context is the dearth of real training data. Policies and cultural sensitivity prevent the capture of training images of real victims of disaster, such as those partially trapped in rubble. Some work has been done on generating synthetic training data using images of subcomponents of people superimposed on rubble and blending the image (Ning Zhang, 2022).

1.1.4 Multiagent Systems and Human Machine Teaming

As with human based search and rescue requiring multiple searchers, there is research showing the need for multiagent systems, or multiple sUAS working together in cooperation to support search and rescue. The state of the art in multiagent systems for sUAS are not ready for deployment for SAR operations (Drew, 2021), but progress is being made toward improved coordination algorithms and platform functionality.

It is also clear that even with AI/computer vision, the remote sensing platforms must provide imagery to the search and rescue personnel for action. This describes a human–machine teaming operation, where the AI/computer vision systems on autonomous aircraft such as sUAS are working in collaboration with each other and with humans to accomplish their mission.

One example of successful human–machine teaming is described in (Tomasz Niedzielski, 2021). The paper describes a live rescue in Poland where a person was detected using the SARUAV software approximately 19 hours after the subject went missing, but only four hours after the software started being used. In all, 782 images were collected by sUAS over 90 hectares in 28 minutes. The software tagged 81 images for review by analysts, resulting in one true positive confirmation of a person in the field.

Such frameworks for leveraging sUAS for search and rescue as well as other emergency management and public safety have been established by public safety organizations such as the Tennessee Department of Transportation (Shuai Li, 2022).

1.1.5 General Remote Sensing and Robotic Considerations

As the literature is trending toward leveraging autonomous vehicles such as sUAS, there are some considerations for their application to search and rescue or urban search and rescue in disaster response. The systems being used must be designed to withstand the harsh environments and the information being provided should be delivered in a way that takes into account sleep deprivation and cognitive deficit of disaster responders (Casper, 2003).

1.2 QUALITATIVE INTERVIEWS

This report has been informed through the process of conducting dozens of informal consultations, which combined with technology and literature review to lay the foundation for approximately 12 formal research interviews, 60-90 minutes each, conducted in the spring of 2023 with USAR stakeholders. Interviewees were selected based on their experience employing, analyzing, or acquiring remote sensing technologies, their data, or the effects they produce for the purposes of urban search and rescue, disaster relief, and emergency response decision-making. The qualitative interviews employed a snowball technique combined with a structured interview instrument (see Appendix A: Interview Tool). Interviewees represented multiple federal, state, and local affiliations and organizations. In many cases, interviewees had direct knowledge of USAR or EM policy and practice within multiple levels of domestic or international responses.

The selected interviewees represent a meaningful cross-section of USAR and can provide insight into the current uses of remote sensing to support their operations, and the anticipated progression of remote sensing being used more in future operations. Each interviewee held multiple roles within the USAR community as well as a role in industry, public safety, or emergency management. Interviewees were selected from both the FEMA National US&R Response System, and from State Urban Search and Rescue (SUSAR).

All interviewees were consumers or producers of satellite, aircraft, and sUAS remote sensing data and derived products during real world disasters. Some have experience with generating and using 3D models from sUAS data. Each person had relevant experience ranging from four years to over 30 years in the USAR domain.

Roles inside of USAR included: various incident support team unit leaders and section chiefs, communications, technical information, planning team manager, structures specialist, rescue team manager, search team manager, program management, and GIS specialists.

Roles outside of USAR consisted of firefighting (including officers up to Battalion Chief for large urban fire departments), law enforcement, professional engineer (structural), state emergency management, federal government, Type 107 sUAS pilot, and Incident Management Team unit leaders and section chiefs.

Interviewees have real-world deployment experience to catastrophic incidents, including the World Trade Center collapse and the Pentagon in 2001, major hurricanes (Katrina, Sandy, Irma, Maria, Ian), the Oso, WA mudslide in 2014, major tornadoes such as Moore, OK in 2013, the Champlain Towers collapse in 2021, and the Turkey Earthquake of 2023.

2. REMOTE SENSING AS A SYSTEM

In discussing remote sensing and how it can be further developed to support USAR, we first define remote sensing. We consider remote sensing to be a system comprised of subcomponents that perform the following steps:

1. Gather sensor data at some location.
2. Process the data.
3. Transmit it to a distant location.
4. Generate a product, based on the sensor data, and provide it to a consumer.

We interpret "remote" in the context of two cases. In the first, the sensor is remote from the observed target or area of interest. In the other, the sensor is in or on the target and the consumer is remote with respect to the sensor. The overall organization of the remote sensing system is the same in both cases. Figure 1 illustrates the organization of the subcomponents in a generic remote sensing system.

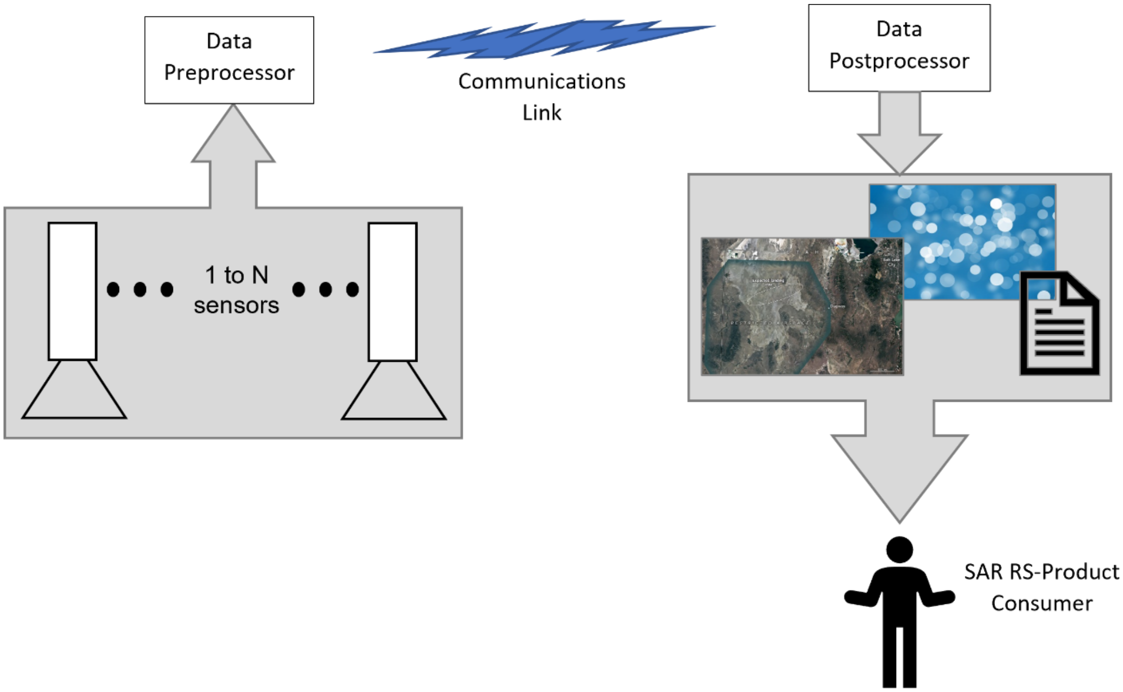

Figure 1. The remote sensing system.

2.1 SYSTEM SUBCOMPONENTS

For each of the subcomponents to remote sensing as a system, we present a key question that speaks to relevance and adaptability of that subcomponent to the USAR mission.

2.1.1 Sensor

The first sub-component consists of the sensor system and platform supporting it. The “sensing” section of a remote sensing system ranges from a single instrument containing millions of tiny sensors—e.g., a digital camera imager—to a collection of sensors that are located kilometers apart from each other—e.g., transducers deployed in an area to monitor seismic activity.

Key Question: *Do opportunities exist for the consumer to modify the characteristics of the sensor through a remote command interface in order to “tune” the system to improve the timeliness and quality of the data/product that will ultimately be delivered to the consumer?*

2.1.2 Platform

Various types of platforms include satellites, manned aircraft, UAVs, ground vehicles, watercraft, and the structures or objects that are being monitored or sensed. This last “platform”, for example, could be a building or a road upon which a seismic sensor or water-level sensor is emplaced.

