Washington, DC 20375-5320



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# **Reflectance-Based Sensing: Data and Device Outputs**

BRANDY J. WHITE Jeffrey S. Erickson

Laboratory for the Study of Molecular Interfacial Interactions Center for Bio/Molecular Science & Engineering

ANTHONY P. MALANOSKI

Laboratory for Biosensors and Biomaterials Center for Bio/Molecular Science & Engineering

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#### **EXECUTIVE SUMMARY**

In October 2012, the Center for Bio/Molecular Science and Engineering at the Naval Research Laboratory (NRL) began an effort intended to develop wireless sensor networks for real-time monitoring of airborne targets across a broad area. The goal was to apply the spectrophotometric characteristics of porphyrins and metalloporphyrins in a colorimetric array for detection and discrimination of changes in the chemical composition of environmental air samples. Prior reporting on this effort has captured design of the six element array, prototype hardware, and algorithms as well as extensive testing of that system. The current document provides a brief description of a new 15 element prototype device with details on the files and data provided following use of the devices.

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#### **REFLECTANCE-BASED SENSING: DATA AND DEVICE OUTPUTS**

#### **INTRODUCTION**

In October 2012, the Center for Bio/Molecular Science and Engineering at the Naval Research Laboratory (NRL) began an effort (69-6594) intended to develop wireless sensor networks for real-time monitoring of airborne targets. The goal was to apply the spectrophotometric characteristics of porphyrins and metalloporphyrins in a colorimetric array for detection and discrimination of changes in the chemical composition of environmental air samples. The effort encompasses hardware, software, and firmware development as well as development of algorithms for identification of event occurrence and discrimination of targets.[1-5] Prior reporting on the devices, versions 1 through 2.08, has addressed the development of a six element array, six element prototype hardware (Figure 1), and relevant detection algorithms as well as extensive testing of that system focused on exposure to either vapors or aerosols. Here, we briefly describe a new prototype iteration for the Array Based Environmental Air Monitor (ABEAM v3) and provide details on the output and use variations for the devices.



Fig. 1 — The six element prototype device includes six color sensing breakout boards, a custom control board, fans, and indicator supports with custom housing. The device requires external power and is controlled by a laptop computer.

The ABEAM v3.2 device iteration is specifically designed to provide isolation of the electronics from the environment as well as from targets. This type of isolation is designed to prevent the failures experienced by the six element prototype during Cl<sub>2</sub> exposures and would be expected to extend overall device durability.[5] Beyond protection of the electronic components, the v3.2 device iteration provides an array of 15 indicators, occupying a footprint of 7.5" x 3.5" x 4.63" at a weight of 293 g (2,000 g with battery pack and housing; Figure 2). For comparison, the six element prototype was 10.8" x 3" x 3" and weighed 1,585 g as well as requiring an external power source. Incorporation of 15 indicators provides the potential for greater target discrimination based on the relative response across the array elements. For example, indicators with greater sensitivity to VX could be incorporated to improve the performance against those targets noted in the previous study.[5] Indicators with lesser sensitivity to Cl<sub>2</sub> and HD mustard could be used to provide improved discrimination between those targets.

#### **METHODS**

Meso-tetra(4-sulfonatophenyl) porphyrin ( $S_4$ TPP), meso-tetra(4-aminophenyl) porphyrin ( $N_4$ TPP), and Deuteroporphyrin IX 2,4 bis ethylene glycol (DIX) were obtained from Frontier Scientific (Logan, UT). Metalloporphyrin variants of  $S_4$ TPP,  $N_4$ TPP, and DIX were prepared by reflux.[1-3] The porphyrin (20 mg) was dissolved in water (4 mL) or dimethyl sulfoxide (DIX only). The metal salt was added to this solution in a 3:1 molar ratio with the porphyrin. The total volume was brought to 100 mL with deionized water and refluxed overnight. The volume of the resulting solution was reduced to 10 mL through rotary evaporation. Prepared porphyrin solutions were stored in the dark at room temperature. The metal salts used here were: copper (II) chloride, gold (III) chloride, silver chloride, and thallium (III) chloride. Paper supported porphyrin indicators were prepared on Whatman Filter Paper by spotting 5  $\mu$ L of the porphyrin solution (2 mg/mL) onto the appropriate area of the coupon (Figure 3). [2, 3] 'Blank' indicator spots used ink from a red Sharpie® to provide a non-responsive, colored indicator. Samples were dried at 100°C before storing in the dark in foil wrappers.

Fig. 2 — The v3.2 prototype iteration includes fifteen surface mount color sensors with custom control board, wireless communications, and can be powered using a battery pack.





Fig. 3 — The coupon layout used for the trials described here unless otherwise indicated. This coupon includes three copies of each of four indicators as well as three negative control spots.

5	4	3	2	1
Red	AgN <sub>4</sub> TPP	TIDIX	CuS <sub>4</sub> TPP	AuS <sub>4</sub> TPP
Sharpie®				
10	9	8	7	6
AgN <sub>4</sub> TPP	TIDIX	CuS <sub>4</sub> TPP	AuS <sub>4</sub> TPP	Red
				Sharpie®
15	14	13	12	11
TIDIX	CuS <sub>4</sub> TPP	AuS <sub>4</sub> TPP	Red	AgN <sub>4</sub> TPP
			Sharpie®	

The original six element prototype reflectance instrument developed by NRL utilizes low cost, commercially available color sensing breakout boards from Parallax, Inc. (model TCS3200-DB, Rocklin, CA), providing a color light-to-frequency integrated circuit from AMS (model TCS3200, Plano, TX), a pair of white LEDs, and an adjustable lens.[1] The device output consists of a stream of digital pulses proportional to the intensity of the color being measured. A custom printed circuit board (PCB) interfaces with and controls six of the commercial color sensors. Communications between the instrument and the computer are via USB; power is supplied through a DC barrel jack. A LabWindows developed software-based graphical user interface (GUI) communicates with the PCB firmware through simple ASCII commands. The prototype sensor device tested through independent evaluation is a slightly modified version of that original NRL device (v2.08) [1-6] (Figure 1). Airflow through the sample tube at 2.7 CFM is provided by two small 5 VDC fans (Orion Fans, model #OD2510-05HB), one mounted at each end.

The new v3.2 fifteen element prototype device was completely redesigned based on user feedback and experimental data. Rather than being composed of a single circuit board with an exposed "wind tunnel" sensor and illumination design, the new device is a stack of three boards. This strategy allowed for a vertical light path directly into the device, completely encapsulating both the electronic and the optical elements in a single compact package and physically protecting them from environmental exposure. The bottom layer board is the heart of the instrument; it consists of power management, data storage, communications, and

processing. The middle layer contains the RGB sensors. In between the middle and top layers, a machined plastic mount holds a set of molded aspheric lenses which are used to focus the reflected light onto the sensors. The top layer board contains eight LEDs, each with an emission profile that has a maximum intensity at 45 degrees, an ideal incidence angle for reflectance measurements. It also contains holes for the reflected light to access the RGB sensors located below. A plastic mount above the top circuit board spaces the sample at the proper distance from both the LEDs and the lenses. A glass plate seals the electronics from the environment while allowing light transmission to the sample.

The older TCS3200-DB breakout boards were replaced with TCS34725 surface mount RGB sensors. Rather than a pulse train proportional to intensity, these sensors output a voltage proportional to intensity of light being measured. This allows a much higher data throughput, resulting in faster cycles than those of the v2.08 board even with double the number of sensing elements. As an example, the v2.08 design could only perform a 5 s sampling cycle at the fastest integration time, 100 ms. The new design can perform this cycle at integration times up to 600 ms. In addition, the new ABEAM v3.2 design includes expanded flash memory, electronics for battery management, and wireless communications. Finally, the all of the software has been completely re-written in Java. The user interface has been completely re-written using Java FX, which removed many of the limitations of the old LabWindows based GUI. The software now contains a suite of tools including calibration and offline data analysis utilities, and experimental modes have been expanded to include drip-feed analysis and a distributed microsensor network in a star-point topology.

