Defense Systems Information Analysis Center

DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Air-to-Ground Target Identification and Tracking

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ABOUT DSIAC

The Defense Systems Information Analysis Center (DSIAC) is a U.S. Department of Defense Information Analysis Center sponsored by the Defense Technical Information Center. DSIAC is operated by SURVICE Engineering Company under contract FA8075-14-D-0001.

DSIAC serves as the national clearinghouse for worldwide scientific and technical information for weapon systems; survivability and vulnerability; reliability, maintainability, quality, supportability, and interoperability; advanced materials; military sensing; autonomous systems; energetics; directed energy; and non-lethal weapons. We collect, analyze, synthesize, and disseminate related technical information and data for each of these focus areas.

A chief service of DSIAC is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry. For more information about DSIAC and our TI service, please visit www.DSIAC.org.

ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information on new sensing technologies, methodologies, and algorithms for air-to-ground target tracking. DSIAC staff and subject matter experts (SMEs) reviewed publicly available documentation and knowledge repositories (e.g., the Institute of Electrical and Electronics Engineering Journal and conference proceedings, Georgia Tech Research Institute [GTRI] research reports, Tri-Service Radar Symposium proceedings, etc.) for information on various sensing technologies, methodologies, and algorithms to prepare its response. DSIAC collated inputs from 4D Tech Solutions, GTRI, and DSIAC SMEs on visual, thermal, acoustic, light detection and ranging, radar, biometric, and facilitating technologies for detecting and identifying personnel and small vehicle targets from airborne platforms. DSIAC staff analyzed the information gathered and provided the inquirer with an overview of technologies, systems, and/or individuals relevant to the inquiry.

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1.0 TI Request

1.1 INQUIRY

What new sensing technologies, methodologies, and algorithms exist to detect and identify ground targets from the air?

1.2 DESCRIPTION

The inquirer requested information on new sensing technologies, methodologies, and algorithms for air-to-ground target tracking.

2.0 TI Response

Defense Systems Information Analysis Center (DSIAC) staff searched various repositories for documents relevant to the inquiry and collated inputs from 4D Tech Solutions, Inc., Georgia Tech Research Institute (GTRI), and DSIAC subject matter experts (SMEs) on visual, thermal, acoustic, light detection and ranging (LiDAR), radar, biometric, and facilitating technologies for detection and identification (ID) of personnel and small vehicle targets from airborne platforms. DSIAC staff reviewed and analyzed the search results and SME inputs to provide a summary of technologies, systems, or individuals related to the inquiry. DSIAC found that a variety of new applications are being developed to track objects (e.g., humans) as they move on the ground; however, there was no indication that the technology has advanced sufficiently to biometrically track individual human targets using light tactical or utility vehicles in a mounted or unmounted position.

2.1 PERSONNEL/BIOMETRIC TRACKING FROM SMALL UAVS

Mr. Brad DeRoos, President of 4D Tech Solutions, Inc., provided an assessment of current technical capabilities to perform airborne tracking and ID of dismounted/mounted personnel and small tactical vehicles. His company specializes in providing military and commercial autonomous and biometrics technology solutions for developing the following:

- Unmanned aerial vehicles (UAVs), unmanned ground vehicles, and unmanned surface vessels.
- Modular UAV architecture for payload testing.
- Advanced UAV flight planning software and photogrammetric imaging techniques for three-dimensional (3-D) mapping.
- Infrared and two-wavelength digital holography biometric equipment.

Tracking individuals on the ground from UAVs has become a key offering of many small UAV manufacturers, mainly due to interest in taking pictures of themselves from the air (e.g., selfies or action videos). This type of cooperative/semi-cooperative tracking is much different than performing personnel tracking from a UAV when the individual being tracked is not compliant. These simple personnel tracking systems increasingly use items, such as a locator or global positioning system (GPS)-derived information from a cellphone or stand-along GPS communicator, to provide effective tracking. DroneGuru provides a list of “follow me” drones [1]. These drones require interface and compliance with the drone (i.e., UAV) doing the tracking.