Key Question: *Do opportunities exist for the consumer to modify the characteristics of the platform through a remote command interface in order to “tune” the system to improve the timeliness and quality of the data/product that will ultimately be delivered to the consumer? This question is probably most relevant for sensor/platform combinations that are controlled at the tactical level. This would include sensors that are mounted on unmanned vehicles that are under the direct control of the USAR team. For example, the USAR team could directly control the flight path and the image collection of an unmanned vehicle in real time.*

2.1.3 Data Preprocessor

The “data preprocessor” takes the sensor raw output and prepares it for delivery across the communications link. The preprocessor system design varies to support a number of different types of sensors—e.g., cameras, radar, and emplaced sensors—and communication links—e.g., satellite, LoRa, and WiFi. At one extreme, the system can be a simple modulator to transmit raw sensor data across a wide bandwidth communications link. At the other extreme, the sensor data must first be processed and essential information extracted to prepare the data for transmission across a bandwidth limited channel.

Not only does the data preprocessor prepare the data for transmission across the channel at a physical signal level, the preprocessor may be able to process the raw sensor data to perform analysis on the sensor data before it is prepared for transmission. As a result, only the minimum data needed by the consumer from this sensor system will be sent.

Key Question: *Do opportunities exist for the consumer to modify the characteristics of the preprocessor, i.e., the software that processes the raw sensor output in preparation for transmission across the communications channel? Can this be done in real time through a command interface or through some type of application programming interface (API) that is available to the SAR component receiving the data product? Again, such a capability would allow the SAR team to "tune" the system to improve the timeliness and quality of the data/product they will receive.*

2.1.4 Communications Link

The "communications link" encompasses how the data is actually transmitted from the output of the preprocessor subcomponent to the postprocessor sub-component. Characteristics of the link include the following:

- Analog or digital channel
- Required antenna systems
- Power requirements
- Channel bandwidth
- Security of data transmitted across the channel
- Is the channel shared among data producers and consumers?

Key Question: *Do opportunities exist for the consumer to "tune" or modify the characteristics of the communications link to improve the timeliness and quality of the data/product that will ultimately be delivered to the consumer?*

2.1.5 Data Postprocessor

The "data postprocessor" formats data into the final data product for the consumer. Typically, but not necessarily, this product takes the form of some geo-referenced image. At this stage, image processing techniques or other processing methods such as machine learning may be applied to the data as it is received from the communications link. This is done to enhance or identify data that will be of particular importance to the SAR element receiving the data product.

Key Question: *Do opportunities exist for the consumer to modify the characteristics of the postprocessor, i.e., the software that processes the output from the communications channel in preparation for producing the remote sensing product? Can this be done in real time through a command interface or through some type of application programming interface (API) that is available to the SAR component receiving the data product? Again, such a capability would allow the SAR team to modify or "tune" the system to improve the timeliness and quality of the data/product they will receive.*

In summary, it is important to note that all five **Key Questions** focus on improving the overall capability of the remote sensing system to obtain the appropriate data, process it as needed, and deliver it in a timely and succinct manner to the ultimate consumer—in this case, the SAR team.

When considered as a whole, the five questions address the larger question of “how can subcomponents of the overall system be modified, in a synergistic way, to improve, if possible, the timeliness and content of the products delivered? One approach is to implement the Use Case method. Application of this method can help to improve existing remote sensing systems for SAR use.

The Use Case method uses actors and their interactions with each other to model a system or operation. Actors can range from actual people to abstract concepts such as a data product or a software process. The interactions are typically signals or data that flows between the actors. Use cases enable modeling how the remote sensing system is planned to be used in a particular scenario by the SAR element.

In modeling the remote sensing system, the subcomponents, to include the consumers, are considered actors. The information, products, or signals that are passed between the subcomponents are the interactions between the actors. The design of each use case is heavily dependent on the remote sensing system from which the information or geospatial product will be generated, the SAR element product consumer, and the scenario and desired product. As a result, SAR teams can use the Use Case method to plan for how they intend to use specific products from specific remote sensing systems or request modification of the data and information flow through a remote sensing system for a particular class of event, e.g., a wildfire or flood, before the event happens. This process can be started based on the reviews of previous events, the SAR response, and the products generated by the system. TTXs can also be a source of similar information. This information combined with the Use Case method can help to identify where changes to subcomponents could be made to fine-tune the type of products for SAR team use and the process to generate these products.

Questions that help specify a remote sensing system appropriate particular SAR use-cases.

- What type of information or data is valuable in a given search scenario? For example, would the sensors and the associated products that are useful in a flood be the same or useful for a wildfire or extreme dry-land seismic event?

- Currently what type of sensors are available that can detect the desired data?

- At what frequency can the desired format of that data be delivered? For example, if a sensor can update its output at a certain rate at a certain number of megabits per second, can the underlying communications channel support this delivery rate? If not, can the data be averaged over time and a reduced-sized data package be transmitted to the consumer?

- Can the priority intelligence/information requirements/requests (PIR) be fed or uploaded into the data preprocessor for a particular sensor or groups of sensors so that the output of the sensor is matched to the type of information needed, the frequency of delivery or need, and the bandwidth of the combined communication and data postprocessor?

- How can the current system be used or modified to improve integration of RS capabilities into USAR planning and operations?

Consider a remote sensing system that has blocks that have parameters for processing the data that passes through them. These parameters may be set depending on the consumer, the sensor, and the desired data type, frequency, and format.

Reconfigurable remote sensing chains would be reconfigurable depending on the event and desired data type and tempo. These could be reconfigured in real-time and as needed. The Remote Sensing Chain becomes a “System-as-a-Service.”

How about a graded response to needs, available technology, fieldable capability, and development funding? As any one of these changes, its effect is fed back into modification of the appropriate remote sensing system.

2.2 NEEDS

These have been gleaned from the literature review and SME interviews**.**

- Onboard image processing
- Equipment field hardening
- Collection and distribution activity needs to match requirements at the tactical level
- Human computer interfaces (HCIs) must match varying mental status
- Algorithmic development to match available RS data and products to the needs at the tactical level
- Software that could control or direct various type of processing and product generation and also controls or guides the area and type of search such as UAV flight planning software
- The use of the technology must be easily integrated into the training and use in order to be effective and used by SAR
- The system should be designed to synergistically combine disparate sensor data or products
- If multiple sensing platforms, e.g., UAVs, are used, they should be operated and their products used in a cohesive manner to maximize data gained and area covered while minimizing control effort and redundancy

- Integrate the use of ML
- Use of a modular model of a remote sensing system to enable exercising, when possible, command and control of sensors and their associated platforms; injection of artificial scenes; implementation of various algorithms or approaches for data pre- and postprocessing with respect to the communications link; model the effect of changes to the communications link in terms of quality and bandwidth that can be supported; and the generation of various information products

The above list of needs could be used as “guiding principles” or desired characteristics to generate requirements in specific use cases that modify or “tune” the combination of sensor, platform, preprocessor functionality, communications channel, and postprocessor functionality in such a way as to support a set of identified needs for a specific scenario or deployment.

In this section, we have defined the remote sensing system and described the subcomponents of that system. We have also posed some key questions that, when considered collectively, suggest a path forward for modifying a generic sensor system to address many of the needs listed above. Additionally, consideration of the remote sensing system in the context of use cases enables the reader to consider potential modifications of each of the subcomponents in order to generate a specific SAR-consumed product that will meet operational needs and timeliness.

The modular nature of the remote sensing system enables testing, when possible, command and control of sensors and their associated platforms; injection of artificial scenes; implementation of various algorithms or approaches for data preprocessing and data postprocessing with respect to the communications link; model the effect of changes to the communications link in terms of quality and bandwidth that can be supported; and the generation of various information products.

Our definition of the remote sensing system facilitates simulation and experimentation with various software to control each sub-component.

3. USAR AND REMOTE SENSING

The USAR community represent a highly skilled group of professionals who are required to operate from the low tactical to the high operational level of domestic and international response activities. They are often required to “dual hat” in multiple professional roles to maintain active involvement in USAR teams. They are also required to maintain an extremely high threshold of annual professional education, testing and qualification in order to reach and secure their status on a small number of highly specialized teams. Many USAR professionals remain active leaders in interconnected local, state, or regional emergency management and response communities for the majority of their professional careers.