The detection algorithm used to identify the occurrence of events has been described previously.[3, 4] A detailed description with implementation approaches is provided in a recent NRL report.[6] The algorithm first populates background windows with the time duration required dependent on sampling increment (total number of points, rather than a time interval). With data collected at the 30 s increment used here, it is necessary to have 120 points for a stable initial condition (Background); 20 additional points fill the detection windows (Active and Snap). The 120 point Background window is intended to provide a smooth, slowly changing slope. This should capture any device drift over time as well as any changes resulting from diurnal and environmental changes. The Active window (20 points) provides a faster changing slope that will respond to chemical presence, while the shorter Snap window (10 points) is used to capture large, rapid changes. Comparing the Active and Snap windows to the slowly changing Background window provides the discrimination needed for identification of an event. Here, the conditions for ending positive event identification were changed based on recent evaluations.[5] The global cool down was changed from 60 min (120 points) to 10 min (20 points), and the buffering period for the global event was changed from 5 min (10 points) to 1 min (2 points).

#### DATA OUTPUT

The 15-element ABEAM device can be used singly or as a network containing up to six devices controlled by a laptop computer. When used singly, these devices can be monitored in real-time with drip-feed analysis, with live data transfer to the control computer without analysis, or autonomously with the data downloaded for analysis after collection. The following sections provide information on data formats and output files. Here, we focus on the data produced rather than on how to use the prototype devices. Operating guides are provided as Appendices to this document (refer to Appendices A, B, C).

#### Single device.

In an autonomous run, the device parameters are fixed using the custom software interface (Figure 4) and the device is started. It is then disconnected from the control computer. This device will continue to collect data until it is reconnected to the control computer and ordered to stop, the onboard memory is completely filled, or there is a power interruption. For either of the latter two conditions, the data in onboard memory is retained and can be recovered by connecting to the control computer. When the device is ordered

to stop, the data can then be downloaded. This approach allows an area to be monitored over durations of up to two weeks with the data analyzed offline at a later time. Live and Live/Dripfeed data collection include real-time transfer of the data to the control computer with real-time analysis included in the Live/Dripfeed version.

Multiplex v3.	.14u Front En	d 1.4 (230.4 k	baud)								- 0	×
Multiplex v3. COM Port COM22 Multi Update C Start Stop Firmware Versi Status: Idle Experiment Na Experiment1_	iplex v3.2 G Open Clo P Status ion: Multiplex me _093019	v 1.4 (230.4 k	Jaud) Instrument Controls Run Type Cycle T Live • 5 s Live/Dripfeed 30 Autonomous V Internal LEDs 2048 value: 1-4096 Erase Flash Downloa _Parameters.txt File Name Choose File	ime Integration Time 100 ms 200 ms 300 ms 400 ms 500 ms 600 ms d Data Force (~7	Gain 1x 4x 16x 60x 7 min)	Software Controls Options V Normalize Data Offset Data Use Calibration Calibration.txt or Choose File Fan Controls Fan 1 On Fan Fan 2 On Fan Mark Event in Data	Norm Const Offset 0 1000 0 Default Defau Parameters.txt File Name	t	Dripfeed An Algorithm StDev Stope	alysis Paramete Over 3 0.00015 0.45 3600 10	rs ide Threshold Se StDev a StDev b Slope c Global Co Buffer Step	aats
Timestep Time [h/m/s] Sensor 1 2 3 4	Clear	Red	Green Blue	] ] ]			Mark Event	x	Dripfeed Eve 15 5	I OFF ent Status:	OFF	

Fig. 4 — Screenshot for the control interface used for single device, autonomous, live, and live/dripfeed data collection.

For each set of data, several text files are generated: \_Parameters, \_Metadata, \_Tagged\_Actions, \_Raw, and \_Data. Tables 1 through 4 provide examples of the contents of the files with descriptions of the values. An example of the \_Data file is not included here; when no normalization is used, this file is identical to the \_Raw file. In Figure 5, a graphical representation for collected data is provided. Here, the data from the \_Raw file has been normalized to the average of the first 120 points. Each element of the array (15 total) provides a stream of red, green, and blue reflectance values on a 30 s sampling increment.

Description	Output by Line
Type of Illumination	1
LED Intensity	3072
Integration Time	3
Gain	0
Sampling Increment	1
Normalization Constant (-1 indicates none)	-1
Calibration Constants (nine total)	1.00
	1.00
	1.00
	1.00
	1.00
	1.00
	1.00
	1.00
	1.00
Offset Constant (-1 indicates none)	-1

Table 1. \_Parameters file for autonomous, single device.

Description	Output by Line
	Multiplex v3.10u Data
	Specific device ID: Multiplex v3.2 G
	Firmware version 3.20
	Software version 1.4
Unit definition	Time data is: timesteps, seconds. These times are equivalent.
	Timesteps and actual times are measured in firmware.
Data organization	Data order is: clear, red, green, blue
Time device was started	Autonomous run started on 03 Oct 2019 at 06:44:08 PM [America/New_York]
Defined integration time	Integration Time: 400 ms
Defined gain	Gain: 1x
Defined sampling increment	Cycle Time: 30 s
Type of illumination	Lighting: internal LEDs
Intensity setting	Intensity: 3072
Use of normalization	Data is not normalized
Use of offset	Data is not offset
Use of calibration	No calibration file used

Table 2. \_Metadata file for autonomous, single device.

Table 3. \_Tagged\_Actions file for autonomous, single device.

Description	Output by Line
	Tagged Actions
	Format is event: seconds.
	All times measured in software only.
First manually stamped event	Event xxx: 153, 4558
Second manually stamped event	Event xxx: 265, 7916
First manually stamped event Second manually stamped event	All times measured in software only. Event xxx: 153, 4558 Event xxx: 265, 7916

#### Table 4. \_Raw file for autonomous, single device.

	Ŷ.
	Timestep, Time, clear1, red1, green1, blue1, clear2,,, blue14, clear15, red15, green15, blue15
Line 1	0, 0, 981, 394, 320, 287, 1489, 608, 506, 427, 1246, 471, 437, 347, 804, 315, 279, 188, 203, 120, 47, 48,
	384, 227, 94, 92, 3725, 1419, 1208, 1030, 3363, 1374, 1038, 892, 2546, 943, 941, 749, 857, 332, 324, 219,
	466, 185, 167, 117, 490, 292, 107, 112, 2112, 828, 669, 592, 1790, 722, 583, 488, 850, 307, 304, 236
Line 2	1, 0, 981, 394, 320, 287, 1489, 608, 505, 427, 1246, 471, 437, 347, 804, 315, 279, 188, 203, 120, 47, 48,
	384, 227, 94, 92, 3725, 1419, 1208, 1030, 3362, 1374, 1038, 892, 2546, 943, 941, 749, 857, 332, 324, 219,
	466, 185, 167, 117, 490, 292, 107, 112, 2111, 827, 669, 592, 1790, 722, 583, 488, 850, 307, 303, 236
Line 3	2, 0, 982, 394, 320, 287, 1489, 608, 505, 427, 1248, 471, 437, 348, 806, 315, 279, 188, 203, 120, 47, 48,
	384, 227, 94, 92, 3724, 1418, 1207, 1030, 3357, 1372, 1036, 891, 2545, 943, 940, 749, 858, 332, 324, 219,
	465, 185, 167, 117, 491, 292, 107, 112, 2111, 827, 669, 592, 1793, 723, 584, 489, 850, 307, 303, 236
Line x	The total number of lines depends on the length of the run and the sampling increment



Fig. 5 —Normalized reflectance for the 15 element array. All data normalized to first 120 points collected.

In addition to this data stream, data analysis is provided in one of two ways. In the Live/Dripfeed usage, analysis is completed in real-time. In this case, indicators are provided on the control computer interface (Figure 6). Red indicates an active event; yellow indicates the cool down window is in progress; gray indicates negative detection status. Two files are also generated: \_slp and \_slp\_detail. The \_slp file provides a running list of the detected events (Table 5) while \_slp\_detail provides this list and includes the details of which indicator elements are involved in the events at what timesteps (Table 6). If offline data analysis is utilized (Appendix Z) for Live or Autonomous data, the \_slp and \_slp\_detail files are generated at that time.

rs ide 'hreshold Seats StDev a StDev b Slope c Global Cooldown Buffer Steps
tive
uve.

