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Environmentally Aware Drones: Automated Impacts Routing (AIR) Embedded into Drone Technology

by Jeffrey O Johnson

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14. ABSTRACT

Military swarming is often encountered in asymmetric warfare where opposing forces are not of the same size or capacity. In such situations, swarming involves the use of a decentralized force against an opponent in a manner that emphasizes mobility, communication, unit autonomy, and coordination or synchronization. On a future battlefield, commanders will deploy intelligent autonomous systems (IASs) that can function in a swarm-like mentality. It is envisioned in 2040 that these IASs will pervade the battlefield. These systems must rapidly sense, react, and learn from the environment in which they function. This report describes the use of CCDC Army Research Laboratory's Automated Impacts Routing as a central part of an embedded system within an unmanned aerial system (or drone), as demonstrated during Phase I of a Small Business Innovation Research program.

15. SUBJECT TERMS

path-finding, software design, unmanned aerial system, UAS, drone, implementation, deployment, weather model data

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1. Introduction

Military swarming is often encountered in asymmetric warfare where opposing forces are not of the same size or capacity.[1] In such situations, swarming involves the use of a decentralized force against an opponent in a manner that emphasizes mobility, communication, unit autonomy, and coordination or synchronization. On a future battlefield, commanders will deploy intelligent autonomous systems (IASs) that can function in a swarm-like mentality, working in a synchronized manner to deploy necessary force or gather intelligence that would otherwise not be available. It is envisioned in 2040 that these IASs will pervade the battlefield. These systems must rapidly sense, react, and learn from the environment in which they function.

The US Army Combat Capabilities Development Command Army Research Laboratory's (ARL's) Battlefield Environment Division (BED) has developed the Automated Impacts Routing (AIR) application (formerly, Atmospheric Impacts Routing),[2] which calculates optimized routes in 3-D space, avoiding adverse atmospheric conditions and other obstacles during mission execution.

This report describes the use of ARL's AIR as a central part of an embedded system within an unmanned aerial system (UAS) (or drone), and as demonstrated during a Phase I Small Business Innovation Research (SBIR) program.

2. Background

In early 2017, ARL-BED developed and submitted an SBIR research topic with specific objectives including the use of ARL's AIR as an embedded system on a drone, allowing a path through varying environmental conditions to be optimized by AIR, with the resulting path routing instructions transmitted to the UAS flight control systems. This SBIR, with NextGen Federal Systems, LLC (hereafter, NextGen), completed the Phase I effort in December 2017, which included a bench demonstration of a prototype drone with AIR embedded as part of the onboard system, including a Raspberry Pi computer and flight controller "auto-pilot". The complete system including AIR was named the Automated Environmental Routing Onboard (AERO) system by NextGen.

The SBIR has since moved to Phase II, with a kick-off meeting held on 31 January 2019.

Developed from scratch, the design of the AIR system allows it to be applied to both air and ground routing applications by its use of 4-D data grids (3-D grids over time) of "impacts". The impacts data may be areas of adverse weather or other environmental parameters that may be used to identify areas to be avoided by an air or ground platform. In addition to the impacts grids, AIR can ingest and avoid obstacles, to include buildings, high-resolution terrain, no-fly zones, areas of known threat, and any other object that can be identified as an obstacle within the area of operation. AIR has been developed as both a web service and a standalone desktop computer application. The primary research objective of AIR is to "improve survivability and movement efficiency of air and ground platforms and systems".[2,3]

3. AIR in Embedded System

Several discussions and technical exchanges between ARL and NextGen occurred during the Phase I execution. As a result of these interactions, adjustments to the planned path forward took place that would still achieve the overall endpoint goal stated in the original SBIR call for proposals.

3.1 Original Design

The SBIR Phase I design and plan by NextGen included a potential to have the My Weather Impacts Decision Aid (MyWIDA; also developed by ARL) as part of the onboard system. For details on MyWIDA, see Brandt et al.[4] After discussions between ARL and NextGen regarding the volume of data that would be required (which would be on the order of gigabytes in a single transmission), ARL provided an option using a submodule of AIR, which is described in the following section.

Figure 1 shows the original design that initially considered MyWIDA as part of the onboard system.