The time and training commitments associated with this profession, along with the top-down bureaucratic nature of emergency response institutions, leaves limited opportunities to explore or develop new capabilities they may need for improved responses. The legal and technical acumen, as well as the monetary demands required to actively pursue innovative solutions in this space, clearly introduce significant barriers to ground-level innovation. However, even with these significant challenges in place, interviews and informal consultations show a significant desire and ability to advance the USAR field from the practitioner level up.

As a professional group, the USAR and Emergency Management community writ large are highly networked and uniquely informed about their industry, their organizational architecture, and those factors that affect their success in the field. Interviewees all showed an acute understanding of the political, legal, and process-based challenges to those advancements they felt were either possible or necessary. They all exhibited a strong sense of both mission and responsibility to tangibly improve their policies, practices, and technologies. While some may have been less optimistic about the chances for particular advancements at the institutional level, there was a general consensus that they must maintain efforts to introduce new solutions regardless of the likelihood of success.

As an industry, the high level of connectivity between teams, training, and ubiquitous involvement in the after-action framework allows for the rapid diffusion of information—from anecdotal lessons shared following a response, to the dominant community assessment of a new tool or technical approach. While many highly skilled communities of practice have innovators who can drive advancements in their respective fields, few professional communities are interconnected and organizationally flat enough for the majority of practitioners to be as directly connected to those innovators in their field on a personal level. A notable aspect of both the interview and informal consultation process in this study was the level of direct personal and professional connection between interviewees as well as other named experts raised in discussions. This enabled interviewees to speak knowledgably and confidently about other members of their community who were actively pursuing different technical solutions both within and outside of their formal professional roles with a strong degree of interpersonal and professional trust.

The net result of these, and other factors, is a professional community uniquely ready to rapidly pilot, evaluate, improve, and adopt new technologies to support their operations. In the interviews conducted, there was a significant thread of measured optimism associated with the necessity to make positive industry-wide technical improvements to meet what were largely characterized as looming and to-date-unprecedented domestic disasters. With an informed and explicit understanding of both the fallibility and demands on practitioners—and those who support them—the adaptability of this community to explore and embrace change was strongly held as unquestionable.

Interviewees had a variety of opinions concerning the efficacy of larger institutions to provide the types of innovation and adoption pathways they might need to reach their goals. Clear frustration was exhibited by some at the USAR supporting institution's inability to drive rapid innovation and improvement in key areas. These frustrations were most often legal-, priority-, and process-related and without clear solutions. For these reasons, top-down innovation advancement was generally dismissed as less viable than outside or bottom-up diffusion of better technology and practice. The general consensus seemed to be that if a practitioner or outside innovator could make a novel solution work in one context, the community and leadership would inevitably be forced to find a way to overcome current barriers to scale that solution. For example, if privacy issues were the major barrier to large scale implementation of a remote sensing solution, successful use and adoption in one major city would quickly result in national access to the same capability. Thus, the major challenge is producing the first reliable test case that finds a means to circumvent a historic barrier and proves its intrinsic value. Once the test case is presented to the community and translated to different contexts, grassroots and top-down adoption becomes more viable, if not inevitable.

This raises an associated challenge for innovation within USAR, the absence of a consistent testing grounds for new technologies outside of the disaster response cycle. While extenuating response circumstances may necessitate the use of new technologies to address the specific factors of the emergency, it makes an extremely risky setting to try new and untested approaches. This is well understood by the community and yet the key examples of why different solutions are adopted are often variations on that exact scenario. This led multiple interviewees to remark that their community isn’t the best consumer of technology because they focus on the requirements to conform to historically proven patterns of action over the less tangible potential of new approaches. This trend is compounded by the fact that the best judge of the technology’s effectiveness is the practitioner in the field, a role that has the least time or resources for deviation from protocol or superfluous activity. Thus, practitioners are the most essential consumer and evaluator of viable new technology solutions and yet they are perpetually constrained in this particular capacity. The result is often an episodic response-driven innovation pathway that requires a specific shared incident or achievement to catalyze community and stakeholder demand for capabilities that already exist, but have not been formally incorporated into their tools or operations.

This aligned with a preponderance of references to a surprisingly small number of recent response examples and the role of technologies introduced during those events. While this tendency was named by some interviewees as a consistent bias toward the most recent response, it did reveal a significant gap in the range of examples most interviewees used to detail areas for improvement or novel uses of relevant technologies. The lessons from the “Surfside building collapse” and recent earthquakes in Turkey may have disproportionally tightened the aperture by which interviewees examined advancing potential requirements and capabilities within their respective roles. This is not to say that the findings from these responses aren’t extremely relevant, but rather to note that there was a significant trend toward “group think” regarding both the subject matter and lessons shared with researchers.

A valuable mitigating factor to potential group-think perception forming related to the USAR technology solution space may be found in the notable tendency of interviewees to characterize the negative sides of technology adoption in tandem with the aspirational. The USAR community is intimately aware of those behavioral and technical patterns that result in errors or sub-optimal mission execution and raise them regularly when discussing the utility of any given technology. One could characterize the interviewees as predominantly self-described “early adopters,” however, they all expressed an equally adversarial relationship with technology use in practice. For example, while a cell phone locating technology may be lauded as a “game changer” for the USAR community, the same interviewees may note that it has the potential to help “make more bad decisions faster” or will become “a data source that fails to translate itself into any meaningful operational decision-making". While these sentiments may seem contradictory, they are actually part of a consistent trend within the community to recognize historic patterns of failure as risks to mission that require mitigation. Hence, the relationship with technology is viewed through the same lens as any other USAR operational reality: there is a window of opportunity and an established method by which action should be taken, and there are myriad factors that will shrink that window or pervert a response action’s intended effect. The role of the seasoned practitioner is to maximize the window of opportunity while actively identifying and mitigating risk. Multiple interviewees were quoted as offering the sentiment of “if it’s another tool in our bag—that is important and of real value, but if it stretches beyond that, it’s fraught with real risk.” In other words, technology advancement and adoption are the means by which they can more effectively do their job, but they will never be beholden to it and it is never an end within itself. This utilitarian framework of thinking gives the USAR community a clear advantage as it positions them as “technology realists” who absolutely understand the need to expand their own capabilities, but by the nature of their work, have little appetite for the risk associated with arguments advancing either technology luddite or evangelist extremes.

The following quotes are representative of content provided during interviews:

- “We’re missing opportunities to help survivors.”
- “Imagery and pixels are cool to look at, but what we need is to know where the damage is.”
- “If we had this imagery 2 days earlier, it would have been a real game changer.”
- “Persistent monitoring would save lives.”
- “In a response perspective, if you don’t have people, it’s not going to work. We have to support technology with people or it’s not going to happen.”

- "Any info we can glean in the before- and after-disaster assessment is valuable. It's all about explaining the before- and after-event to understand the scope. We have to understand the scope, scale, and gravity of events and we're always 24-48 hours behind on that. All the muscle memory can kick in if you better understand the scope and scale quicker."

The following sections summarize answers to the interview tool.

3.1 PAST SUCCEESSES IN REMOTE SENSING

Interviewees gave several examples where remote sensing was seen as successfully contributing to the USAR mission. Notable examples are listed here.

During a training exercise that included assessment of survivor needs in hard-to-reach neighborhoods, specifically survivors on rooftops of flooded homes, the interviewee described using sUAS to remotely assess the situation and needs before making the effort to enter the flooded neighborhood.

A similar use case was described for the application of sUAS during the response to Hurricane Ian, where sUAS were used to visually triage water craft that were entangled in mangroves. By determining which craft may have been inhabited pre-storm, the teams were able to reduce the total number of hard-to-get-to boats to inspect in person.

During the response to the Champlain Tower collapse in Surfside, FL, sUAS were used to create periodic photomosaics of the collapse site. This effort proved extremely helpful in tracking the progress, mapping the site, and being able to conduct volumetric estimates used to support the logistics of debris removal.

At the same incident, a different sort of remote sensing was used: Total Station survey equipment monitored the remaining building parts to detect any movement or sign of secondary collapse.

In several hurricane responses, overhead imagery was cited as being useful in identifying structures that have moved location due to storm surge.

