Millimeter Wave Ranging and Synchronization System (MiRS)

SBIR Kickoff Meeting
October 2020
Period of Performance: 09/10/20 – 03/15/21

Presented to:
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intellisense SYSTEMS

Two years of steady progress and growth

2020

Grew to ~150 employees (>50 with advanced degrees)
Military veterans make up 6% of our staff.

2019

2018 revenues were $26.1 million USD
40% SBIR, 60% Production/Tech transition.

Intellisense Systems, Inc. began independent operations in February 2018 as a private small business.

2018

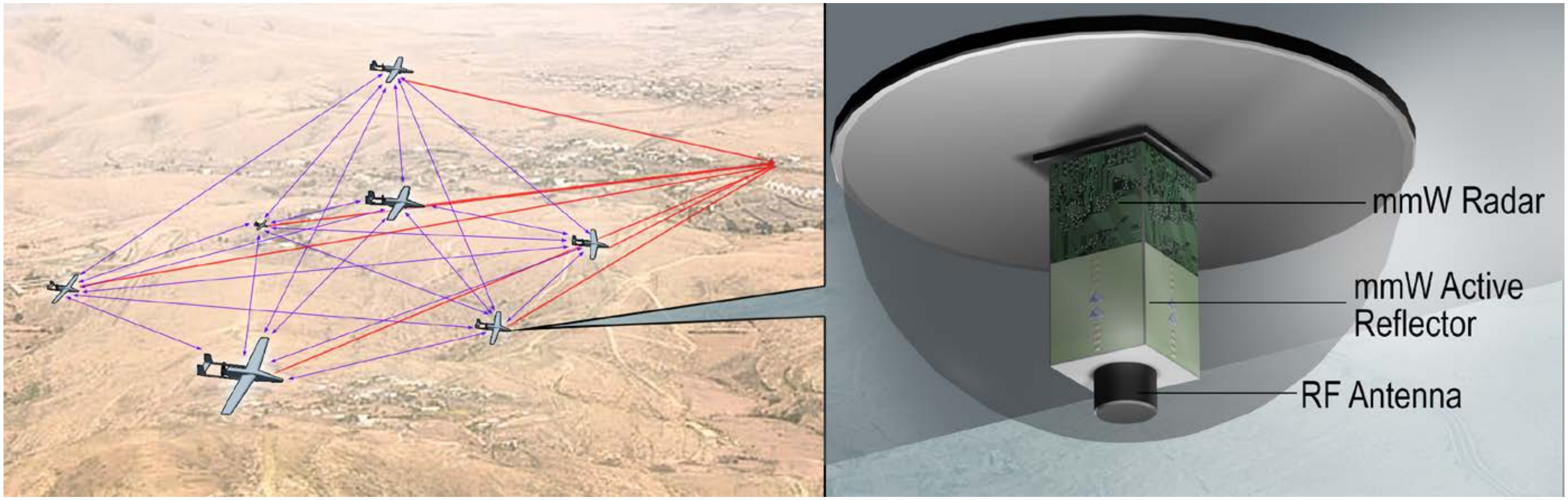
Previously a wholly owned business within Physical Optics Corporation, Intellisense has three decades of product development and technology transition experience.

- Intellisense Systems creates advanced sensing and display solutions supporting a data continuum from acquisition to visualization.
- Our systems are enhanced with software, adding intelligence so raw data can be translated into useful information for improved decision making and process automation.
- We offer off-the-shelf products and custom development services.
- Intellisense Systems has been qualified across engineering, accounting, and manufacturing to serve government and commercial customers.

Review of Navy Needs

- With the increasing use of small unmanned aerial systems (UASs), the Navy wants to equip them with radio frequency (RF) sensors/payloads to permit them to work together to form a coherent beam on a target.
- To do this, precise time synchronization among the UASs is essential: current techniques for this rely on the use of either GPS or an embedded signal from the target.
- To be more operationally suitable, development of a solution to the time synchronization problem for multiple spatially dispersed UASs, which works in the absence of both GPS and cooperative targets, is needed.
- The goal is to obtain accuracy in timing (10 to 100 picoseconds) and phase coherency to within 1/10 to 1/12 of a relevant RF operating wavelength (from UHF to C- Band) between nodes (or between slave nodes and the master node).