The ability to perform biometric tracking is a subset of personnel tracking. Based on a review of the article “Army Tracking Plan: Drones that Never Forget a Face” [2], it is apparent that visually and thermally tracking individuals is still a challenge. Biometric-based tracking presents several challenges, including the issues that pose and gait analysis capture angles create regarding the ID of prey. The pose angle is important for two-dimensional biometric facial image matching (visual and thermal/multispectral), and the capture angles are important for gait analysis. Non-biometric tracking must be reliably solved as a precursor to biometric tracking. The concept of drones tracking an individual based on biometrics was presented as early as 2011, but no progress appears to have been made by the company that suggested the idea (i.e., Progeny Systems Corporation).

2.1.1 Visual Tracking

Research is being performed to extend the capabilities of commercial off-the-shelf technologies for individual/pedestrian tracking from UAVs. Recent technical advances in UAVs made a realm of applications possible. In the 2015 publication, “On-Board Real-Time Tracking of Pedestrians on a UAV” [3], the researchers focused on “the application of following a walking pedestrian in real time, using optimized pedestrian detection and object tracking.” For this, they used an on-board embedded system, offering an optimal ratio of computational power and weight. They extended the commonly used ground plane estimation technique, which can be used to reduce the search space, based on the sensor data off the UAV. The integration of the ground plane constraint obtains a significant speed-up over the already optimized aggregate channel feature detector. To compensate for the frames without detections, they used a particle tracker based on color information. The tracking algorithms were successfully validated from a flying UAV.

As identified in the documents “UAV-Based Monitoring of Pedestrian Groups” [4] and “Visual Object Tracking for Unmanned Aerial Vehicles: A Benchmark and New Motion Models” [5], tracking pedestrian groups is a potentially plausible means by which UAV tracking of individuals on the ground can occur.

One commercialized technology of interest is that which is embedded within the Skydio R1 drone [6]. The R1 control system is based on a fully integrated, end-to-end, autonomous software stack (i.e., Skydio Autonomy Engine [7]) that is powered by a NVIDIA Jetson TK 256 compute unified device architecture (CUDA) core artificial intelligence (AI) supercomputing device [8]. Skydio R1 provides complex real-time video imagery analytics and integration with time-space-position information for fully autonomous launch, flight planning, maneuvering, target tracking, and landing. The R1's app software can also be used to launch and land, control the system, and preset certain filming and flying conditions [6–8].

The Skydio R1's control, vision, navigation, and data processing/analytics systems integrate advanced algorithm components spanning perception, planning, and control, which gives the R1 a unique intelligence that's analogous to how a person would navigate an environment. On the perception side, the system uses computer vision from 13 cameras that capture omnidirectional video to determine the location of objects. Using a deep neural network, it compiles information on each object and identifies individuals or vehicles by size, shape, color, clothing, etc. For each target, it builds up a unique visual ID to tell people and vehicles apart so that it stays focused on the right one [6–8].

That data feeds into a motion-planning system, which pinpoints a targets location and predicts upcoming movements. It also considers its own maneuvering limits to continually trade off and balance parameters to optimize tracking and filming. This predictive mode allows the drone to "lead" targets as they maneuver through difficult terrain.

The system's use of deep neural networks, deep learning, and machine learning allow it to build up unique visual identifiers and perform discrimination between different people and object IDs (see Figures 1–3). This allows the system to stay locked onto a single target and even switch between individuals as necessary (e.g., follow the trail of a package passed from individual to individual).

DSIAC contacted SOFWERX and verified that they have a Skydio R1 in house for testing purposes.