During several tornado responses, using imagery to define the swath of damage has enabled subsequent analysis. These analyses include incorporating other data sets like building footprints, infrastructure details, and demographic data, to enable search prioritization and track progress.

During the recovery efforts after the mudslide in Oso, WA, remote sensing was used extensively. Specifically, lidar collected of the area generated an elevation product, which could be combined with pre-event data to determine mud flow depths across the valley. This supported general situational awareness and also estimates for work required to excavate areas. The information was also used to determine the survivability of areas, and predict movement of structures.

On at least one occasion, sUAS orthomosaic imagery of hard-to-reach areas, such as populated islands offshore, has been used as input into the search planning cycle and guided more efficient resource allocation than would have been possible in the absence of the imagery.

3.2 NEW TECHNOLOGY SUCCESSES

Near unanimous sentiment across interviewees was that the most recent and striking example of new technology success is the implementation of SARCOP, a collection of field data collection applications and centralized repository of the collected data used as a Common Operating Picture for combining federal, state, and local USAR activity.

Two specific aspects of this tool repeatedly cited as helpful were the ability to track team members in the field and the ability to digitally mark houses as searched instead of using paint or stickers on the outside. This digital marking has the side effect of protecting property from looters.

The SARCOP tool evolved out of multiple efforts and is indicative of how USAR adopts major technology changes: a GPS-receiver-based federal system named "Iron Sights," which established the data to be collected in the field and the standardized symbols to represent that data, and a state program that leveraged these standards using a smartphone platform. Time elapsed from initial introduction of GPS receivers to the current SARCOP system was approximately 20 years.

3.3 NECESSARY TECHNOLOGY

When asked about technology that has become necessary to do their job effectively, respondents cited several things:

1. Field data collection such as Iron Sights and SARCOP, as it allows for tracking search progression, can impact demobilization planning, and informs the financial aspect of the response.

2. Location information such as a GPS receiver.

3. Internet connected portable smart device such as cell phone or tablet.

4. Cellular communications with data support. When infrastructure is damaged, systems such as FirstNet can be brought in to provide this capability.

5. Satellite based internet—particularly for situations where cellular data does not exist. Various providers were cited, with the most recent being Starlink, which was deemed as performing well so far.

6. ESRI ArcPro or a similar tool that enables geospatial analysis.

A challenge cited by several interviewees was the need to revert to paper when the technology fails. As the systems and processes become more reliant on technology, reproducing those processes manually can be difficult if not impossible under operational constraints.

3.4 PERCEIVED CAPABILITY GAPS AND USE CASES FOR REMOTE SENSING

The interviewees were able to articulate several USAR capability gaps and use cases that could be filled to some extent by applying remote sensing. The use cases and capability gaps have been consolidated into Sections 6, 7, and 8 of this report.

3.5 IMPLEMENTATION CHALLENGES FOR REMOTE SENSING SUPPORT

The following challenges were cited as the greatest barriers to supporting USAR through the application of remote sensing:

1. Finance and budget: Satellite and aerial data is costly, algorithm development is time consuming and costly, federal programs require that sUAS platforms be the much more expensive "Blue UAS".

2. Speed of adoption: Adopting new technology in USAR can be slow, given the high level of scrutiny. The pace of technology evolution is much faster and can result in obsolete systems being adopted due to the time required to go through the adoption process.

3. The gap between training and implementation: USAR members train periodically, but skills such as imagery analysis or sUAS piloting can atrophy, making field application of these skills less fluid.

4. Staffing: Any system requires the right quantity of people who have the aptitude and skill to leverage remote sensing data or platforms.

5. Leadership reluctance: In some cases, local or agency leadership has been perceived as being reluctant to adopt remote sensing technology.

6. Policies: Required changes to agency policies are time consuming and are sometimes hindered by leadership reluctance.

7. Technology resilience in the USAR environment: All hardware and software must be capable of performing under extreme conditions.

8. Trust: Decision inputs must be proven to be accurate before they are relied upon.

9. Information overload: Any decision input provided needs to be relevant and easily digested by responders, without significantly increasing cognitive load.

3.6 CONFIDENCE IN ADOPTION

When asked about their confidence in the USAR system adopting remote sensing as a viable input to operations, the interviewees were generally very optimistic. The implementation challenges were cited as the greatest barriers, but there was an articulated belief that the benefits of remote sensing support of USAR would be worth the effort required to overcome the challenges. There was a tension identified within the USAR community, between remote sensing proponents, and those in the community who are more interested in continuing operations the way they have been done in the past.

4. OPERATIONAL TIMELINES

Disaster operations typically operate in 12-hour cycles with major milestones marked at the 24-, 36-, 48-, and 72-hour marks. For example, the response phase is considered to be the first 72 hours where efforts are really focused on understanding the extent of the situation, stabilizing the impacted community, and starting the recovery. This time range can be shorter for smaller scale incidents, and longer for larger scale incidents.

In this context, the operational tempo of every 12 hours for coordination calls and meetings to facilitate resource requests and allocations, including remote sensing tasking and dissemination information, makes sense. However, the USAR mission is much more dynamic and immediate. USAR teams often fall into 12-hour operational cycles, but the desire for information to plan ongoing operations never ceases.

In some cases, the decision inputs that remote sensing could provide are only relevant if they can be provided within the first 24 hours after an event, with updates every 12 hours or faster—timed to coincide with USAR planning cycles. Even more granular, there are some decision inputs that would require real-time or near real-time remote sensing products.

For each of the use cases described in this report, a general idea of the timelines required for the information to be useful is provided. In some cases, information received later may still be useful.

It is important to note that the urgency of the USAR mission typically dictates that teams will not wait for complete information, but rather will immediately proceed as best they can with what information they have.

5. WIDE-AREA SEARCH USE CASES

In this section, we describe the specific use cases for remote sensing supporting the USAR mission in the context of a wide-area search. A wide-area search is defined as searching for an unknown number of people in an undefined area. Wide-area search typically occurs in response to hurricanes, tornadoes, floods, and wildfires. In Table 1**,** we list the information that remote sensing and supporting analytics could provide to enable or inform a particular decision and action, along with the ideal most useful timeline for that information to be delivered.

Table 1

Wide-Area Search Use Cases for Remote Sensing Support

Information	Decision/Action	Most Useful Timeline
Boundary of impact area (AOI)	Constrain search area	First 24 hours
Evacuation zones that were not fully evacuated	Prioritize search locations	First 24 hours
Location of survivors	Immediately rescue them	First 24 hours
Locate all structures within AOI	Quantify and plan search effort	First 24 hours
Clusters of damaged structures	Resource allocation	First 24 hours
Transportation network status	Ingress, egress, local navigation	From pre-event to first 24 hours
Road and bridge damage	Navigation by class of vehicle	First 24 hours
Hard/flat surfaces connected to transportation network	Staging and base of operations (BoO) placement options	From pre-event to first 24 hours
Navigability of damage areas that are geographically irregular	Develop search plans for areas difficult to search systematically	From pre-event to first 24 hours
Critical infrastructure damage	Focus efforts away from intact infrastructure	First 24-72 hours
Remote inspection of difficult-to-access structures	Signs to warrant further search	Real time

Remote, interactive survivor assessments	Further search or assistance requirements	Real time
Blue force tracking	Accountability and progress of USAR personnel	Real time
Debris outside of settled area	Additional areas to search for human remains	First 96 hours
Neighborhood scale aid assessment	Deliver or communicate need for specific aid for neighborhoods	First 24-72 hours

The subsequent subsections describe each of these use cases and requirements in more detail.

5.1 BOUNDARY OF IMPACT (AREA OF INTEREST)

For a wide-area search, it is critical to bound the damage area, determining the size, scope, and extent of the event. Doing so allows for the proper number of USAR resources to be applied and an exhaustive search can be conducted of all structures, cars, watercraft, or other places where people may be within that boundary.

Current Approach: An iterative approach to refining the boundaries of the disaster is often taken using a combination of efforts, depending on what is available for the particular disaster. Inputs to the AOI definition can include: tornado swath estimates, flood extent estimates, modeling outputs for impact areas, USAR staffed aerial flyover for direct observation, USAR observers traveling by ground vehicle, and ultimately observers on foot.