Fig. 6 — Control interface showing ongoing detection event.

Table 5.	Event report	provided by	slp file.

Description	Output by Line
Type of analysis used	Slope Data Analysis
Device specification	15 instrument seats numbered 1 - 15
User selected threshold minimum	Minimum Threshold Seats: 2
Sampling increment	Timestep: 30
Default detection parameter	Slope Threshold parameter: 0.45 degrees
Active event cool down window	Global Cooldown [s]: 600
	Buffer Zone [timesteps]: 10
Beginning of event 1 and involved elements	New Event: 1 at 4708 s. Initial Positive Seat(s): 9 10
End of event 1 and all elements involved	Event 1 ended at 6087 s. All Positive Seat(s): 1 3 5 6 9 10 12 13 15
Beginning of event 2 and involved elements	New Event: 2 at 8066 s. Initial Positive Seat(s): 1 2 12 14 15
End of event 2 and all elements involved	Event 2 ended at 10855 s. All Positive Seat(s): 1 2 3 4 5 6 7 8 10 11 12 13 14 15

Description	Output by Line
Type of analysis used	Slope Data Analysis
Device specification	15 instrument seats numbered 1 - 15
User selected threshold minimum	Minimum Threshold Seats: 2
Sampling increment	Timestep: 30
Default detection parameter	Slope Threshold parameter: 0.45 degrees
Active event cool down window	Global Cooldown [s]: 600
	Buffer Zone [timesteps]: 10
Beginning of event 1	New Event: 1 at 4708 s.
Elements leading to triggering of event	Positive Seat(s): 9 10
Involved elements at next change of state	Added new Positive Seat (s) at 4768 s: 5 9 10
Involved elements at next change of state	Added new Positive Seat (s) at 4798 s: 5 6 9 10 12 15
Involved elements at next change of state	Added new Positive Seat (s) at 4828 s: 1 5 6 9 12 15
All elements reporting non-event	Event 1 ended at 4978 s
New detection within the cool down window	Event 1 extended at 5427 s
Elements leading to triggering of event	Added new Positive Seat(s): 3 13
Involved elements at next change of state	Added new Positive Seat (s) at 5787 s: 3 13
Involved elements at next change of state	Added new Positive Seat (s) at 5847 s: 3 13
Involved elements at next change of state	Added new Positive Seat (s) at 5997 s: 10 13
End of event	Event 1 ended at 6087 s.
Beginning of event 2	New Event: 2 at 8066 s.
Elements leading to triggering of event	Positive Seat(s): 1 2 12 14 15

Table 6. Event report provided by \_slp\_detail file.

#### **Device Network**.

In networked use scenario, several devices (for examples provided here, we use six) are controlled by a single computer. Communication is established between the controlling computer and each device via onboard wireless one at a time, but parameters are fixed simultaneously with all devices using the same parameters. The custom software interface is used to begin data collection by all devices with the start time for each device associated with the sequence used to establish communication with the controlling software (Figure 7). The devices collect data until ordered to stop. As in the single device use case, interruptions, for example communications or power, will result in cessation of the real-time reporting, but the data in onboard memory is retained and can be recovered by reconnecting to the control computer.

For each set of data, several text files are generated: \_Network\_Data (Table 7), \_Parameters (as in Table 1), and \_Tagged\_Actions (as in Table 3). In addition, a folder is created for each of the devices in the network. These folders contain \_Metadata (as in Table 2), \_Raw (as in Table 4), and \_Data (again omitted here) files as well as a subfolder, 'Dripfeed\_Data'. The subfolders contain \_slp and \_slp\_detail files as described above (Tables 5 and 6).

										_
OM Port	Distributed N	letwork		Instrument Contro	ols			Dripfeed An	alysis	
Press Update to Populate 🛛 🔻	None 🔻			Run Type	Cycle Time	Integration Time	Gain	Algorithm	Paramet	ters
Update Add	Remove	Clear Table		Live	• 5 s	100 ms	• 1x	StDev	Ove	rride
Chart Char				Live/Dripfeed	🔵 30 s	200 ms		Slope	3	Threshold Seats
Start Stop				Autonomous		300 ms	0 10x		0.0001	5 StDev a
ress Update to Populate	Ean Controls			✓ Internal LEDs		500 ms	000		0.015	StDev b
	Fan 1 On	E 1.0#		4096		600 ms			0.45	Slope c
kperiment Name	ran i On			volue: 1-4006					0.43	
	Fan 2 On	Fan 2 Off		value: 1-4090					3600	Global Cooldown
	Mark Event in	n Data File							10	Buffer Steps
Stature OFF	Stature OFF		Stature OFF		Status OFF		Status OFF			Status OFF
Status: OFF	Status: OFF		Status: OFF		Status: OFF	DEE	Status: OFF	OFF		Status: OFF
Status: OFF Event: OFF	Status: OFF Event: OFF		Status: OFF Event: OFF		Status: OFF Event: C	DFF	Status: OFF Event	: OFF		Status: OFF Event: OFF
Status: OFF Event: OFF Timestep:	Status: OFF Event: OFF Timestep:		Status: OFF Event: OFF Timestep:		Status: OFF Event: C Timestep:	DFF	Status: OFF Event Timestep:	: OFF		Status: OFF Event: OFF Timestep:
Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15	11	Status: OFF Event: OFF Timestep: 15	11	Status: OFF Event: C Timestep: 15	DFF 11	Status: OFF Event Timestep: 15	: OFF 11		Status: OFF Event: OFF Timestep: 15 1
Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15	11	Status: OFF Event: OFF Timestep: 15	11	Status: OFF Event: C Timestep: 15	11	Status: OFF Event Timestep: 15	: OFF 11		Status: OFF Event: OFF Timestep: 15 1
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Status: OFF Event: OFF Timestep: 15 11 5 1 5 1 Sensor 1	Status: OFF Event: OFF Timestep: 15 5 Sensor 2	11 • • • • • • • • • • • • • • • • • • •	Status: OFF Event: OFF Timestep: 15 5 Sensor 3	11	Status: OFF Event: C Timestep: 15 5 Sensor 4	11 1 1	Status: OFF Event Timestep: 15 5 Sensor 5	11 1		Status: OFF Event: OFF Timestep: 15 1 5 5 Sensor 6

Fig. 7 — Screenshot for the control interface used for networked devices with live/dripfeed data collection.

Description	Output by Line
	Distributed Microsensor Experiment Data
	Global Level Information
Total number of devices used	Number of sensors in network: 6
	Specific device IDs:
	Sensor 1: Multiplex v3.1 AW
Individual device identification for each	Sensor 2: Multiplex v3.1 BW
element in the network	Sensor 3: Multiplex v3.1 CW
element in the network	Sensor 4: Multiplex v3.2 DW
	Sensor 5: Multiplex v3.1 EW
	Sensor 6: Multiplex v3.1 FW
Software iteration	Software version 1.4
Start time stamp for data collection	Network run started on 04 Oct 2019 at 10:24:24 AM
Start time stamp for data conection	[America/New_York]
	All instrument parameters are identical. They are:
	Integration Time: 400 ms
	Gain: 1x
	Cycle Time: 30 s
Parameters fixed within the user interface	Lighting: internal LEDs
	Intensity: 3072
	Data is not normalized
	Data is not offset
	No calibration file used
Stop time stamp for data collection	Network run stopped at 04 Oct 2019 at 02:08:22 PM
Stop time stamp for data conection	[America/New_York]

Table 7. \_Network\_Data file for multiple device use scenario.