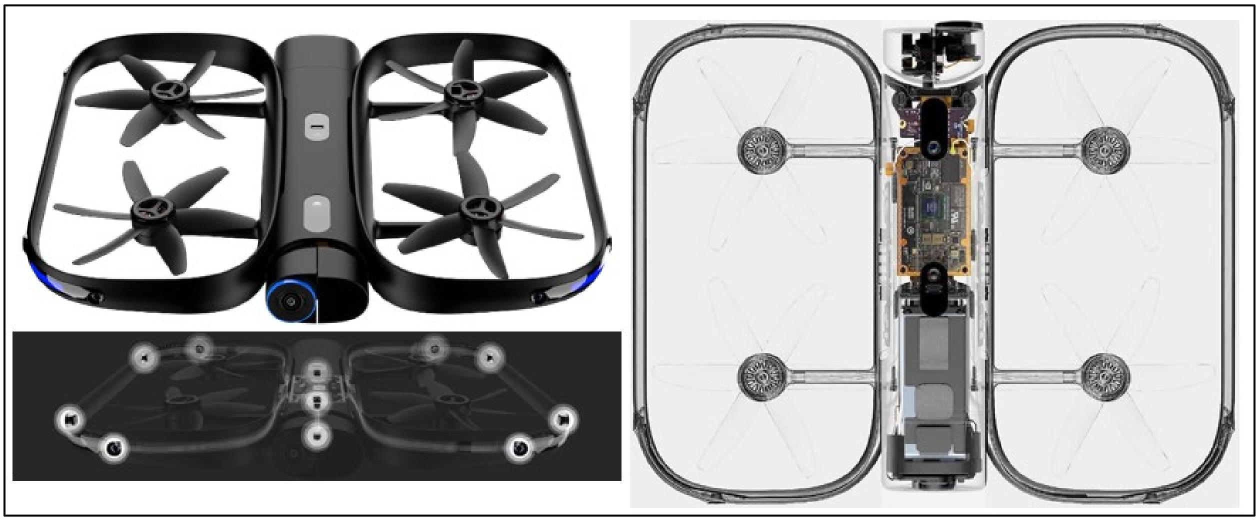

Figure 1: (Left) 13 Cameras Enabling Full 360 ° Vision, Continuous Target Tracking, and Obstacle Avoidance [9, 10] and (Right) NVIDIA Jetson TK CUDA-Core AI Supercomputer With Fully Integrated Autonomous Software Stack [10].

Figure 2: Simultaneous Localization and Mapping to Construct and Update an Environment Map While Keeping Track of a Target's Location Within [9].

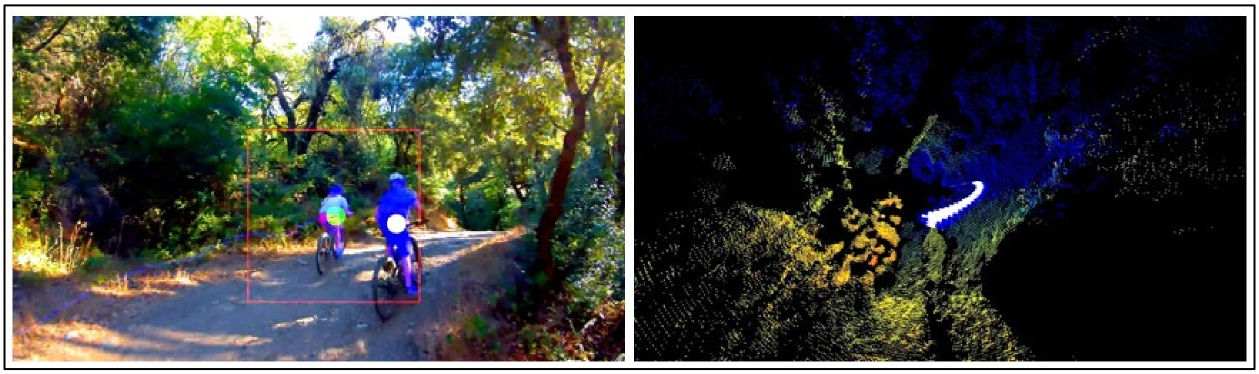

Figure 3: (Left) Deep Learning to Develop Unique Visual Identifiers, Improve Behavior, and Become More Capable Over Time and (Right) 3-D Environment Mapping, Maneuvering Limitations, and Target Movement Prediction to Flight Plan [11].