Each disaster type may have different indicators to describe the boundary of the area of impact. In some cases, such as hurricanes, the boundary may be defined by more than one type of damage: flooding in some areas and wind damage in others. Below, each category of impact describes the phenomenology to detect, and ways that remote sensing technology could detect them.

5.1.1 Water/Flooding Extents

One of the challenges with determining the extent of damage from a flood is that the floodwaters are in motion and the full extent of the flood may change geographically over time as waters recede in one location but flood in others.

To account for this, snapshots over time can observe the water itself, or the effects of water having been in a flooded location. Below are some observable indicators of floodwaters.

Observable Indicators/Phenomenology

- Water present where water has not been present in the past or is obviously not supposed to be present.
- Scoured terrain indicating flood waters that have since receded
- Structures moved by water
- Roadways washed away or undercut by water
- High water marks on buildings

Remote Sensing Based Detection Methods

- Unattended ground sensors (e.g., flood water sensor with beacon)
- Synthetic Aperture Radar
- Multispectral Imagery

5.1.2 Wind Damage Extent

Wind damage to structures or infrastructure can present itself in a few distinct ways:

- Debris distributed in a linear pattern such that the origin of the objects that became debris can be inferred.
- Circular patterns, particularly visible in vegetation surrounding structures or debris can indicate tornado impacts.
- Damage to rooftops: missing shingles, portions of a roof, or entire rooftops can be an indicator of wind damage.

5.1.3 Wildfire Damage Extent

Similar to flooding, wildfires present a temporal challenge where the mechanism of damage (fire) is in motion and may be captured by remote sensing at one point in time. The edge of a wildfire can be identified through several modalities (multispectral imagery, infrared) and is currently provided at coarse resolution via satellite systems such as MODIS (NASA, n.d.) and VIIRS (NASA, n.d.).

5.1.4 Landslide/Debris Flows

The edges of a landslide or debris flow can be observed visually as the newly revealed material will often be strikingly different from the area around it.

5.1.5 Tornado Swaths

The path of a tornado is often very easy to discern from above as there is often a well-defined path of wind damage to structures and vegetation, generally in a consistent direction. In past cases, video footage from news media overflying the area can be manually geo-registered to define the boundaries of damage. For tornadoes that have a longer path, in some cases a hundred miles or more, the boundaries can be seen in MSI imagery collected by satellite, or fixed wing aircraft.

5.2 LOCATE SURVIVORS DIRECTLY

It should be noted that much of the ongoing research and development regarding AI/ML exploitation of remote sensing to support disasters is focused on finding and categorizing damage. USAR teams are searching for people, and a common approach is to use information about damaged structures as a proxy for where people may be. There are examples in wilderness SAR where technology is being advanced toward the direct detection of people.

5.2.1 Multispectral Imagery (MSI)

Wilderness SAR efforts have shown that detecting people using multispectral (e.g., color) imagery is possible when the subject is not occluded. For some disaster scenarios where wide-area search is being conducted, MSI may be directly applicable.

5.2.2 MWIR Thermal

Midwave Infrared is effective at differentiating people from the surrounding environment. In a disaster scenario, this would be useful only for detecting people who are not obscured by buildings or other insulation. A sample use case would be people who have evacuated to the rooftop of their flooded homes.

Existing sensor and platform combinations in this category range in coverage rates from very small, as in sUAS, to city-scale systems such as a Wide-Area Motion Imager.

5.2.3 RF Scanning for Cellular Devices

The high prevalence of cellular phones warrants investigation into leveraging their persistent beacon as a means for locating people. There are several ways to approach this:

- An aerial platform that is able to scan for and localize cellular devices
- Access to cellular provider data that records device pings and locations

- A cooperative approach with cell phone manufacturers, where users can opt-in to enable an SOS type beacon. This technology is already being implemented, but has not been tested at scale. Aerial scans of an area could assist for areas that have lost cellular infrastructure.
- Rapid comparison of pre-disaster activity with post-disaster activity to identify hot spots where clusters of people may be located.

There is a limited window of time where such an approach is most helpful, as cell phones are battery powered and without external power, they will stop working.

5.2.4 Individualized Beacons

A cooperative approach could be taken with the populations that live in areas prone to disasters requiring a wide-area search. There exists a number of commercial products that can be used as a personal locator beacon for individuals. Typically marketed toward adventurers who may need rescue from remote locations, these devices are costly.

Aerial remote sensing assets such as Civil Air Patrol could be trained and equipped to look for and catalog beacons at scale as they fly over an area. Those beacon locations could be passed down to USAR teams and incorporated into search planning.

If such a searching asset were available, it would then be feasible to create a low-cost beacon that residents of disaster-prone areas can include as part of their emergency kits. Ideas for possible beacons fall into two categories:

1. Active: An electronic device that generates a signal. Advances in low-cost computing, energy efficiency, sensors, and long-range radio transmitted data make it possible to build a simple emergency beacon that transmits a location and other pertinent information far enough and frequently enough to be detected by an aircraft. This concept could be expanded to include communicating specific needs such as medical requirements.
2. Passive: A distinct marker that could be placed outside by a survivor to indicate their need for assistance. Countless photos of disasters show people having painted calls for help on rooftops or roadways. Formalizing a deployable signal that is made from a material that is highly likely to be detected by existing sensors (e.g., Glint Tape) provides a repeatable target for aerial remote sensing assets to locate and report. This concept could be expanded to include encoding additional information, such as medical needs, through material patterns in the deployable signal. An analogy would be a “Medic Alert” bracelet, but deployable by a survivor and detectable from the air.

5.3 LOCATE STRUCTURES WITHIN AOI

Understanding the number and layout of structures in the AOI informs search requirements and planning. External datasets such as building footprints can be leveraged, but they are not guaranteed to exist or be complete for all areas.

There are numerous R&D activities and consumer products related to creating building footprints, but the slow update cadence of the data does not guarantee accuracy at the time of a disaster. Being able to detect and geolocate structures within the AOI through remote sensing immediately post-disaster can incorporate high confidence building footprint data into the search planning cycle.

5.4 CLUSTERS OF DAMAGED STRUCTURES

As structures with damage are used as proxy for locating people in need, detecting, localizing, and characterizing the level of damaged to structures becomes a valuable input to search planning and periodization.

There is much work being done in the space of structure damage detection and classification. Referenced by interviewees, well known damage classifiers are developed against Defense Innovation Unit’s xView2 dataset (Defense Innovation Unit, n.d.).

Work has also been done by MIT Lincoln Laboratory with the National Institute of Standards and Technology to create a labeled training dataset of low-altitude imagery of disaster scenes taken by Civil Air Patrol. Work on building classifiers trained on this dataset is ongoing.

Future work could be explored using quad pole Synthetic Aperture Radar (25 cm) data, collected from space or aircraft.

5.5 TRANSPORTATION NETWORK STATUS

Using remote sensing to detect road damage at scale can then be used in conjunction with road network data to identify ingress and egress to the AOI, and locations within the AOI. Such information can also be used to identify isolated communities with limited or no access, requiring US&R support.

5.6 ROAD AND BRIDGE NAVIGABILITY

At the very-real-time tactical level is the need to verify certain roadways or bridges are navigable by a typical USAR convoy as they make their way into the AOI. Large, heavy vehicles such as full tractor trailers passing over a bridge that was recently subjected to floodwaters is a dangerous situation. Structural engineers embedded with USAR teams have the expertise to determine the safety of a bridge, but in some cases need access to the underside of the bridge to conduct the inspection. Extreme cases, where there may be significant question about the bridge’s safety and a lack of other options, may drive the USAR team to the time-consuming effort of establishing a rope system to lower an engineer below the bridge to visually inspect. Deployment of a sUAS with upward facing live feed camera can facilitate this task very quickly and introduces no risk to the participants.

5.7 STAGING AND BASE OF OPERATIONS LOCATIONS

A single USAR team travels with numerous trucks and establishes a Base of Operations requiring a ground footprint that is reasonably flat, and preferably a hard surface. Collocating and staging numerous USAR teams requires a much larger footprint. For large responses, staging and base of operations have been established at locations such as military bases, theme park parking lots, and stadiums. Combining the damage information from other remote sensing efforts with a focused analysis on areas that are large and open (like large parking lots) can assist in locating the Base of Operations as close to devastated area as possible.