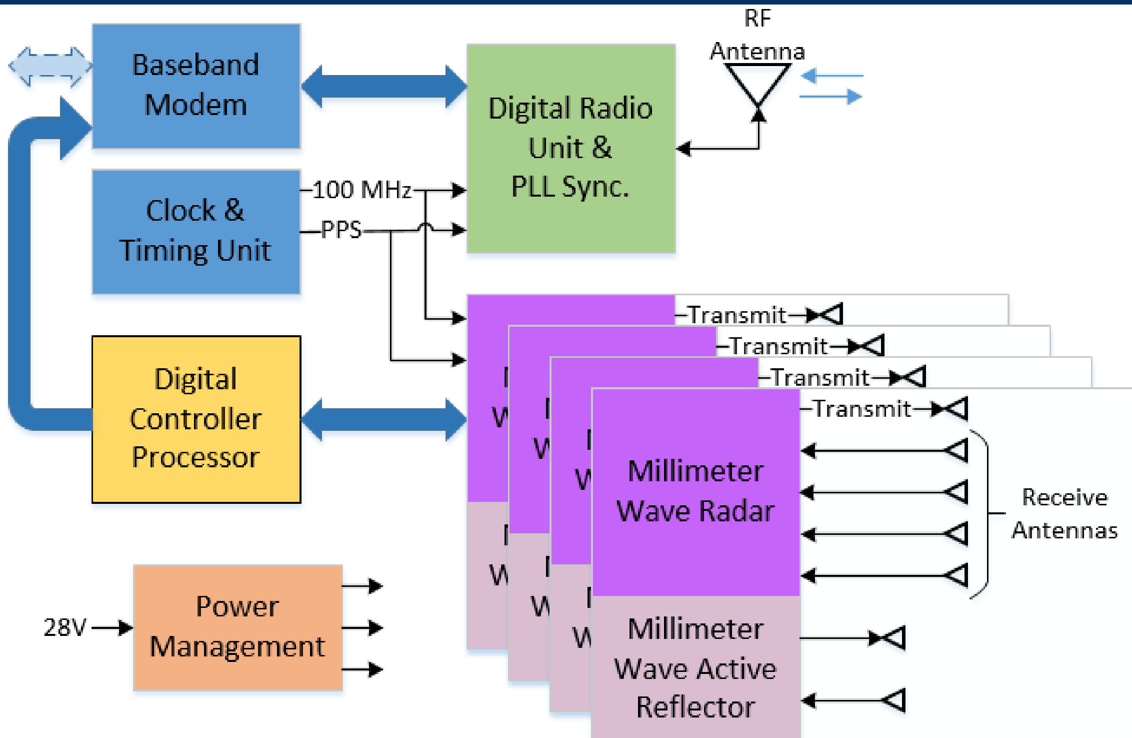
Intellisense's Solution: The MiRS (Millimeter Wave Ranging and Synchronization System)



The MiRS system applies a novel multimode ultrawideband (UWB) millimeter wave (mmWave) 76-81 GHz radar and active reflector configuration to determine the mutual UAS positions with millimeter accuracy, meeting or exceeding the Navy requirements. Located on multiple UAS platforms, the MiRS system enables an accurate synchronization of the RF sources, thus allowing them to work together to form a coherent beam on a target.

MiRS utilizes a highly integrated and low-cost mmWave single chip radar product developed for the nascent autonomous vehicle market. These chips provide simultaneous multibeam capability by applying digital beamforming and multiple-input-multiple-output (MIMO) technologies. Quad-sensor assembly allows 360° coverage, permitting each radar to simultaneously track all the swarm members. Use of active reflectors, each of which includes two (receive and transmit) mmWave omnidirectional antennas with an amplifier in between, allows for longer maximum range and better radar accuracy.