Data for each of the devices in the networked scenario is processed independently while the output is displayed within the single interface. Report of an event by Sensor 1 has no impact on Sensor 2 in the current implementation. Data analysis, forced data downloads, etc can be completed offline using

approaches as described above for single devices. As in the case of the single device, Live/Dripfeed analysis is completed in real-time. In this case, indicators are provided on the control computer interface (Figure 8). Red indicates an active event; yellow indicates the cool down window is in progress; gray indicates negative detection status. The data reported for each device will reflect that presented in Figure 5.



Fig. 8 — Control interface showing ongoing detection event. Here, a three element minimum response threshold is used. Sensors 1 and 5, therefore, are in an overall negative state by failing to meet this requirement.

#### Offline Data Analysis.

Analysis of data files subsequent to cessation of data collection provides the opportunity to process data following a communications failure. This would be the data downloaded from the device flash memory upon reconnection or that collected during Autonomous or Live device use scenarios. Alternatively, it provides an opportunity to process the data using different requirements for detection, for example, with higher or lower sensitivities, different numbers of element minimums, etc (Figure 10). The output from this process is a subfolder 'Offline\_Analysis' that contains \_slp and \_slp\_detail files (Tables 5 and 6).

ABEAM Offline Data Analysis	5			- 🗆	×
			Choose Input		
Instrument Type ABEAM-6	Algorithm O StDev	Parameters	Threshold Seats	Override	
ABEAM-15     ABEAM-15 Networked	Slope	0.00015	StDev Threshold a		
ABEAMI-15, Networked		0.015	StDev Threshold b		
Use Raw Data		0.45	Slope Threshold c		
		3600	Global Cooldown		
		10	Buffer Steps		
Start Analysis Reset					

Fig. 9 — Interface for post data collection, offline analysis.

#### CONCLUSIONS

The discussion presented here is intended to offer a quick reference to the data output and supporting files provided under the various use scenarios for the v3.2 prototype reflectance devices. The files resulting from use of these prototypes vary significantly from those of the original reports on the six element prototypes.[1, 5, 6] The ongoing effort continues to screen additional indicators and targets as well as to address development of the target identification algorithms.

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Appendix A

# ABEAM OPERATING INSTRUCTIONS: SINGLE DEVICE, AUTONOMOUS, LIVE, AND LIVE/DRIPFEED

#### **DEVICE CONSIDERATIONS**

**Housing options:** The ABEAM-15 has two separate housing options: an open housing, and an outdoor housing. The open housing is designed for indoor use and for the detection of non-corrosive compounds. It provides access to the power and USB connectors, as well as the wireless module. Reset pins are easily available. The outdoor housing is designed to completely enclose the instrument electronics. As such, it is specifically designed for use with batteries and wireless communications only. The sealed nature of the housing provides protection from the elements and against corrosive compounds that might otherwise damage the instrument. It is not designed for submersion. In addition, the outdoor housing has a sun shield to prevent lighting variations from impacting measurements.

**Power options:** The ABEAM-15 can use either a 7.5 V DC power supply, or a 6S-NiMH rechargeable battery pack. The DC supply should have a 2.5 mm barrel jack with positive center polarity. The battery pack should be terminated with a standard male Tamiya connector. Configurations other than 6S are not recommended. ABEAM-15 hardware version 3.1 must be manually switched between the power supplies. This is accomplished by moving the position of a jumper.

ABEAM-15 hardware version 3.2 will automatically switch between the supplies. If a 7.5 V DC supply is plugged into an instrument with an attached battery, the instrument will automatically switch to the DC supply to conserve battery life. If the DC power supply is subsequently removed, the instrument will switch back to battery power.

Future hardware versions will incorporate built-in charging. At the moment, batteries must be externally charged.

Known Bug: Version 3.2 hardware will not cold start from a battery if a USB cable is connected and powered. You must first disconnect the USB cable, then wait a few seconds for the instrument capacitors to discharge.

**Communication options:** The ABEAM-15 can use either wireless or tethered (USB) communications. The USB requires a mini-B terminated cable. Wireless uses XBee modules, from Digi International. Series 3 modules are preferred, although series 2 modules are compatible. Due to speed, reliability, and power issues, all instrument hardware versions will automatically switch from wireless to tethered communications if a USB cable is plugged in. Note that in order to use XBee wireless, you will also need a coordinator, typically in the form of a dongle with a USB plug (not shown here). The coordinator is plugged into the computer.

#### **USE MODES**

The ABEAM-15 is a multiplexed, reflectance-based sensor for detection of chemical target vapors and aerosols. The full instrument package contains sensor hardware, a housing, and a software suite to control the instrument and for offline data analysis. The ABEAM-15 operates in three different modes:

- 1. Live Mode
- 2. Autonomous Mode
- 3. Network Mode

These three different modes are designed to provide utility in a wide variety of operational scenarios.

**Live mode:** In live mode, a single sensor is connected directly to a computer through either a USB cable or by wireless communications. Data generated by the sensor is transmitted directly from the instrument to the computer in real time. For each experiment, the software produces a folder containing files with raw data, run parameters, and metadata such as the hardware and firmware versions. Results are

available in real time through dripfeed data analysis, if desired. In addition, an offline data analysis can be performed using the analysis utility tool, which allows the user to optimize analysis parameters.

Live mode is useful for short term experiments, primarily laboratory experiments. Live mode provides the opportunity to obtain calibration data, to select indicators, or to optimize the instrument for use in a specific scenario. Live mode is also useful when the instrument will be used in conjunction with an unmanned vehicle, especially if the instrument can be directly controlled from the platform.

**Autonomous mode:** A sensor can be set up to run in autonomous mode. In this case, the instrument is initially connected to a computer in order to select run parameters and issue a 'start' command. Once the instrument has started running, the USB cable or wireless connection is removed, and the sensor can be transported to any desired location. The sensor will continue to run and collect data until either there is a power interruption, the internal (flash) memory is filled, or the user re-connects the control computer and issues a 'stop' command. In autonomous mode, a live stream of data is not available. In order to recover data, the user must re-connect the control computer and manually download the files. Once this has been completed, offline data analysis can be performed anytime using the analysis utility tool.

Autonomous mode is useful for long-term experiments, especially those completed outdoors. A large number of instruments can be set up, one at a time, in an outdoor location for perimeter monitoring or other applications. Experiments can be started and stopped at the point of collection using the control computer.

**Network mode:** Network mode combines features of both live and autonomous modes. Similar to autonomous mode, multiple sensors can be run simultaneously, and data is stored on the instrument in flash memory for later recovery if desired. Similar to live mode, data is also transferred to a computer in real time. Dripfeed data analysis is performed on each connected sensor as data comes in, making results available in real time. Offline data analysis can be performed at any time on the raw data files. If a network connection is broken, data can still be recovered through individual sensor downloads.

At present, the software suite allows network runs of up to six sensors. All sensors must be connected through wireless; USB is not an option for a network run. We anticipate that future software versions will relax this requirement and increase the number of sensors that can be networked in a single experiment.

Network mode is useful for setting up distributed microsensor networks with real-time feedback.

#### Live, Live/Dripfeed, Autonomous

The software is a file named "Multiplex\_314u.jar". You can run the program by double-clicking on it. After doing this, you should see the startup screen, shown in Figure A1.

In order to run an experiment, the following steps should be performed:

- 1. Connect the ABEAM-15 USB cable to the computer, or connect the XBee wireless dongle
- 2. Start the software
- 3. Populate the COM port list and open the selected instrument
- 4. Choose a filename
- 5. Set the instrument parameters
- 6. Set the software parameters
- 7. Set the dripfeed analysis parameters (if using)
- 8. Start the experiment

Press Update to scan the COM ports for attached devices. In the example shown (Figure A2), two different instruments are attached to the computer; they are identified as G and H. Select the desired instrument and press Open (the button is hidden under the drop box).

Fig. A1. Startup screen.