5.8 IRREGULAR GEOGRAPHIC AREAS

Some disasters take place in locations that have varied terrain and irregular population distribution, making it difficult to apply the same systematic search planning that is used for urban and suburban geographies that are more geometric in nature.

An example of this would be the region of Hazard, Kentucky which was struck with catastrophic flooding in 2022. The terrain in and around the impacted area is very hilly with numerous rivers. Settlements tend to follow rivers and extend into hollows, resulting in a populated area that is irregularly shaped.

According to interviewees, a current overhead image during the flood response would have helped search planners to understand the unique distribution of structures, extent of flooding, and available pathways to communities given the terrain and rivers. This assistance would have aided in their creation of custom search plans.

5.9 INFRASTRUCTURE DAMAGE

Remote sensing assistance in determining infrastructure that is damaged is important. Cited as equally important was determining infrastructure that was intact and not damaged. USAR may be asked to conduct surveys of critical infrastructure in their AOI to determine their status. If remote sensing is able to make this determination, it offloads that work from the USAR teams, allowing them to focus resources wholly on life saving.

5.10 REMOTE INSPECTION OF DIFFICULT-TO-ACCESS LOCATIONS OR STRUCTURES

Several scenarios were described by interviewees that can be generalized as using sUAS to interactively inspect structures or locations that are difficult to access quickly, with the intent of determining if further assessment is required.

Some examples of this use case include: across rivers, roadway around the corner beyond flooded or blocked roads, and structures located beyond an obstacle such as a flooded or very long driveway.

Per interviewees, equipping each squad with a sUAS would enable real-time tactical observation, increasing movement speeds and reducing exposure to risk.

5.11 REMOTE, INTERACTIVE SURVIVOR ASSESSMENTS

A unique suggestion from more than one interviewee was the ability to use sUAS to conduct interactive, remote assessment of survivors. This would include sending live video to the sUAS operation and supporting bidirectional audio communication. In one described scenario, a flooded neighborhood had survivors on rooftops. The USAR team envisioned being able to fly a sUAS to the survivors to gather information about their specific situation and needs (e.g., medical, or mobility) in order to best prepare the boat rescue team before it entered the flooded neighborhood to perform the rescues.

5.12 DEBRIS FIELDS OUTSIDE OF SETTLED AREA

Much focus is placed on debris and damaged structures within a neighborhood or settled area. As such, debris fields that lie outside of the core populated area may be missed. Using remote sensing to locate debris piles like this is important because these are places where human remains have been found in the past, as victims have been carried along with the debris well outside of the populated area by impacts such as storm surge or other flooding.

6. STRUCTURAL COLLAPSE USE CASES

In this section, we describe the specific use cases for remote sensing supporting the USAR mission in the context of a structural collapse. When a building collapses, the materials can fall in such a way that survivable area is preserved. This area is called a “void space” by USAR practitioners. USAR teams are specially trained and equipped to search a collapsed building to find void spaces, search for people in those void spaces, perform medical treatment to stabilize survivors, and ultimately extract them from the rubble.

Disaster events where structural collapse is the primary response include earthquakes, man-made or accidental explosions, and other structural failures.

6.1 REMOTE SENSING GENERATED 3D MODEL OF STRUCTURE BEFORE AND AFTER

There are numerous uses for having a digital 3D model of the collapsed structure before and after collapse. Pre-collapse models can occasionally be obtained from urban planning authorities, or open-source.

Comparing the before and after 3D model would assist in estimating where occupied portions of the building are in the collapse, which can help pinpoint the potential locations of survivors or victims.

For extended operations that include delayering of the collapse and removal of the debris, using a routinely collected 3D model to estimate and track the debris volume informs logistics surrounding the debris removal.

6.2 REMOTE INSPECTION OF UPPER FLOORS

For partially collapsed structures with multiple stories, accessing the upper floors can be extremely dangerous and technically challenging. A sUAS with live video feed and articulated camera can be used to inspect the upper floors to determine:

1. Are victims or survivors present? If so, how urgently do they need to be accessed?
2. Go/no go decisions based on structural integrity
3. Structural reinforcement requirements
4. Additional sensors can be added to determine if the environment is hazardous

6.3 STRUCTURAL INSPECTION

Structural engineers can use sUAS to conduct a visual inspection of partially collapsed structures, looking at areas they cannot reach easily. Inspection targets include wall cracks, moisture in material, or other signs of secondary collapse.

There is interest in leveraging AI/ML on sUAS imagery to help identify wall cracks or other structural failures.

6.4 VOID SPACE LIKELYHOOD

A key part of structural collapse is identifying entryways into void spaces within the rubble. Remote sensing imagery collected of the collapse from above could be analyzed visually or paired with AI/ML to identify potential void space entries across the surface of the rubble pile. A reference map of void space entries would assist in search planning and tracking progress, a void space can be virtually marked as having been explored fully.

6.5 PATIENT ASSESSMENT IN VOID SPACES USING VERY SMALL UAS

A recent demonstration of a very small UAS named The Black Hornet (Verger, 2023) showed that aerial inspection of void spaces within a rubble pile was possible. The current technology supports visualizing the subterranean spaces with color imagery and thermal imaging sensing, capable of highlighting people. Some amount of patient assessment could also be conducted using the onboard sensors and photoplethysmography.

7. EARTHQUAKE USE CASES

Conceptually, the urban search and rescue response can be viewed as a combination of Wide-Area Search and structural collapse. This size and scope of the event is initially unknown, so methods like recon are required to understand the event, but instead of quickly moving from house to house, the USAR teams will work structural collapses that are spread out over the area.

7.1 SPECIFIC WIDE-AREA SEARCH USE CASES

Many of the use cases in the Wide-Area Search section would be applicable to an earthquake, but specific use cases cited by interviewees included:

1. Transportation network status
2. Staging/Base of Operations locations

7.2 WIDE-AREA STRUCTURAL TRIAGE

A major earthquake could result in a scenario where USAR teams are faced with a very difficult challenge: which collapsed structure to search first to give the most people the greatest chance of survival. In the recent (2022) earthquake in Turkey, reports on the quantity of structural collapses vary, but all estimated over 160,000 buildings collapsed, spread out over a large geographic area.

The U.S. Army Corps of Engineers has established a standard Structural Triage approach, which evaluates a building in terms of the likelihood of finding survivors and the difficulty and danger involved in rescuing those potential survivors.

Building a new algorithm or adapting existing AI/ML damage classification algorithms could potentially inform portions of the USACE structural triage rubric, providing the capability of triaging across thousands of structures to guide extremely limited USAR resources to greatest effectiveness.

8. CURRENT TECHNOLOGY SUMMARY

The following remote sensing related technologies were cited as having been used by urban search and rescue during responses.

1. Civil Air Patrol (CAP): CAP is very often tasked with collecting aerial photos over disaster prone areas. There are numerous CAP wings across the country and the can be mobilized very quickly if needed. They typically collect the following:
    a. Oblique images taken with handheld cameras. These images are high resolution and are embedded with the coordinates of the aircraft at the time the photo is taken. Interviewees report the following challenges:
        i. Timing: CAP is not always deployed and is not always tasked with capturing the same areas that USAR is concerned with, slowing the capture and delivery of images available for USAR.
        ii. Overwhelming quantity of images: By design, CAP takes a large number of oblique images to record the full extent of a disaster. However, this can make it difficult for a USAR team to sift through the photos to find just those depicting damage. In some cases, a disaster may result in tens of thousands of CAP oblique images.
        iii. Localization: The standard CAP oblique image is geotagged, but the location is that of the aircraft, making it a manual process to visualize that location on an imagery base map and then discern where on the ground the image footprint would align.
    b. Nadir Images take with action cameras: It is unclear if this is still a practice CAP engages in, but for a period of time, nadir imagery could be collected using downward facing action cameras (e.g., Garmin VIRB or similar). This approach had the benefit of being a low-cost way to get nadir imagery. Interviewees report the following challenges:
        i. Availability: The images are not always available
        ii. Fisheye: The images have a very wide-angle lens which distorts the outer edges of the image. If the flight pattern doesn’t provide enough overlap, it is possible that the features of interest to USAR are located in the distorted part of the image.
        iii. Resolution: If the images are collected from too high an altitude, the resulting images are not high enough resolution for analysts to identify damage of interest to USAR.
        iv. Overwhelming quantity of images: The nadir images present the same challenge as the Oblique image in that the sheer quantity of images is overwhelming to the end user.