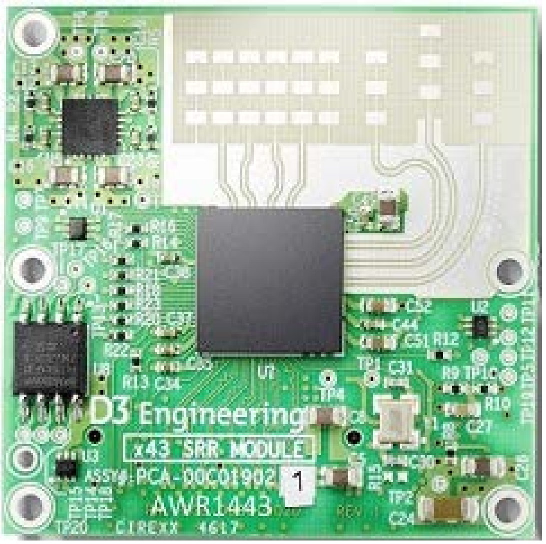
Intellisense's Solution: The MiRS (cont.)



MiRS will use digital signal frequency synthesis technology with a single 100 MHz clock for both the RF radio source and mmWave radar. To provide millimeter-scale accuracy for 1-mile-scale distance, the clock accuracy will be ≤1 ppm. Thermostabilization of the clock will be applied to provide the accuracy. A low repetition rate pulse-per-second (PPS) signal, obtained by dividing the clock frequency, will be used for both the radar modulation waveform's timing and triggering the communication signal symbols (e.g., for orthogonal frequency division multiplexing, OFDM).

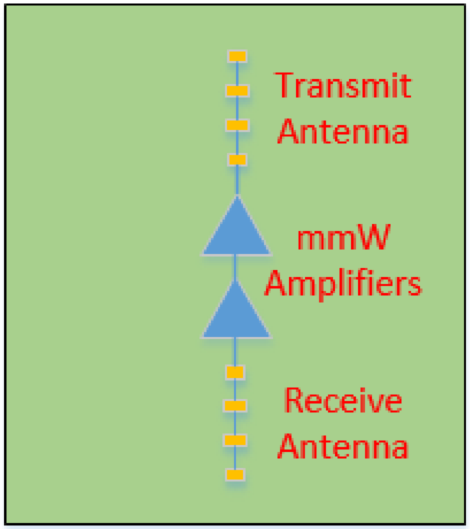
The MiRS true time delay synchronization mechanism allows for wideband digital communications using existing datalinks and radio designs, including UHF, C-band, S-band, single carrier modulation, spread spectrum, OFDM, or a common data link (CDL). These radios are assumed to have a high sampling rate (one order higher than instantaneous radio bandwidth) digital registration system and digitally controlled phase shifter to achieve a high-accuracy RF signal delay. The delay is controlled by both coarse (limited by the sampling period) time and fine (with 5.625° carrier frequency resolution of the 6-bit phase shifter) phase adjustments to implement the delay calculated by the master for each slave node. This results in phase adjustment resolution of 1/64 of the RF wavelength, which exceeds the accuracy requirement.

Intellisense's Solution: The MiRS (cont.)



- AWR2243 is the mmWave single chip radar developed by TI for automotive applications. The radar operates in the 76-81 GHz band and includes three Tx channels (13 dBm each) with flexible modulation control (based on a phase-locked loop (PLL) synthesizer) and four Rx channels with a full down-conversion chain and multichannel analog-to-digital converter (ADC) for complex (I/Q) baseband signals.
- AWR2243 provides fast FMCW waveforms with up to 5 GHz bandwidth to reach 3 cm range resolution. 3 mm range and 10 ps time accuracies can be reached if the radar signal-to-noise ratio (SNR) exceeds 20 dB.
- The radar uses Doppler information to determine the node's mutual velocity, which allows better ranging in dynamic flight conditions by extrapolating the range changes.
- The radar chip, in combination with the multiple microstrip antennas, supports digital beamforming and MIMO operation, which provide beamforming capability and increase radar sensitivity.
- AWR2243 supports individual phase control in the transmit chain, which can be used for phase coding of the modulation signal. We plan to use individual phase codes for each radar in the MiRS system to separate the radar signals from each other.

Intellisense's Solution: The MiRS (cont.)



- The MiRS system's active reflector includes receive and transmit antennas and an amplifier between them. The active reflector provides a compact alternative to a passive corner reflector. The expected RCS (radar cross section) of the active reflector is 200 sm.
- HMC8325, a low noise 71-86 GHz amplifier with 21 dB gain, can be selected as the amplifier for the active reflector. Three amplifier chips will be combined to achieve total gain of 60 dB.
- Isolation of the high transmit-receive antennas should be addressed in the active reflector design to avoid self-oscillation.
- We will design an active reflector based on planar patch antennas, in collaboration with our consultant, Dr. Avakian, to be built and integrated in the Phase II prototype.