Multiplex v3	3.14u Front En	nd 1.4 (230.4 k	baud)								-	
COM Port			Instrument Cor	ntrols			Software Controls			Dripfeed An	alysis	
Press Update Start Press Update Press Update Experiment N Press	e to Populate pen Clo op Status to Populate ame ss Upd attach	ate to	Run Type Live Live/Dripfe Autonomou Internal LEC 4096 value: 1-4096 France Flach Scan for vices	Cycle Time © 5 s ed  ③ 30 s us Download D. File Name	Integration Time 100 ms 200 ms 300 ms 400 ms 600 ms ata Force (~	e Gain	Options Normalize Data Offset Data Use Calibration.txt or _F Choose File Fan Controls Fan 1 On Fan Ank Event in Data	Norm Const 5000 Default Parameters.txt F	Offset Const O Default ile Name	Algorithm StDev Slope	Parameters           Override           3         Thresh           0.00015         Stf           0.015         Stf           0.45         Slc           3600         Glob           10         Buffe	old Seats Dev a Dev b Ipe c al Cooldown rr Steps
Timestep Time [h/m/s] Sensor 1 2	Clear	Red	Green	Blue				Mark Ev		Dripfeed Ev	I OFF ent Status: OFF	
3 4									v	5	1	

Fig. A2. Connect the software to the instrument.

Multiplex v3	.14u Front En	d 1.4 (230.4 k	baud)								- 🗆 ×
COM Port			Instrument Cont	rols			Software Controls			Dripfeed Ar	alysis
COM22 Mult COM22 Mult COM23 Mult COM22 Multip Experiment Na	tiplex v3.2 G iplex v3.2 G inlex v3.2 H olex v3.2 G ame Selec press 1 locato	ct an it the <i>Op</i> ed und	Instrument Cont Run Type ● Live ● Live/Dripfeee ● Autonomous ✓ Internal LED: 4096 value: 1-4096 Ence Clubb Instrument en button lerneath t	Cycle Time 5 5 5 3 30 5 Countrated De- The , which he dro	Integration Time	e Gain	Software Controls Options Normalize Data Offset Data Use Calibration _Calibration.txt or _P Choose File Fan Controls Fan 1 On Fan 1 Fan 2 On Fan 2 Mark Event in Data F	Norm Const 5000 Default arameters.txt F 0 Off 2 Off ile Mark Ev	Offset Const Default ile Name	Algorithm StDev StDev	Parameters Override 3 Threshold Seats 0.0015 StDev a 0.015 StDev b 0.45 Slope c 3600 Global Cooldown 10 Buffer Steps
The second		de	own box.						^	Dripfee	d OFF
limestep											
Time [h/m/s]										Ev	ent Status: OFF
Sensor 1 2 3 4	Clear	Red	Green B	lue						15 00 00 5	11

After opening the instrument, the firmware version and instrument status will appear in the status box (Figure A3). You can check the status of the connected instrument at any time by pressing Status.

Multiplex v3.14u Front End 1.4 (230.4 I	c baud)		– 🗆 X
COM Port	Instrument Controls	Software Controls	Dripfeed Analysis
COM22 Multiplex v3.2 G Update Open Close Start Stop Status Firmware Version: Multiplex v3.20 Status: Idle Experiment Name You COM	Run Type Live Live Live Live Cycle Time 100 ms 200 ms	ain Options Norm Const Offset Const 1 x Normalize Data 5000 0 4 x Offset Data Default Default 16 Use Calibration Default Default Calibration Det of Parameters.txt File Name Calibration Det of Parameters.txt File Name Calibration Det of Parameters.txt File Name mnect the esssing Close of Pan 2 On Fan 2 Off Mark Event in Data File Mark Event	Algorithm Parameters StDev Slope 3 Threshold Seats 0.0015 StDev a 0.015 StDev b 0.45 Slope c 3600 Global Cooldown 10 Buffer Steps
Timestep         Image: Clear         Red           1         Image: Clear         Red           2         Image: Clear         Red           3         Image: Clear         Red           4         Image: Clear         Red	Green Blue	Ĵ	Dripfeed OFF Event Status: OFF 15 11 5 1

#### Fig. A3. Instrument status

Before starting an experiment, it is necessary to give it a unique name. Type it into the Output File box, under the heading "Experiment Name" (Figure 4). Do not add file extensions to the file name. This will be done automatically as needed.

A unique Experiment Name must be chosen before starting an experiment. When running an experiment, the software generates a folder, named Experiment Name, containing five different files. The folder and all of these files will have their names constructed from the Experiment Name. These five files are:

[Experiment Name]\_Raw.txt Raw experimental data collected from the instrument. It is not modified in any way.

[Experiment Name]\_Data.txt Similar to the \_Raw file, the data file is experimental data collected by the instrument, but modified by any software parameters or calibration as selected by the user. This will be described later.

[Experiment Name]\_Metadata.txt Contains information about the experiment including firmware and software version, timestamp, and values for the user selected instrument parameters. If a calibration file was used, the filename and its values are listed.

[Experiment Name]\_Parameters.txt Similar to the metadata file, it contains the user selected instrument parameters. The difference is that the \_Metadata file is in a text format intended to be read by the user. The \_Parameters file is in a numerical format meant to be used as an input to the software.

[Experiment Name]\_Tagged\_Actions.txt Any user tagged actions and the time at which they were tagged are listed here. Tagging the experiment in real time will be described later.

Multipley v3 14u Front Fr	od 1 4 (230 4 k	haud)								
COM Port	IG 1.4 (200.4 K	Instrument Cont	trols			Software Controls			Drinfeed An	alveic
		Run Tune	Curcle Time	Integration Time	Gain	Ontions	Norm Const	Officiat Counct	Algorithm	Darameters
COM22 Multiplex v3.2 G	•	(a) Live	© E a	Integration rime	<ul> <li>Gain</li> <li>The</li> </ul>	Nermaline Date	Norm Const	Onset Const		
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Start Stop Statur		Cive/Driplee	a 0 50 s	200 ms	4x	Ulse Calibration	Default	Default	<ul> <li>Siope</li> </ul>	3 Intestiold Seats
Start Stop Status	2.20	Autonomou	5	0 300 ms	0 10x	Calibration but on D	ana ana tana tan I	ile Name		0.00015 StDev a
Firmware Version: Multiple	ex v3.20	Internal LED	-	- 400 ms	OUX	_Calibration.txt or _P	arameters.txt r	ne Name		0.015 StDev b
Status: Idle			S	600 ms						0.015
Experiment Name		4096		000 ms		Choose File				0.45 Slope c
Experiment1_093019		value: 1-4096				5.0.1.1				3600 Global Cooldov
		Frase Flash	Download Da	ta Eorce (~	7 min)	Fan Controls				10 Buffer Steps
	<b>\</b>	Description	File Name		,	Fan 1 On Fan 1	1 Off			
		_Parameters.txt	File Name			Fan 2 On Fan 2	2 Off			
						Mark Event in Data E	File			
	- N	Choose File								
	]	Don't add	file ex	tensions	to the		Mark Ev	vent		
		evn	orimon	t name						
Timestep		Слр		it name.				â	Dripfeed	d OFF
Time [h/m/s]									Ev	ent Status: OFF
Sensor Clear	Red	Green E	Blue						15	11
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2										
2										
3										
4									5	1
e								~		

Fig. A4. Choose experiment name

Instrument parameters (Figure A5) control the way data is collected at the hardware level, such as integration time. The effect of any instrument parameters will be reflected in both the \_Raw and \_Data files. Before starting an experiment, it is necessary to set the instrument parameters. They are: run type, cycle time, integration time, gain, LED, and LED intensity. Once an experiment has started, these parameters may not be changed.

*Run Type:* Live or Autonomous. In a live run, the instrument must remain tethered to the computer and connected to the software. Results are updated at the end of each measurement cycle. In contrast, after starting an autonomous run, the software can be disconnected and the instrument detached from the computer. Results can only be downloaded after the experiment is complete.

*Cycle Time:* This is the amount of time between each successive measurement. One measurement is a datapoint from all 15 sensors.

*Integration Time:* Choices are 100 - 600 ms. Each sensor will collect light over a finite period of time, the integration time, before reporting the result. The longer the collection period, the higher the signal.