    c. Waldo-Air Nadir imagery: A subset of CAP aircraft are outfitted with a sensor package from Waldo-Air, which provides high-quality georeferenced nadir images. The imagery can be stitched together to create a georeferenced orthomosiac of the area. If the CAP pilots fly in a particular path, the imagery can also be used to generate a 3D model of the area. Interviewees report the following challenges:
        i. Availability: Few aircraft are equipped with this sensor package, so they are not always available.
        ii. Timing: The time it takes to collect the imagery, process the orthomosiacs, and then make them available to USAR as a tile service that can be consumed in the field is long enough that the product has not become expected.
    d. CAP sUAS operators and aircraft: Civil Air Patrol maintains an extensive cadre of Type 107 certified sUAS pilots and a fleet of sUAS. They can be tasked to provide support to the USAR mission. Interviewees report the following challenges:
        i. The federal mission assignment process to activate and task CAP sUAS teams is not always in time-sync with the USAR mission, so teams are not in the field early enough into the operation.

2. National Geospatial Intelligence Agency (NGA): The NGA has been providing remote sensing support to the FEMA US&R mission for many years. As a federal entity supporting another federal entity, the relationship has a lot of value, and some interviewees spoke highly of the products and support they have received over the years. Specific remote sensing products provided by NGA have varied, but consist of satellite-based imagery, analysis of satellite and aerial imagery, and more recently, sUAS support. Interviewees report the following challenges:
    a. Availability: The NGA is not always tasked for every disaster. This makes it difficult for USAR to train their processes against decision inputs they can expect from NGA. Availability is uncertain for interviewees for disasters that do not include a federal declaration or FEMA US&R assets.
    b. Timing: There were challenges reported with the delivery of products being delayed due to information release processes internal to NGA.

3. National Guard Assets: Some interviewees described have a strong relationship with their state's National Guard, including remote sensing assets. This has included various imagery and analysis support. Interviewees report the following challenges:
    a. Availability: Not all states have the same remote sensing assets within their National Guard. This makes the availability of these assets uncertain, making it difficult to train USAR processes against decision inputs that they can expect from the National Guard in the state where the disaster is occurring.

4. National Oceanic and Atmospheric Administration (NOAA): NOAA provides orthomosiac imagery over disaster-impacted coastal regions. NOAA is able to collect this imagery under its own authority and funding. NOAA collects the imagery, processes it, and makes it available in relatively easily digestible formats very quickly. When available, the imagery can be added to the SARCOP as an optional basemap, giving USAR a valuable perspective when planning and executing searches. Interviewees report the following challenges:
    a. Availability: NOAA's response is typically limited to disasters that occur in coastal areas, making their availability limited for disasters that occur inland.
    b. Manual analysis: Finding damage or other features of interest to USAR in the imagery is a manual process, which consumes time and personnel.

5. Commercial vendors: Numerous commercial vendors have provided remote sensing support to USAR over the years. Typically, the state or FEMA will fund an aerial collection of a damaged area, and when the timing of that collection and delivery of imagery is fast enough, USAR has reported being able to incorporate it into their operations. Interviewees report the following challenges:
    a. Availability: Commercial vendors are not always engaged for a disaster, making it difficult to train USAR processes against these decision inputs.
    b. Manual analysis: Finding damage or other features of interest to USAR in the imagery provided by commercial vendors is a manual process, which consumes time and personnel.

6. FEMA HQ coordinated satellite imagery: For some disasters, FEMA is able to task commercial satellite vendors to collect imagery over the impacted area and then provide that imagery to the emergency management community supporting that disaster. Products provided include color imagery and analysis derived from synthetic aperture radar. Interviewees report the following challenges:
    a. Availability: Satellite imagery is only collected for the most significant events, making it unavailable for most responses.
    b. Timing: Satellite imagery is rarely acquired quickly enough to be useful to the USAR mission.
    c. Manual analysis: Finding damage or other features of interest to USAR in satellite imagery is a manual process, which consumes time and personnel.
    d. Data logistics: The imagery collected is often very large files that are difficult for USAR to consume in the field. Imagery is also often licensed and restricted by the commercial vendors, making it possible to share the imagery with FEMA US&R but not other USAR teams working the same incident.
    e. Data sources: Some commercial satellite providers will deliver a secondary analytical product (e.g., flood extent or depth grid derived from Synthetic Aperture Radar), without providing access to the original data. Interviewees indicated this reduces the confidence in the product because there aren't corroborating visuals.

These are the technologies most cited by interviewees. There are certainly more examples, but the consistent themes across existing technologies are:

1. Availability: If USAR is going to use a decision input, they need to develop workflows and train against those workflows. If the decision input isn’t always available, it is difficult to impossible to develop consistent workflows that can be executed under the challenging and austere USAR conditions.
2. Timing: The products are rarely available when they are most useful.
3. Overwhelming: The volume of data, manual exploitation methods, and lack of dedicated staff make it extremely difficult for USAR to use most of the remote sensing data.

9. TECHNOLOGY DEVELOPMENT ROADMAP

This section describes technology development paths that could facilitate better integration of remote sensing into the support of USAR. Each technology development path should be considered with two key factors in mind:

1. **Availability**: Putting a better sensor package onto a platform that isn't guaranteed to be available at the time USAR needs it won't help. Capabilities need to be consistently available so that USAR teams can develop workflows and training to ingest the decision support provided by the remote sensing capability.

2. **Staffing**: Numerous interviewees identified a lack of personnel in a USAR response available to support ingestion of remote sensing decision support inputs. The force structure of a USAR team is well defined and there is strong resistance to deviating from that force structure, making it difficult to add the personnel who have the aptitude and expertise to leverage remote sensing. Staffing recommendations, inspired in part by the activities already occurring within the USAR community:
    a. **Simplified products**: Tailor remote sensing–derived decision input deliverables to be as digestible and understandable as possible so that existing personnel are able to incorporate them into their existing workflows. This has the benefit of supporting USAR, but the detriment of adding additional duties to personnel who are already over taxed.
    b. **Mission Ready Package**: Expanding on the existing USAR concept of a small deployable group of personnel with a specific capability to augment a response that needs that type of resources. Current examples include water rescue teams and canine search teams. A remote sensing and GIS MRP could be established to provide the personnel needed without changing the USAR force structure. Examples of this general approach can be seen in the deployments by NGA and also the sUAS team deployed by Missouri Task Force One.

The remainder of this section focuses on the development of technology that can fill gaps documented in the literature review and illustrated through interviews.

1. **Foundational Requirements**:
    a. Formalize quantitative requirements for each use case. That is, for every use case determine what the remote sensing requirements are in terms of:
        i. Resolution/ground sample distance/pixels per meter.
        ii. Area coverage rates.
        iii. Acceptable AI/ML algorithm performance. Define how accurate is accurate enough for USAR use cases.

        iv. Standardized schemas for communicating observations described in the USAR use cases.
        v. Output product requirements: How the remote sensing data and derived decision support should be delivered: GeoTiff, vector tile service, shapefile, json, etc.

2. **Small Uncrewed Aerial Systems:** The USAR gravitation toward sUAS is clear as the technology provides full control over the tasking, collection, processing, exploitation, and dissemination workflow. The technology has proven useful in real-world events, and interviewees provided numerous use cases for their use. These recommendations are meant to support the gaps identified and set the foundation for a future where the sUAS tool is ubiquitious amongst USAR teams.
    a. Power efficiency: Enabling longer flight times.
    b. Manufacturing of the technology required for the "Blue UAS" accreditation needs to be more efficient and less expensive.
    c. Improved Edge computing for on-board processing and real-time AI/ML analysis. Improvements include:
        i. Smaller form factors
        ii. Greater computation
        iii. Lower power requirements
    d. Air-to-ground data communications bandwidth: Need to send more data, faster, and over greater distances, to support human/machine teaming.
    e. Bidirectional communication support: Two-way audio communications that is capable of being heard over the sound of the sUAS propellors, and microphone technology capable of discerning human speech in the same noisy environment. Such a system needs to be lightweight enough to fit within sUAS SWAP (size, weight, and power) constraints.
        i. Reducing the noise of the sUAS itself would also be useful in this context. Research has been conducted at MIT LL to develop a toroidal sUAS propellor to serve this purpose (MIT LL, 2022).
    f. Swarm technology: sUAS provide small area coverage rates, but several sUAS combined can provide a larger area coverage rate. The ability for sUAS to communicate with each other, and with the human teams on the ground, has the potential to provide remote sensing capabilities with a much larger combined coverage. As a result of this study, MIT LL has initiated research into what such a configuration would require in order to be competitive with fixed wing aircraft for area coverage rates.