Project Tasks

Task 1. ***Develop a MiRS System Architecture***
Intellisense will develop the MiRS concept system architecture and approach for time synchronization of RF sources across a distributed system to meet the Navy's requirements.

Task 2. ***Develop a mmWave Ranging Solution***
Intellisense will develop RF diagrams and an antenna design, in collaboration with our consultant, Dr. Avakian, for both mmWave radar and active reflector units. Intellisense will develop the MiRS simulation model and ranging algorithms in MATLAB®. We will also conduct experiments with key hardware components to validate the estimates of accuracy in timing between nodes.

Task 3. ***Develop a High-Accuracy Synchronization Algorithm***
Intellisense will develop a synchronization algorithm that, based on the ranging data, will calculate the delays for each node participating in distributed beamforming to allow them to form a coherent RF beam on a target.

Task 4. ***Simulate the MiRS System Operation to Demonstrate Its Feasibility***
Intellisense will simulate the system's performance for various test configurations, including a swarm consisting of ten UASs (Group 1 and Group 2) randomly distributed spatially throughout a 1-mi area, and quantify the beam pointing error as a function of frequency. Intellisense will analyze the test results and prepare the Phase II prototype development plan.

Project Tasks (cont.)

Task 5. ***Explore Commercial Potential, Technology Transition, and Product Viability***
Intellisense will explore the potential to transfer MiRS to military systems and civilian applications. Market research will identify the most promising applications of the MiRS system.

Task 6. ***Manage Program and Submit Reports***
Intellisense will undertake program management and reporting, as well as communication with the Technical Point of Contact (TPOC). Intellisense will prepare and submit reports and attend a kick-off meeting in accordance with contractual requirements. The final report will contain a summary of the work performed as well as prototype plans to be developed under Phase II.

Phase I Option for Transition to Phase II
Task 7. ***Refine the System Design***
Intellisense will identify and implement the improvements and modifications of the MiRS system design based on experimental results and computer simulation. The complete system design will include detailed schematic drawings and HFSS antenna design.

Task 8. ***Enhance Phase II Plan and Design Description***
Intellisense will prepare a detailed development plan for the Phase II prototype, including risk management based on technical challenges identified in Phase I, and a system design with cost estimates, to facilitate the development progress in Phase II.

Performance Schedule

TASKS	MONTHS AFTER PROJECT INITIATION											
	Base						Option					
	1	2	3	4	5	6	7	8	9	10	11	12
1. Develop a MiRS System Architecture	■	■	■									
2. Develop a mmWave Ranging Solution			■	■	■							
3. Develop a High-Accuracy Synchronization Algorithm				■	■	■						
4. Simulate the MiRS System Operation to Demonstrate Its Feasibility				■	■	■						
5. Explore Commercial Potential, Technology Transition, and Product Viability	■	■	■	■	■	■	■	■	■	■	■	■
6. Manage Program and Submit Reports	■	■	■	■	■	■	■	■	■	■	■	■
7. Refine the System Design							■	■	■	■	■	■
8. Enhance Phase II Plan and Design Description											■	■

Period of Performance
09/10/20 – 03/15/21

Funding
$139,997

Challenges/Risks and Proposed Mitigation

Challenges and Risks:

- Transmit-receive isolation in the active reflector will not the planned RCS of 200 m^2 to be attained.
- Phase-coding of the radar transmit signals will not provide robust enough separation between the different radars in the MiRS system.
- Modeling and simulation of the MiRS system will demonstrate limitations in the radar's ability to accurately and unambiguously determine positions of the network nodes.

Mitigations:

- Use additional partition covered by absorption material between transmit and receive sections.
- Use different time windows for each radar transmission cycle.
- Specify the limitations for multiple node distribution parameters, such as max number of nodes, mutual range between them, and max volume occupied by the nodes.

Key Personnel

Mr. Victor Khodos, Sr. RF Engineer, Principal Investigator
Brings to the project expertise in radar system design and development, digital signal processing, and wireless communications.