2.1.2 Thermal Tracking

Detection and tracking people in visible-light images has been subject to extensive research in past decades, with applications ranging from surveillance to search-and-rescue. Following the growing availability of thermal cameras and the distinctive thermal signature of humans, research efforts have been focusing on developing people detection and tracking methodologies applicable to this sensing modality. Many challenges arise in transitioning from visible light to thermal images, especially with the recent trend of employing thermal cameras on aerial platforms. The following papers present the challenges of tracking individuals from UAVs using thermal cameras:

- "People Detection and Tracking From Aerial Thermal Views" [12].
- "Real-Time People and Vehicle Detection From UAV Imagery" [13].
- "Pedestrian Detection and Tracking From Low-Resolution Unmanned Aerial Vehicle Thermal Imagery" [14].
- "Persistent Visual Tracking and Accurate Geo-Location of Moving Ground Targets by Small Air Vehicles" [15].

2.2 TRACKING LIGHT TACTICAL AND UTILITY VEHICLES FROM SMALL UAVS

2.2.1 Enhancing UAV Target Detection and Tracking With Real-Time Self-Learning

UAVs have been widely used for commercial and surveillance purposes in the recent year. Vehicle tracking from aerial video is one commonly used application. In the paper "Robust Vehicle Tracking and Detection From UAVs" [16], a self-learning mechanism is proposed for vehicle tracking in real time. The main contribution of this paper is that the proposed system can automatically detect and track multiple vehicles with a self-learning process, enhancing tracking and detection accuracy. Two methods were used to detect vehicles—(1) the features from the accelerated segment test with the histograms of oriented gradients method and (2) the hue, saturation, and value color feature with grey-level, co-occurrence matrix method. A forward and backward tracking mechanism was employed for vehicle tracking. The main purpose of the research effort was to increase vehicle detection accuracy by using the tracking results and the learning process, which can monitor detection and tracking performance by using their outputs. Videos captured from UAVs were used to evaluate the performance of the proposed method. According to the results, the proposed learning system can increase the detection performance.

2.2.2 Enhancing UAV Navigation With Target Motion Estimation

Small UAVs are increasingly popular in many applications for their low cost, ease of use, and rapid deployment. One highly desirable capability is pursuing a target along a roadway while providing a persistent aerial view. This is made difficult by large UAV state uncertainty and limited maneuverability. However, technical papers indicate that by carefully representing state uncertainty, planning in the space of available control actions, and using environmental knowledge to constrain possible target motion, adequate performance can be achieved with existing fielded vehicles. The first reference paper, “Persistent Visual Tracking and Accurate Geo-Location of Moving Ground Targets by Small Air Vehicles” [15], presents a comparative study of several target estimation and motion planning techniques. Results from field experiments applying these ideas to a commercial human-portable, fixed-wing UAV system are also presented in the document “Intelligent Motion Video Guidance for Unmanned Air System Ground Target Surveillance” [17].

2.3 TRACKING UAVS FROM SMALL UAVS

Drones usually cannot be tracked by conventional radar systems due to their small size. To solve the problem in the civilian sector, Vodafone created a fourth generation network subscriber identity module card that makes drones visible on air traffic control systems and allows operators greater control if they go off course. This radio positioning system can track a drone in real time with up to 50-m accuracy by the operator and authorized bodies like air traffic control. It can force a drone to land automatically or return to the operator if it approaches excluded zones like airports and prisons. It also has an emergency override function.

Also related to the civilian sector tracking of drones, Chinese company DJI recently introduced its own Wi-Fi-based drone ID and tracking system for use by the Federal Aviation Administration and law enforcement. DJI’s “Aeroscope” will operate on the 2.4- and 5.8-GHz Wi-Fi bands and broadcast each drone’s position, altitude, direction, speed, make, model, serial number, and any additional ID information that pilots provide [18].

Tracking small UAVs from the ground is problematic and even more so if detection and tracking occurs from the air due to sensor payload weight and size. This research identified three technologies that can potentially track UAVs from UAVs.

2.3.1 Acoustic Tracking

Acoustic detection and tracking UAVs is attractive, as the technology can be inexpensive and lightweight. The ability to track a UAV using tracking technology deployed from another UAV would need to be assessed [19–21].

2.3.2 Light Detection and Ranging (LiDAR) Tracking

Figure 4 shows images taken from a small LiDAR system developed by the U.S. Army Research Laboratory (ARL) in Adelphi, MD. Small LiDAR sensors can offer very high-resolution images out to a range of over 500 ft. The sensor has a laser pulse repetition frequency of up to 400,000 pulses per second and a controllable scan rate which would allow detecting other small UAVs and tracking them as well [22].