3. **Fixed Wing Airborne Platform Augmentation**: Sensor packages and on-board processing could be developed to augment the existing fixed wing remote sensing assets. As previously stated, this does not address the availability issue if these assets are inconsistently available, but the overall delivery time of decision support products can be shortened.

    a. Augment CAP aircraft and operations operations to provide inputs to USAR use cases

4. **Dedicated USAR Remote Sensing Asset for Persistent Monitoring**: As mentioned earlier, interviews noted that having persistent monitoring from above available would “save lives.” One solution to consider would be to either build one or more systems from scratch or find a suitable existing partner that has a system that can be readily available nationwide. Based on interviewees and use case analysis, such an airborne platform would have:
    a. Multiple sensing modalities to support human observation, detection of people, differentiation of materials, and ability to generate a 3D model of the space. A suite of sensors that would meet these requirements would include:
        i. Multispectral Imagery
        ii. Infrared
        iii. Hyperspectral
        iv. Synthetic Aperture Radar
        v. Lidar
    b. Guarantee of availability for disasters
        i. Ownership, maintenance, and tasking authorities should allow for such asset(s) to be available for disasters that do not result in a federal declaration of FEMA Urban Search and Rescue.
    c. Availability for training to allow USAR components to develop workflows against the use of such support and train against the output.

5. **Satellite Imagery**: MIT LL has conducted research into how satellite-based systems could support USAR and emergency management writ large. This work is codified under the name “DisasterSat”, with publications forthcoming (DisasterSat, n.d.).

6. **Architecture Design**: Providing remote sensing–derived decision support tools in an easily digestible format under austere and communications deprived conditions presents unique challenges. A purposeful effort should be undertaken to design and develop an expandable and adaptable data and processing architecture that can reliably support this mission. Aspects of this architecture design should:
    a. Support the requirements described in the Foundational Requirements section.
    b. Enable the free flow of information across many tiers of government, private sector, NGOs, volunteers, and survivors. The security of such as system should allow for easy restriction of data if needed, with access granted to entities that need it with minimal to no human effort. The fundamental design should trend toward making all data and derived products freely available, with securing data as the exception.

7. Cooperative Developments with Industry and Society: As described in the Wide-Area Search Use cases, a number of ideas emerged through this project that could enable USAR teams to find people directly. A non-trivial challenge associated with these approaches is that they rely on a relationship where survivors trust USAR enough to share their personal data.

a. Engage with smartphone technology: Most people in the U.S. have a cellular connected smart device. These devices present a number of options for connecting USAR with survivors in a cooperative manner. There are two parts to this concept: the device communicating survivor location and needs, and USAR being able to receive that communication.
    i. Communicating location and/or needs:
        1. Service provider or manufacturer applications on the device, similar to the iOS "SOS" feature can broadcast the device location and basic information when triggered by a person, or in circumstances where the device has detected a significant event such as a car crash. This technology could be adapted to the disaster survivor context.
        2. Federal, state, local, or industry created application that the user installs on the device. This approach gives the user the ability to provide much more information (medical needs, pets, etc.) and be in control of what information is shared. If users register themselves and home location, and then during a disaster their device does not provide an update or status, that lack of update could itself be an indicator of being in need.
        3. Cellular "pings": cellular devices send periodic transmissions to cell towers. In the absence of a specific data product provided by an app on the phone, these regular interval transmissions serve as a beacon that can be found if searched for.
    ii. Receiving location and/or needs:
        1. For disasters where cellular internet connectivity remains in-tact and survivors are able to push their notifications, USAR could develop tools and processes to consume location-based status and needs direct from the internet.
        2. For disasters where cellular internet is not an option, USAR could listen for reports by:
            a. Partner with an aerial support entity (e.g., CAP, National Guard) which has been equipped with technology capable of picking up the "SOS" communication or cellular pings.
            b. Quickly traverse neighborhoods by ground vehicle with equipment capable of picking up the "SOS" communication or cellular pings.
            c. Leverage sUAS swarms capable of picking up the "SOS" communication or cellular pings.
            d. Work with industry to rapidly reestablish temporary internet activity (e.g., AT&T FirstNet). If this is done quickly enough, the total elapsed time of reestablishing the network, coupled with faster search and rescue, may be overall faster at getting to survivors in need than a systematic search.

b. Establish an active or passive survivor alert system: As described in the Wide-Area Search use cases, government and industry could partner to establish a standardized beacon—either an active radio or optical beacon, or a passive beacon such as a highly reflective “X” that can be easily deployed outside a survivor’s home. As with the cell phone approaches, the corresponding sensing would need to be standardized, developed, equipped, and trained on—either with a partner organization or directly with USAR.

10. CONCLUSION

Based on the state of the art described in the literature review, use cases and successes derived from the qualitative interviews, and our own internal analysis and discussion, we developed a Technology Development Roadmap. This roadmap provides guidance for industry and academia on technical areas that need improvement or present opportunities for new innovation. The roadmap also provides guidance for the USAR community to be able to better receive and incorporate decision support information derived from remote sensing.

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APPENDIX A: INTERVIEW TOOL

Interview participants were read the following script. After their agreement to the interview, they were then asked the 15 questions over the course of 60-90 minutes.

Introduction:

We're conducting research into how remote sensing can support urban search and rescue. We're going to ask you a series of questions about your experience in USAR and your experience with remote sensing. Your answers will be synthesized with other answers into a final report.

The goals are:

- Provide an overview of ways that remote sensing has successfully supported USAR
- What barriers exist to incorporating remote sensing into USAR
- Additional ways that remote sensing could potentially support USAR

Some administrative notes:

- This interview is not for attribution, though it is possible that answers could be specific enough so as to identify someone due to their role
- Feel free to tell us to stop at any time, or to strike anything from our notes
- There's no compensation

Do you have any questions?

Does that sound ok to you?

OK let's get started:

Questions

1. Can you describe your USAR experience: include time on the job, titles, scope of responsibility
2. What do you do outside of USAR and is that relevant to the USAR mission?
3. Can you describe your comfort level with technology in general? Would you call yourself an early adopter or maybe someone who's more resistant to technological changes?

4. Can you describe a situation where technology has successfully assisted your USAR mission?
5. Are there any relatively new technologies that you could not do your job without?
6. Can you describe a situation where technology has directly impeded your USAR work?
7. OK let's dig into remote sensing. Do you have any experience with remote sensing - in general or with USAR?
8. From your experience, do you think there is a capability gap in USAR operations that remote sensing could fill?
9. Can you describe a success where remote sensing has helped with your USAR mission?
10. How about a situation where you think having a particular remote sensing capability could be transformative?
11. If leadership wanted to adopt new remote sensing technologies for USAR, what are the most significant challenges that would be faced by someone trying to implement those technologies?
12. Can you think of 3 ways that USAR that could benefit from remote sensing - across any part of deployment, from activation, to traveling, to pre-staging, structural triage, or logistical support?
13. If there was a remote sensing technology that clearly gave USAR an advantage, how confident are you that the USAR community could find a way to adopt that change and employ it in operations?
14. What else should we have asked about that we didn’t?
15. Who else should we speak to?

That concludes the questions - thank you very much for your time.

Sign off

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13. ABSTRACT
In this report, we have conducted an overview of remote sensing support to Urban Search and Rescue (USAR). To do this, we conducted a literature review to understand the state of the art in R&D as applied to this mission space. To further our understanding of the current operational needs and environment, we also conducted numerous qualitative research interviews with subject matter experts in both USAR and remote sensing.

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