*Gain:* Choices are 1x, 4x, 16x, and 64x. This is a digital gain; it simply multiples the result by the selected constant after the integration has finished.

*LED:* Select this box to use the instrument's eight internal LEDs. Un-check the box if you wish to use your own light source, or none at all.

*LED Intensity:* If the internal LEDs are used, this value specifies their intensity. 1 is the minimum value, and 4096 is full. Response is roughly linear.

Advice: sensor data is reported as a 16-bit number (0 - 65,535). Making full use of this range may be advantageous. Then darkness would be close to 0, while complete saturation would be close to 65,535. For fast sensor response, it is good to minimize integration time. Therefore, increase the gain first to expand the instrument range. Only when gain is maximum should integration time be increased. Note that for

technical reasons, integration times of less than 154 ms will provide less than the full 16-bit range. High LED intensity (especially coupled with long integration times) can cause photobleaching, but, in general, LED intensity should be set as large as possible.

During a live experiment, the ABEAM-15 sends its data to software as soon as it is collected. During an autonomous experiment, this data is saved to internal flash memory and retrieved at a later time. Before an experiment can be run, the firmware must first erase the flash. This process can take 30 seconds or more. In many cases, this is not a problem; however, if the operator requires an "instant start" or needs to know the exact time at which the ABEAM-15 starts collecting data, this erase cycle can be completed in advance by selecting the Erase Flash button, before starting an experiment.

Multiplex v3.	14u Front End	1.4 (230.4 k bau	d)									-		$\times$
COM Port			Instrument Contro	ls			Software Controls			Dripfeed Ana	lysis			
COM22 Multi Update C Start Stop Firmware Versi Status: Idle Experiment Na Experiment1_	iplex v3.2 G Open Clos p Status ion: Multiplex v .093019	e 63.21	Run Type Live Dripfeed Autonomous V Internal LEDs 2048 value: 1-4096 Erase Flash [ 	Cycle Time 5 s 30 s Download Date e Name	Integration Time 100 ms 200 ms 300 ms 400 ms 500 ms 600 ms a Force (~7	Gain 1x 4x 16x 60x 7 min)	Options Normalize Data Offset Data Use Calibration.txt or Choose File an Controls Fan 1 On Fan Fan 2 On Fan Mark Event in Data	Norm Const C 5000 Default Parameters.txt File	0 Default Name	Algorithm StDev Stope	Parameter Overri 3 T 0.00015 0.45 3600 10	s de hreshold StDe StDe Slope Global Buffer	d Seats v a v b c Cooldov Steps	wn
Timestep Time [h/m/s]									Î	Dripfeed Even	OFF nt Status: C	)FF		
Sensor 1 2 3 4	Clear	Red	Green Blu	e					×	15 00 5		11		

Fig. A4. Instrument parameters

Software parameters control modifications to the data after it is collected and downloaded (Figure A5). The effect of any software parameters will be reflected in only the \_Data file. The \_Raw file captures the same data, but without any of the software parameters applied. It is not necessary to select any of the software parameters before starting an experiment; however, these parameters may not be changed during an experiment. Live data will be displayed with modifications specified by the software parameters, and software modified data is recorded in the \_data.txt file. Raw data (before modification by any software parameters) is always available to the user. It is stored in a separate location, in the \_raw.txt file.

Software data modification is a three-step process. All of these processes are optional and any of them can be skipped. Those processes that are selected will always be performed in order: normalization, calibration, offset.

*Normalize Data:* This attempts to address incident light non-uniformity and drift. If Normalize Data is checked, a value for Normalize Constant must be specified (a value of 1 is acceptable). For each sensor, the R, G, and B values will be divided by the C value. This addresses the fact that different sensors may be illuminated at different intensities. Then, the data will be multiplied by the value of Normalize Constant, which sets the magnitude of the baseline. After normalization, it is possible to get fractional (but not negative) data.

*Calibration:* Calibration allows the user to experimentally measure color standards with the sensor and set their default values in a calibration matrix. If Use Calibration is checked, a file must be provided with

these calibration constants. After calibration, it is possible to get negative data. It is also possible to expand (stretch) the range of data beyond 16 bits. To create a calibration, a different software program is required. The calibration file ALSO stores hardware parameters from the instrument control menu. When Use Calibration is checked, these parameters will also be implemented. The calibration matrix is currently an average over ALL sensors.

*Offset:* This attempts to deal with negative data that may result from using a calibration. If Offset Data is checked, it transforms the entire dataset by adding a constant value (the Offset Constant). The value of Offset Constant must be between 0 and 65,535.

		hereits									
Multiplex V3. 14u Front E	na 1.4 (230.4 k	baud)									- 0 /
COM Port		Instrument Contr	ols			Software Controls			Dripfeed An	alysis	
COM22 Multiplex v3.2 G	-	Run Type	Cycle Time	Integration Time	Gain	Options	Norm Const C	ffset Const	Algorithm	Parameter	rs
Update Open C	lose	Live	• 5 s	100 ms	1x	✓ Normalize Data	1000	0	StDev	Overri	ide
		Live/Dripfeed	i 🔵 30 s	200 ms	<u> </u>	Offset Data	Default	Default	Slope	3 Т	Threshold Seats
Start Stop Statu	IS	Autonomous		300 ms	16x	Use Calibration				0.00015	StDev a
Firmware Version: Multiple	ex v3.20			400 ms	0 60x	_Calibration.txt or _P	Parameters.txt File	Name			StDay b
Status: Idle		✓ Internal LEDs		500 ms		-				0.015	SLDEV D
Experiment Name		2048		600 ms		Choose File				0.45	Slope c
Experiment1_093019		value: 1-4096								3600	Global Cooldowr
		Erase Flash	Download Da	ata Force (~	7 min)	Fac 1 On	6.0%			10	Buffer Steps
		_Parameters.txt F	ile Name								
						Fan 2 On Fan 2	2 Off				
			alv an	nonatad		Mark Event in Data F	File				
		A previou	siy ge	nerateu			Mark Even				
	cal	ibration o	r para	meters f	ïle						
Timestep		can be	used	here				^	Dripfeed	OFF	
Time [h/m/s]	-	cun se	abea						Ev	ent Status: O	DFF
Sensor Clear	Red	Green Bl	ue						15		11
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c								~			

A file can be used to set the instrument and software parameters. As noted above, when Use Calibration is checked, it implements both the calibration matrix and (hardware) instrument parameters stored in the file.

There are three things to note:

- (1) It is possible to duplicate all of the software and hardware parameters from a previous run by checking Use Calibration and simply using the \_parameters.txt file as input. Either a calibration file ("Calibration.txt") or a \_parameters.txt file can be used here. Both can be read by the software.
- (2) A calibration file with values of 1 in every entry in its matrix will have no effect on the data. When the \_parameters.txt file is generated by the software, if no calibration file was used, it does exactly this: the matrix values are all populated with 1's.
- (3) This allows the user to regenerate all of the conditions used in a previous experiment by simply linking to the old parameter file that was used to collect that particular data set.

In order to use real-time, dripfeed analysis, you must select Live/Dripfeed from the instrument controls (Figure A6). These parameters affect the data analysis and are fully described in an NRL Report (NRL/MR/6930-18-9812; this report is available at Distribution A) Selecting "Override" will allow you to set the values that are normally greyed out.