Figure 4: Images From ARL LiDAR System [22].

2.3.3 Radar Tracking

Phased-array radars use a grid of antennas that can steer a radar beam in a desired direction by emitting radio waves in precisely defined patterns. By doing this multiple times per second, users can scan the beam over a whole field of view (FOV) without ever moving the device itself. However, the radar devices have proven to be difficult to miniaturize beyond a certain point because of the amount of electronics involved (e.g., the antennas must be a certain size to work with a given wavelength, their controllers take up space, there is processing for received data, etc.).

A phased array technology that may prove useful for tracking UAVs from UAVs is being developed by a company named Echodyne. It uses metamaterial to create a phased array on a significantly smaller scale. Instead of dozens of individual antennas, the device uses a surface with a carefully engineered 3-D pattern that allows beams to propagate in a similar manner but with more precision and lower power. It sweeps across a maximum of 120° horizontal and 80° vertical (azimuth and elevation), a FOV roughly equivalent to humans. These systems are meant to replace the vigilance of a pilot, onboard or remote. An effective replacement for human visual acuity and search capability is a prerequisite for autonomous flight outside the operator's line of sight [23].

The U.S. Army has a goal of mounting fire-control radar and cameras on UAVs to detect and track hostile drones. The purpose is to create small, man-portable UAVs that troops can use on the spot to detect and track hostile drones rather than having to call in aircraft or other support to identify the target. The data could then be relayed to friendly weapons that can destroy the airborne intruder. According to an Army research proposal, "A radar system mounted on a UAV will provide high fidelity radar information to Blue forces on forward observation missions…. The actionable intelligence gathered from this detailed radar track information will allow for timely decisions on how to react to any potential airborne threats. Operators will be able to request visual confirmation from the UAV's on-board camera system prior to engaging the threat." However, the proposal also notes that size, weight, and power considerations will be key to installing fire control radar on a small UAV. A search was performed of FedBizOpps, but neither a request for information or the sources sought could be found [24].

2.3.4 Emerging Technologies

Other emerging technologies are maturing that may facilitate implementing the previously mentioned methodologies in effectiveness and cost reduction. DSIAC provided a few samples of technologies, including the following:

- ARL face recognition technology [25].
- Air Force Institute of Technology (AFIT) enhanced imaging system [26].
- University Centre in Svalbard (UNIS), Norway, small low-cost hyperspectral imagers [27].

The first two are developmental technologies that could directly improve detecting and identifying mounted/dismounted personnel. The third shows a developmental technology that could allow implementation on small UAVs if sensitivity were improved.

It is beyond the scope of a DSIAC technical inquiry to perform a comprehensive assessment of the domain in question or associated facilitating technologies and how they might be applied in an airborne operational environment. However, this could be accomplished under a DSIAC extended technical inquiry or core analysis task, if desired.

2.3.4.1 ARL Face Recognition Technology

U.S. Army researchers developed an AI and machine-learning technique that produces a visible image from a thermal image of a person's face captured in low-light or nighttime conditions.

This development could lead to enhanced real-time biometrics and post-mission forensic analysis for covert nighttime operations. The technology enables matching between thermal face images and existing biometric face databases/watch lists that only contain visible face imagery. It provides a way for humans to visually compare visible and thermal facial imagery through thermal-to-visible face synthesis (see Figure 5). The goal of the program is to enhance both automatic and human-matching capabilities [25].

Figure 5: ARL Conceptual Illustration for Thermal-to-Visible Synthesis for Interoperability With Existing Visible-Based, Facial Recognition Systems [25].

2.3.4.2 AFIT Enhanced Imaging System to Differentiate Human Skin From Other Materials

The AFIT Sensors Exploitation Research Group developed a process for differentiating human skin from other materials within an image to reduce false detection rates in support of search, rescue, and recovery; security; and surveillance operations (see Figure 6). Instead of using bulky, expensive, and relatively slow hyperspectral camera systems, Dr. Michael J. Mendenhall's research team developed a prototype camera system that specifically works with a skin detection and color estimation approach. The system requires only a small number of spectral channels. The multispectral camera system enhances skin detection by focusing on the amount of melanin in the skin, allowing filtering of detection for different concentrations of melanin (fair or dark skin or anything in between) to improve the capability of locating a person of interest [26].