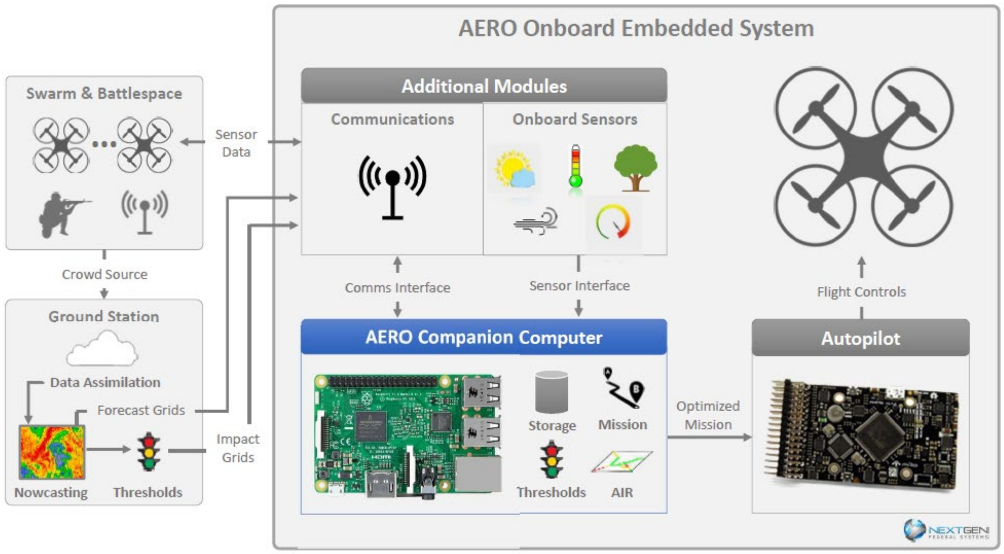

Fig. 1 Original draft design of AIR embedded as part of AERO system (figure courtesy Next Gen Federal Systems, LLC)

3.2 Modified Design

One of the major concerns with the original design (discussed between ARL and NextGen) and expected volume of data was the relatively narrow bandwidth that might be expected in a network where the Department of Defense (DOD) may be conducting operations. Based on recent events, a given theater of operation would likely not be conducive to supporting a high-bandwidth communication network, such as would be required in this case. Additionally, a design for lower bandwidth functionality would allow uses within a greater number of operations and/or situations.

Due to these considerations, a modified design of the data flow pipeline has been implemented, allowing impacts data to be generated at a ground station and processed into AIR-format data. This results in data set sizes on the order of 300 times smaller than the original environmental data set, reducing the volume of information that would need to be sent through a Wi-Fi data network to the UAS platform. The design of reduced meteorological data and reduced bandwidth, which would send only the impacts data of concern to the receiving platform, was met with strong positive response from DOD leadership.[5]

4. AIR Impacts Generator Tool (AIGT)

A submodule within the AIR software package was written specifically to allow direct ingest of data from atmospheric forecast models using NetCDF,[6] a standard atmospheric forecast model data format. The submodule, called

WRFImactsGenerator.java (also referred to as the "AIR/Atmospheric Impacts Generator Tool" [AIGT] henceforth in this report), allows ingest of any NetCDF data and generates an impacts grid for any user-selected variable for any forecast hour and for one or more levels. The "thresholds" for the impacts are set at the code level. This submodule allows a quick analysis of any data for a particular variable of interest, without the need for a larger full web service system such as MyWIDA. The AIGT will output an AIR-compatible impacts grid (matching AIR's required XML schema) for immediate use by the AIR software system.

A screen capture of the AIGT front end is shown in Fig. 2.