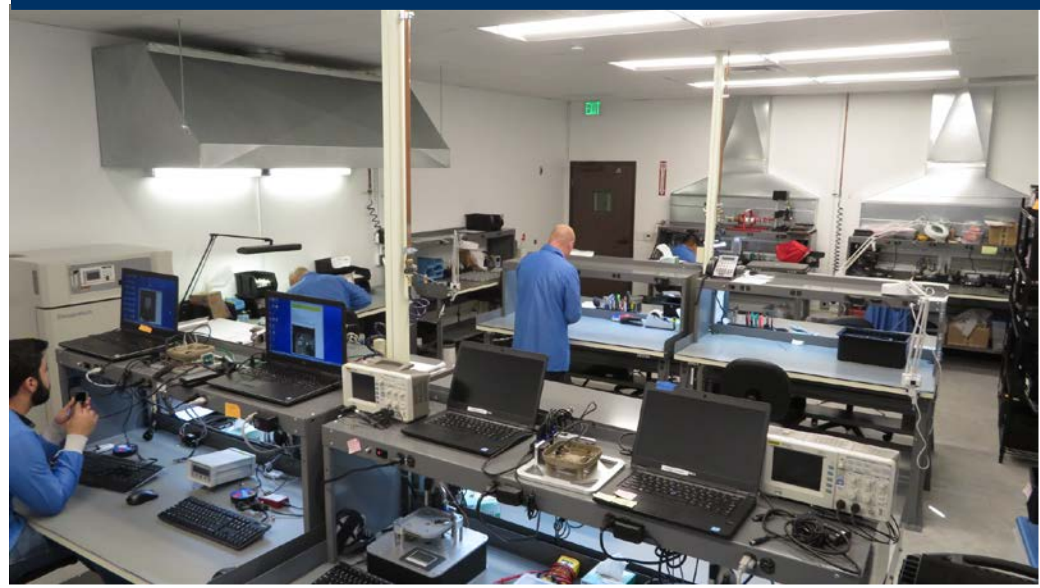
Mr. Alexander Genusov, Director, Electronic Systems Development, Project Manager
Brings to the project expertise in development of communications systems and in project management. *Clearance application is under review.*

Mr. Joseph Storniolo, Principal RF Engineer
Brings to the project expertise in wireless communication and RF system development, modeling, and simulation.

Mr. Sean Holloway, Research Engineer
Brings to the project his experience in development of RF systems, modeling, and simulation.

Dr. Min-Yi Shih, VP and General Manager
Brings to the project expertise in technology development, program management, technology transition, and commercialization. *Holds an active Secret clearance.*

Intellisense's state of the art labs and manufacturing facility



- While all of the company's facilities will be available for this project, most of the work will be performed in the RF and Communications laboratories equipped for prototyping and testing microwave and mmWave electronic systems. Both laboratories have a full set of high-precision electronic equipment including RF spectrum analyzers, multi-GHz oscilloscopes, signal and waveform generators, vector network analyzers, a selection of microwave and mmWave components. In addition, the laboratories have evaluation kits enabling rapid prototyping and testing of digital signal processing using FPGAs and multiprocessor systems on chips.
- The RF Laboratory was developed for radar and RF sensor systems for frequencies from 3 GHz to 94 GHz. It has evaluation kits for key technologies including mmWave radars operating in the 60-81 GHz spectrum, used in development and testing of advanced pulse and FMCW radars using MIMO, hybrid beamforming, and custom antennas.
- The Communications Laboratory is equipped for wireless and light communication systems. The communication evaluation kits include microwave and mmWave wireless transceivers for 5G, Wi-Fi, and radio networks operating in 1-85 GHz spectrum, used in development and testing of complex communication systems using MIMO, hybrid beamforming and custom antennas.

- Our infrastructure supports technology transition, based on well-established processes for production and testing.
- The Intellisense manufacturing capabilities include electronics fabrication, unit qualification testing, systems integration, and volume production with full quality assurance.
- Our facilities have Secret clearance, comply with all applicable ITAR provisions, and meet all applicable environmental laws and regulations.