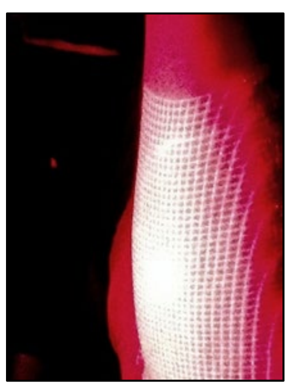

Figure 6: AFIT Skin Detection [26].

2.3.4.2 UNIS Small Low-Cost Hyperspectral Imagers

Researchers used 3-D printing and low-cost parts to create an inexpensive hyperspectral imager that is light enough to use onboard drones. They offer a recipe for creating these imagers, which could make the traditionally expensive analytical technique more widely accessible. The researchers detail how to make visible-wavelength, hyperspectral imagers weighing less than half of a pound for as little $700. They also demonstrate that the imagers could acquire spectral data from aboard a drone. Currently, the imagers lack the sensitivity necessary for intelligence, surveillance, and reconnaissance operations from significant altitudes, but this will improve with time [27].

2.4 GTRI SEARCH

Dr. Power Garmon, the principal research scientist at GTRI's Sensors and Electromagnetic Applications Laboratory, searched GTRI and Institute of Electrical and Electronics Engineering (IEEE) for technical reports, journal publications, and conference proceedings related to the inquiry, resulting in a bibliography of over 110 references.

For more than a decade, a host of GTRI researchers has been funded by the U.S. Department of Defense to perform research in air-to-ground targeting. This research includes ground moving target indication (GMTI) research that addresses vehicles and dismounts in real-world environments. The research addresses latest hardware, algorithms, and processing methods.

Unclassified publications authored by GTRI researchers, as well as those not affiliated with GTRI, are provided in the Bibliography. In addition, GTRI researchers have presented numerous papers related to the inquiry at the Tri-Service Radar Symposium in the past decade; information on this can be provided for valid requests.

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BIOGRAPHIES

BRADLEY DEROOS is the President of 4D Tech Solutions, Inc. and has over 25 years of experience in the research, development, and commercialization of unmanned vehicle systems and associated sensors. His accomplishments include delivering over 2,000 "Bombots" to support the Warfighters in Iraq and Afghanistan and managing the development of advanced wireless communication systems for unmanned ground vehicles, improvised explosive device disrupters, and manipulators for ground and subsea vehicles. Throughout his career, Mr. DeRoos performed numerous advanced technology assessments that have served to guide technology development efforts for unmanned vehicle systems. 4D Tech Solutions is currently developing advanced unmanned ground vehicle technologies and light detection and ranging sensors for unmanned aerial systems.

SCOTT ARMISTEAD is a Defense Systems Information Analysis Center subject matter expert who has over 30 years of experience in developmental and operational testing of air-to-ground precision guide munitions and associated electro-optical/radio frequency targeting systems. He served as the Senior Test Engineer and Technical Advisor for the Air Force Electro-Optical and Millimeter Wave Test Flight for nearly 10 years. He also served as the Test Manager for the Air Force/Army Joint Munitions Test & Evaluation Program Office for over 5 years. His areas of testing expertise include automatic target recognition; moving target indication; and camouflage, concealment, and deception countermeasures against these systems.

POWERS GARMON, PH.D. is a principal research scientist at Georgia Tech Research Institute's (GTRI's) Sensors and Electromagnetic Applications Laboratory. He has 38 years of experience in research and development in industry, which includes knowledge-based computer program development, radar/avionics, photonics, and materials engineering. He has authored/co-authored over 50 publications in his areas of research interest and holds two U.S. patents on optical fiber technology. He was the recipient of the 1998 GTRI Researcher of the Year award for "Pioneering Achievements in Fiber Optics and Laser Communication." Dr. Garmon received a Ph.D. in physics from Clemson University and a bachelor's degree in physics from Berry College.