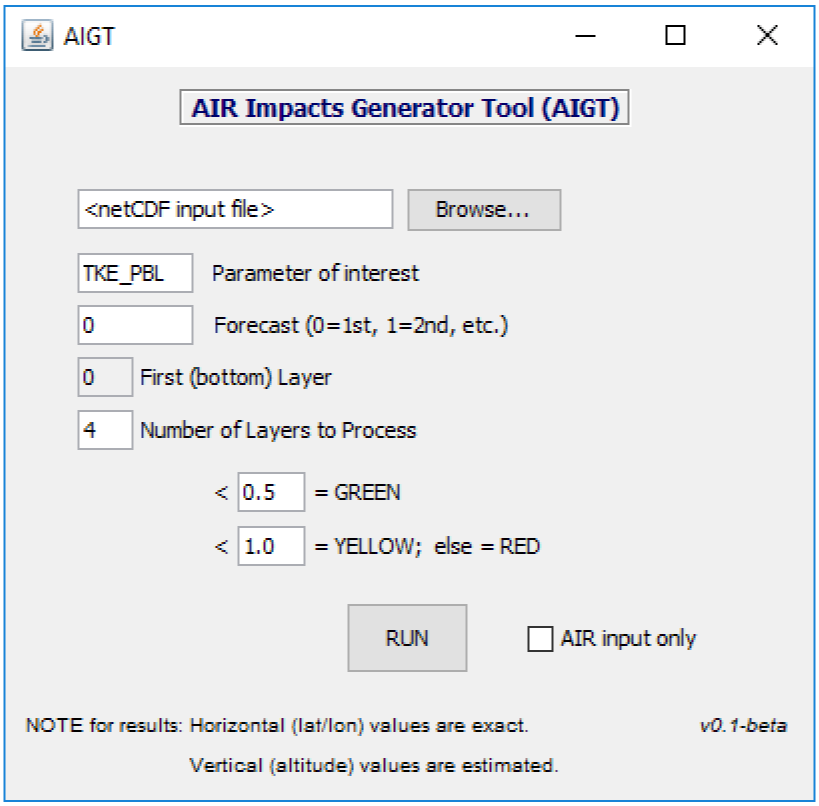

Fig. 2 AIGT used to directly ingest netCDF data and generate an atmospheric impacts file for AIR use

Since AIR's AIGT submodule does not require a relatively heavy system such as MyWIDA and also allows impacts to be generated immediately for any particular variable in standard atmospheric model format, ARL suggested using the AIGT to implement a method to send a very small data set, a factor of approximately 400 times smaller than the original data set, through a network (e.g., Wi-Fi) to the drone for use by the embedded AIR.

Further details on the AIGT submodule will be described in a separate future report.

5. AIR Processing from Multiple Data Sources

A key point in the call for proposals from BED that resulted in this SBIR effort was to have the capability for dual-mode operation:

1) Receiving atmospheric forecast data and/or weather impacts data through a network (wireless) connection and
2) Operating in a disconnected mode, receiving impacts data from a forward-looking onboard sensor.

It is envisioned that the dual-mode operation will be automated, switching between receipt of forecast model data to the use of the onboard sensor, depending on network connectivity. In addition, the use of both networked data coupled with sensed data will be a potential system state.

5.1 Atmospheric Forecast Models

Atmospheric forecast model data that are used as input to the IAS-embedded system are not dependent on a particular source. The forecast model can be mesoscale, meso-gamma, or in the case of urban or complex terrain operations, microscale.

As described in Section 3.2, the full model data would likely not be sent to the IAS directly due to bandwidth considerations. Instead, the forecast model data would be collected at a ground station that is in communication with the IAS. The ground station would process the forecast model data into a set of "impacts" data, using a system such as MyWIDA, as well as other impact assessment services that supplement weather impacts with obstacle data. The data generated by these impact models would match the AIR XML schema (see the Appendix), allowing data to be reduced in size by up to a factor of 300 times smaller than the original forecast model gridded data.

An example of forecast model data being read/processed by the AIGT and subsequently used directly by AIR for path optimization is shown in Fig. 3. In the image, both the desktop version front-end graphical user interfaces (GUIs) for both the AIGT and AIR are also shown. The start to end point for the processing chain for these data is as follows:

- NetCDF format model data → AIGT → AIR → Google Earth rendering

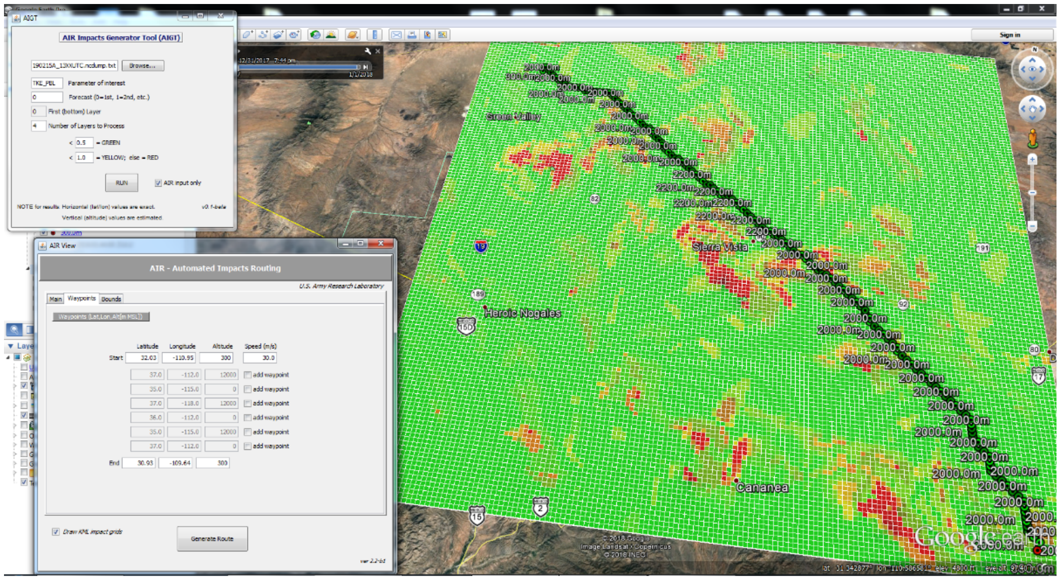

Fig. 3 NetCDF format model data → AIGT → AIR → Google Earth output. Result is an optimized path through user-defined variable and thresholds, resulting in an impact grid. The front-end GUI for the AIGT and AIR are shown on the left.

5.2 Onboard Sensors

The "dual-mode" SBIR requirement included having a forward-viewing sensor to adaptively detect environmental hazards, including adverse weather and obstacles. The sensor is front mounted, scanning a field of view (FOV) in front of the UAS, with the FOV determined by the specifications of the sensor.

The general idea for using the onboard sensor(s) in this manner is to have a 3-D "picture" of the volume that the UAS is about to fly into. The data from the forward-viewing sensor would be digitized into a 3-D field of impacts and obstacles, and this 3-D field of data would then be sent to AIR for processing to determine and optimized path through the volume of impacts/obstacles. Similar to operating with atmospheric model forecast data, AIR would subsequently send the resulting optimized path result(s) to the autopilot/flight control systems of the host UAS. The onboard sensor will also allow opportunities for onboard machine-learning approaches to the sensed data.

The onboard sensor(s) would be vital in cases of non-networked mode, where the UAS would then be completely independent of outside information and only rely on its onboard sensors, maneuvering through the environment on a path to execute its mission. The "dual-mode" operation will also then allow a "switching" between the onboard sensor data and the forecast model data, depending on what is available. In addition, this will allow some hybrid of sorts of both data sets (model and sensor).

6. Summary and Conclusion

In very near future battlefields (and indeed in some current battlefield situations), commanders will make use of IASs to expand operational intelligence on the battlefield. In such situations, it is paramount to reduce the time to operate such systems by already time-taxed deployed units with multiple responsibilities. UASs/drones are already integrated into operational units, and the self-reliance and intelligence of these systems will improve a unit's ability to operate in complex battlefield situations.

The ARL-developed technology AIR operates as an embedded system within a drone, allowing autonomous path-finding, avoiding adverse weather and obstacles, and is a key element to a fully autonomous airborne platform. Such embedded technology will also be applied to autonomous operation of a swarm of such platforms.

7. References

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Appendix. Automated Impacts Routing (AIR) Schema

AIR schema

```
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSpy v2010 rel. 3 sp1 (http://www.altova.com)
by Jeffrey O. Johnson (US Army Research Lab) -->
<!--W3C Schema generated by XMLSpy v2010 rel. 3 sp1
(http://www.altova.com)-->
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
 <xs:element name="Projection">
	<xs:complexType>
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			<xs:element ref="maxcols"/>
			<xs:element ref="firstpointplacement"/>
			<xs:element ref="firstpointlatitude"/>
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			</xs:simpleType>
		</xs:attribute>
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value="imetsprojection"/>
				</xs:restriction>
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 <xs:element name="maxrows">
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							<xs:element ref="Projection"/>
							<xs:element                    ref="Layer"
maxOccurs="unbounded"/>
					</xs:sequence>
			</xs:complexType>
	</xs:element>
</xs:schema>
```

List of Symbols, Abbreviations, and Acronyms

3-D	three-dimensional
4-D	four-dimensional
AERO	Automated Environmental Routing Onboard
AIGT	AIR Impacts Generator Tool
AIR	Automated Impacts Routing
ARL	Army Research Laboratory
BED	Battlefield Environment Division
CCDC	US Army Combat Capabilities Development Command
DOD	Department of Defense
FOV	field of view
IAS	intelligent autonomous system
MyWIDA	My Weather Impacts Decision Aid
NetCDF	Network Common Data Form
SBIR	Small Business Innovation Research
XML	Extensible Markup Language
UAS	unmanned aerial system

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