Transition

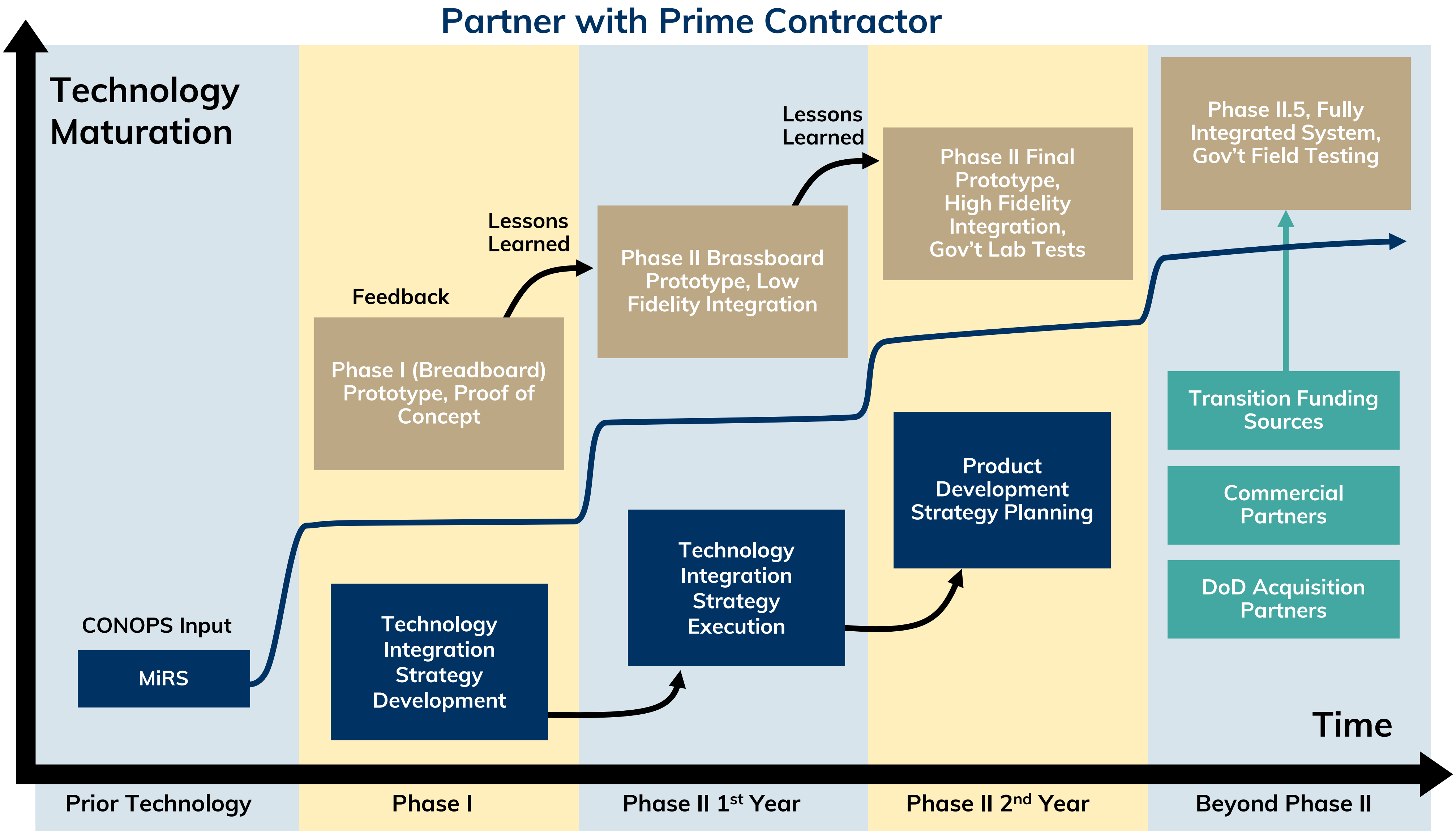
Military/Commercial Applications. The wireless communication systems in the UAS swarm, enhanced by MiRS, support distributed beamforming that allows narrow beam transmission directly applicable to SIGINT, ELINT, COMINT, EW, radar, including synthetic aperture and maritime patrol radar (SAR/MPR), and other airborne electronic systems with LPD/LPI and tolerance to jamming and interference and capable of operating in GPS-denied environments. MiRS will enable UAS swarm operations in commercial applications, including cooperative missions, and provide situational awareness, especially in contested/ congested environments.