15 G G

Multiplex v3.14u Front End 1.4 (230.4 k bau	d)			×
COM Port	Instrument Controls		Software Controls	Pripfeed Analysis
COM22 Multiplex v3.2 G 🛛 👻	Run Type Cycle Time	Integration Time Gain	Options Norm Const Offset Const	Algorithm Parameters
Update Open Close	Live 💿 5 s	0 100 ms 1x	V Normalize Data 1000 0	StDev Override
	Live/Dripfeed 30 s	200 ms 4x	Offset Data Default Default	Slope 3     Threshold Seats
Start Stop Status	Autonomous	300 ms 16x	Use Calibration	0.00015 StDev a
Firmware Version: Multiplex v3.20		• 400 ms • 60x	_Calibration.txt or _Parameters.txt File Name	0.015 StDev b
Status: Idle	V Internal LEDs	000 ms		0.015
Experiment Name	2048	000 ms	Choose File	0.45 Slope c
Experiment1_093019	value: 1-4096		Fan Controls	3600 Global Cooldow
	Erase Flash Download Da	ta Force (~7 min)		10 Buffer Steps
	Parameters.txt File Name		Fan TOn Fan TOm	
			Fan 2 On Fan 2 Off	
			Mark Event in Data File	
	Choose File		Mark Event	
			Walk Event	
Timesten			<u>^</u>	Dripfeed OFF
		Dripfeed ana	alysis results	Event Status: OFF
Time [h/m/s]		annaar hara	in real time	→
Sensor Clear Red	Green Blue	appear nere	iii i cai tiine	15 11
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2				
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4				2
E C C C C C C C C C C C C C C C C C C C			~	

#### Fig. A6. Dripfeed analysis parameters (if used)

To stop a device, press the Stop button (Figure A7). For autonomous use, you must first tether the instrument to the computer and connect the software.

Fig. A7. Stopping an experiment

Multiplex v3	.14u Front En	d 1.4 (230.4 k b	aud)								– 🗆 ×
COM Port			Instrument Co	ntrols			Software Controls			Dripfeed An	alysis
COM22 Mult Update Start Sto Running Live B Experiment Na Experiment 1,	iplex v3.2 G Open Cle p Status ixplicit internet ame _093019	Selec	Run Type Live Live/Dripfi Autonome 2048 value: 1-4096 Erase Flash t Stop to experime	Cycle Time Cycle Time 5 s us Ds Download D end th ent	e Integration Time 100 ms 200 ms 300 ms 400 ms 500 ms 600 ms Porce (~ e e mples, 314 data \ fx	e Gain 1x 4x 1bx 60x 7 min) rperimen	Options ✓ Normalize Data Offset Data Use Calibration _Calibration.txt or _I Choose File Fan Controls Fan 1 On Fan Fan 2 On Fan Mark Event in Data	Norm Const 1000 Default Parameters.txt F 10ff 2 Off File Mark Ev	Offset Const Default ile Name	Algorithm	Parameters Override Threshold Seats 0.00015 StDev a 0.015 StDev b 0.45 Slope c 1800 Global Cooldown 10 Buffer Steps
Timestep	27								Â	Event Numb	er: 1
Time [h/m/s]	0	2	15							Event :	Status: Positive
Sensor	Clear	Red	Green	Blue						15	11
1	2304	159	300	570							
2	3885	141	305	588						ŎŎŎ	
3	4041	152	292	568							
4	3980	147	279	559						5	1
£	2002	140	202	671					~		

Specifically for autonomous experiments: When a live device run is started, five different files are created (as described in a previous slide). In the case of an autonomous experiment, only three are created immediately: \_Metadata.txt, \_Parameters.txt, and \_Tagged\_Actions.txt. The other two files are created during the download process itself: \_Raw.txt and \_Data.txt. In order to properly process the incoming data, the software parameters must be known. Unlike the instrument parameters, they are not stored in the flash memory at start time. In theory, software parameters could be entered at the time of the download. However, there are two problems with this:

(1) It is important to record the exact conditions used to create the \_Data.txt file.

(2) An autonomous experiment could have been started some time ago (days, weeks, or even months) by one operator and later retrieved by a second one. It is possible that the second operator does not remember or have access to the desired software parameters for that particular experiment.

Issue #1 could be addressed by generating the \_Parameters.txt file at the time of download, rather than at the time the experiment was started. However, this does not address issue #2. For now, the software is set up to require a \_Parameters.txt file to complete the download. This may be changed in the future by adding two radio buttons: "Use \_Parameters file" and "Generate \_Parameters file". (In case of lost files, there is an alternative described later)

If an instrument is not shut down in an orderly way during an experiment, there may be problems downloading the data. When this happens, the operator should check the Force button before pressing Download Data (Figure A8). This does two things: (1) It downloads the entire contents of the flash memory, whether there is data there or not. Blank data points will have a raw value of 65,535. (2) It allows the operator to download data from the instrument without the use of a \_Parameters.txt file. In this case, only \_Raw.txt will be created, and it will assume that no software modifications to the data are desired. If modifications are desired, they will need to be performed at a later time.

Fig. A8. Force download of	ption										
Multiplex v3.14u Front End 1.4 (230.4 k bau	ıd)								-	- 0	×
COM Port	Instrument Contro	ls			Software Controls			Dripfeed Ana	alysis		
COM22 Multiplex v3.2 G Update Open Close Start Store Status Firms Parameters not r Status Idle can be used if Experiment Name	Run Type Live Live/Dripfeed Autonomous Cequired, Autonomous required, Parameters.txt File	Cycle Time • 5 s 30 s <b>but</b> • Nownload Data • Name	Integration Time 100 ms 200 ms 300 ms 400 ms 600 ms a V Force (~)	Gain 1x 4x 16x 60x 7 min)	Options  Normalize Data Offset Data	Norm Const 1000 Default Parameters.txt F 1 Off 2 Off File Mark Ev	Offset Const 0 Default ile Name	Algorithm StDev Slope	Parameter Overri 3 T 0.00015 0.015 0.45 3600 10	s de hreshold Sei StDev a StDev b Slope c Global Coo Buffer Step	ats Idown s

Time is measured in two different ways during an experiment. The hardware inside the ABEAM-15 times the measurement cycles. The experiment start and stop times are recorded using the software computer's clock. Both of these will appear in the output files. However, it is possible that neither of these agree with the operator's clock (a watch, cell phone, or similar). Tagging events can be used to synchronize these two clocks to the third (the operator's clock).

To tag an event, simply name the event and press the Mark Event button. The event will appear in the \_Tagged\_Events.txt file. For a live run, the event name is accompanied by the current datapoint (hardware clock) and timestamp (software clock). For an autonomous run, there is no datapoint information. This function can be used to effectively identify calibration peaks, to mark a synchronization point, or to measure instrument response time to an exposure.

#### Fig. A9. Tagging events

Multiplex v3.14u Front End 1.4 (230.4 k baue)	ł)							-		Х
COM Port	Instrument Controls			Software Controls		[	Dripfeed Analy	/sis		
COM 22 Multiplex v3.2 G  Update Open Close Start Stop Status Firmware Version: Multiplex v3.20 Status: Idle Experiment Name	Run Type Cycle T Live Order 5 s Live/Dripfeed 30 Autonomous V Internal LEDs 4096 value: 1-4096 Erase Flash Downloa _Parameters.bt File Name Choose File	Time Integration Time s 100 ms 0 s 200 ms 300 ms 400 ms 500 ms 600 ms ad Data ✔ Force (~7	Gain 1x • 4x 16x 60x min)	Options Options Normalize Data Offset Data Use Calibration Calibration.txt or _P Choose File Fan Controls Fan 1 On Fan 1 Fan 2 On Fan 2 Mark Event in Data F	Norm Const Offset	Const /	Ngorithm F StDev StDev	Parameters Override 3 Thr 0.00015 0.45 3600 C 10 B	e eshold Seat: StDev a StDev b Slope c Slobal Coold iuffer Steps	; own

Appendix B

# ABEAM OPERATING INSTRUCTIONS: MULTIPLE NETWORKED DEVICES

The interface and use guidance for ABEAM-15 devices in a network scenario is similar to that described for the individual units of Appendix A. In this case, the software is a file named "starPointSix.jar".

Fig. 1	B1.	The startup	screen	for the	network	software
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Wireless Distributed Sensor Interface	v1.0 (230.4 k baud)							- C	1 ×
COM Port Press Update to Populate Update Start Stop	Distributed Network None Remove Clear Table	Ins Rui Ins	trument Controls n Type Cy Live Live/Dripfeed Autonomous	rcle Time Integration Time 5 s  100 ms 30 s 200 ms 300 ms	e Gain • 1x • 4x • 16x	Dripfeed Ana Algorithm StDev Slope	Aysis Parameters Override 3 Thresh	old Seats Dev a	
Press Update to Populate Experiment Name	Press Update for attached of Fan 2 On Fan 2 Of Fan 2 Of Mark Event in Data File	to scan for levices	Internal IEDs 096 uer 1–1096	<ul> <li>400 ms</li> <li>500 ms</li> <li>600 ms</li> </ul>	60x		0.00015 StD 0.45 Slo 3600 Glob 10 Buffe	)ev b ipe c al Cooldowi ir Steps	n
Status: OFF Event: OFF Timestep: 15 11 5 1	Status: OFF Event: OFF Timestep: 15 11 5 1	Status: OFF Event: OFF Timestep: 15 11 5 1	Stat	us: OFF Event: OFF estep: 11	Status: OFF Event: Timestep: 15	11 11	Status: E E Timest	: OFF Event: OFF tep:	11
Sensor 1 ID:	Sensor 2 ID:	Sensor 3 ID:	Sen: ID:	sor 4	Sensor 5 ID:		Sensor ID:	rб	

All sensors in the network must be wireless and connected to the same dongle (single COM port). The order of the instruments in the COM port list is not important. Updating the COM port list will not change the Distributed Network list.

Fig. B2. Populating the network

Wireless Distributed Sensor Interface	v1.0 (230.4 k baud)							- 0	×
COM Port COM24 Multiplex v3.1 CW COM24 Multiplex v3.1 EW COM24 Multiplex v3.2 DW COM24 Multiplex v3.1 FW COM24 Multiplex v3.1 AW COM24 Multiplex v3.1 BW	Distributed Network None  Remove Clear Table Fan Controls Fan 1 On Fan 1 Off Fan 2 On Fan 2 Off Mark Event in Data File	Instrument Contr Run Type Live Live Live/Dripfeec Autonomous V Internal LEDs 4096 value: 1-4096	Cycle Time Cycle Time 5 s 30 s	Integration Time 100 ms 200 ms 300 ms 400 ms 500 ms 600 ms	Gain 1x 4x 16x 60x	Dripfeed Ana Algorithm StDev Slope	alysis           Paramete           Overr           3           0.00015           0.015           0.45           3600           10	rs ide Threshold Seats StDev a StDev b Slope c Global Cooldown Buffer Steps	1
Status: OFF Event: OFF Timestep: 15 11 5 1 5 1 5 1 5 1 1 5 1 1 5 1 1	Status: OFF Event: OFF Timestep: 15 11 5 1 5 1 Sensor 2 ID:	et sensors to add to ork one at a time. ( ) add them individ 15 11 5 1 5 1 5 1 5 1 1 5 1	the Click ually. 15 5 Sensor 4 D:	11 1 1	Status: OFF Event: C Timestep: 15 5 Sensor 5 ID:	11 •••• ••• 1		Status: OFF Event: OFF Timestep: 15 5 Sensor 6 D:	11

The order of the sensors in the Distributed Network is important. You can remove a sensor at any time by clicking *Remove*. Or, clear the entire list by clicking *Clear Table*. The Network can hold no more than six instruments. Less than six is OK.



Network experiments will always use dripfeed analysis. Set instrument controls, dripfeed analysis parameters, and choose an experiment name. Details are provided in Appendix A. Press Start to begin data collection.

/ireless Distributed Sensor Interface	v1.0 (230.4 k baud)				
OM Port COM24 Multiplex v3.1 FW Update Add	Press <i>Start</i> to h data collecti	begin Run Z	nent controls pe Cycle Time Integration re	Dipried A n Time Cein Algorithm is StDev is 4x Slope	Inalysis Parameters V Override 3 Threshold Seats
start stop ensor Multiplex v3.1 FW added	Network on COM24	Au	itonomous 300 m	s	0.00015 StDev a
operiment Name	Fan Controls Fan 1 On Fan 1 Of	ff 4096	ternal LEDs 500 m 600 m 1-4096	s s	0.45 Slope c
	Mark Event in Data File				10 Buffer Steps
		Mark Event			
Status: OFF	Status: OFF	Mark Event Status: OFF	Status: OFF	Status: OFF	Status: OFF
Status: OFF Event: OFF	Status: OFF Event: OFF	Mark Event Status: OFF Event: OFF	Status: OFF	Status: OFF Event: OFF	Status: OFF Event: OFF
Status: OFF Event: OFF Timestep:	Status: OFF Vent: OFF Timestep:	Mark Event Status: OFF Event: OFF Timestep:	Status: OFF Event: OFF Timestep:	Status: OFF Event: OFF Timestep:	Status: OFF Event: OFF Timestep:
Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11	Mark Event Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 1
Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11	Mark Event Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 1
Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11	Mark Event Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11	Status: OFF Event: OFF Timestep: 15 11
Status: OFF Event: OFF Timestep: 15 11 5 1	Status: OFF Event: OFF Timestep: 15 11 5 1	Mark Event Status: OFF Event: OFF Timestep: 15 11 5 1	Status: OFF Event: OFF Timestep: 15 11 5 1	Status: OFF Event: OFF Timestep: 15 11 5 1	Status: OFF Event: OFF Timestep: 15 11 5 1
Status: OFF Event: OFF Timestep: 15 11 5 11 5 1 5 1 5 1 5 1	Status: OFF Event: OFF Timestep: 15 11 5 1 5 1 5 1 5 1	Mark Event Status: OFF Event: OFF Timestep: 15 11 5 1 5 1 5 1 5 1	Status: OFF Event: OFF Timestep: 15 11 5 1 5 1 Sensor 4	Status: OFF Event: OFF Timestep: 15 11 5 1 5 1 Sensor 5	Status: OFF Event: OFF Timestep: 15 11 5 1 5 1 5 1 5 1

Fig. B4. Set instrument and dripfeed parameters

As in Appendix A, selecting *Stop* will end data collection. This will take 1 to 3 minutes during which the software will be frozen; do not force quit.

The StarPointSix interface only contains options that affect all six sensors. However, individual instruments do save their data to flash, and it is possible to analyze an individual instrument's data offline.

- (1) To download data from an individual sensor, connect to it using Multiplex\_314u (Appendix A).
- (2) To analyze data from an individual sensor file in a network run, use the Analysis.jar tool (Appendix C).

Tagging events in StarPointSix.jar works exactly like it does in Mulitplex\_314u.jar, except that it affects all of the attached sensors.

There are both global and local metadata files in a network run. Tagged events are saved to the global file. Also, time is kept from a single master clock. Individual timesteps are recorded for each sensor, but the real time measurement is in reference to the central clock. The times from different sensor files can be compared directly against each other.

Appendix C

### ABEAM OPERATING INSTRUCTIONS: OFFLINE DATA ANALYSIS

Offline, post-collection analysis of the data can be completed using the software is a file "Analysis.jar". Many of the options look identical to those in Multiplex\_314u (Appendix B), and they work the same way. When selecting the instrument data to analyze, the exact file chosen is not important. It just needs to be in the correct directory. For example, you could choose the \_data, \_parameters, or \_raw file for the particular set of data.



Be sure to specify the instrument type that was used to obtain the data. Instruments using network mode have different file structures than instruments in live and autonomous mode. It is important to get this distinction correct or the software will return errors.



	ABEAM Offline Data Analysis			- 🗆	×
Instrument Type Algorithm   ABEAM-6   ABEAM-15   ABEAM-15   ABEAM-15, Networked   Use Raw Data     Isope   Isope	Algorithm ABEAM-6 ABEAM-15 ABEAM-15, Networked Use Raw Data Start Analysis Reset	Parameters 3 0.00015 0.015 0.45 3600 10	Choose Input Threshold Seats StDev Threshold a StDev Threshold b Slope Threshold c Global Cooldown Buffer Steps	Override	

Select *Start Analysis* to analyze your data set.

A data file may be analyzed more than once with different sets of parameters. In order to do this you must re-name or remove the original offline analysis. It is located in a folder named "Offline\_Analysis". The entire folder must be moved, renamed, or deleted.