Transition to Military Markets. We believe that the key to transitioning will be the engagement of the program office and prime contractor, Raytheon, early in Phases I/II, to design MiRS to meet platform requirements. We expect to produce a TRL-5/-6 prototype in Phase II that is ready for qualification in Phases II.5/III.

Transition to Commercial Markets. Intellisense has a long history of customizing products developed for DoD for specific commercial markets. Our business development (BD) team seeks new commercial opportunities for transitioning Phase I/Phase II prototypes to commercial products. The company has invested internal funds to achieve certifications necessary to supply products for commercial applications. To address the commercial markets, we will follow a path similar to that of the Micro Weather Sensor (MWS®), which began as a SBIR Phase I and is now a program of record under AFLCMC and USSOCOM.

Technology Transition Infrastructure and Capability. Intellisense's scientific, engineering, and management team executes programs and technology transition from development, test, and qualification through production. Our Quality Management System is certified to comply with the requirements of ISO9001:2015/AS9100D and ISO9001:2015/AS9110C as well as CMMI-DEV:ML3 standards. Intellisense is one of just ten U.S. companies that have all of these certifications and is one of only two small businesses to earn this distinction.

SBIR Technology Transition Roadmap

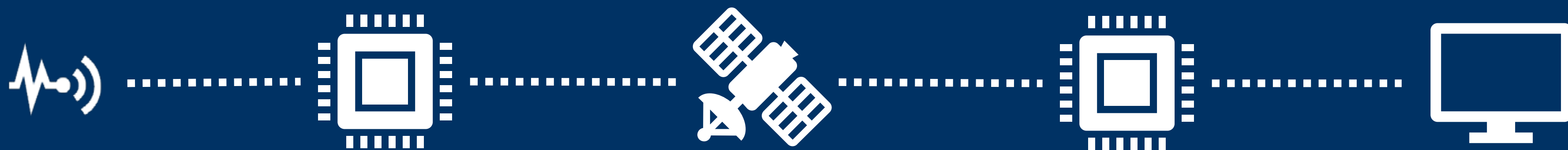


Back-up Material

Corporate Products

intellisense SYSTEMS

The data continuum from sensor to display



Sensor data acquisition

- Environmental
- Acoustic
- Seismic
- Structural
- Image (UV/VIS/IR)
- LIDAR
- RADAR

Processing

- Compression
- Sensor Interpretation
- Recognition
- Classification
- Augmented Intelligence (AI)
- Machine Automation and Control
- Data logging

Communications

- Iridium
- Cellular 4G/5G
- Bluetooth®
- WiFi
- LiFi
- Cabled

Processing

- Cloud Management
- Big Data
- Augmented Intelligence (AI)
- Human Machine Interfaces (HMI)
- Non-Destructive Inspection
- Machine Automation and Control
- System Optimization
- Open-Architecture Avionics Systems

Visualization

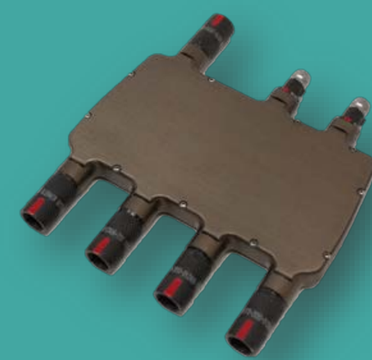
- Avionics Displays
- Rugged Displays
- Smart Displays
- Image Fusion
- Image Enhancement
- Night Vision
- AR/VR Goggles
- Web-based User Interfaces

Commercial off-the-shelf (COTS) products

All-in-One
Weather
Sensors

IoT
Flood
Sensors

Rugged
Avionics
Displays



Soldier Wearables
Power & Data
Management

intellisense SYSTEMS

Technologies and capabilities from our Innovation Lab

Night Vision, Laser Range Finders, Sights

EO/IR and LIDAR Sensing

Non-Destructive Inspection

Augmented Intelligence

Aerial Sensors

LiFi Lightwave Communications

4K, 8K, Touchscreen Rugged Displays

Situational Awareness

Intellisense Systems development model

Small Business Innovation Research (SBIR) Technology Development

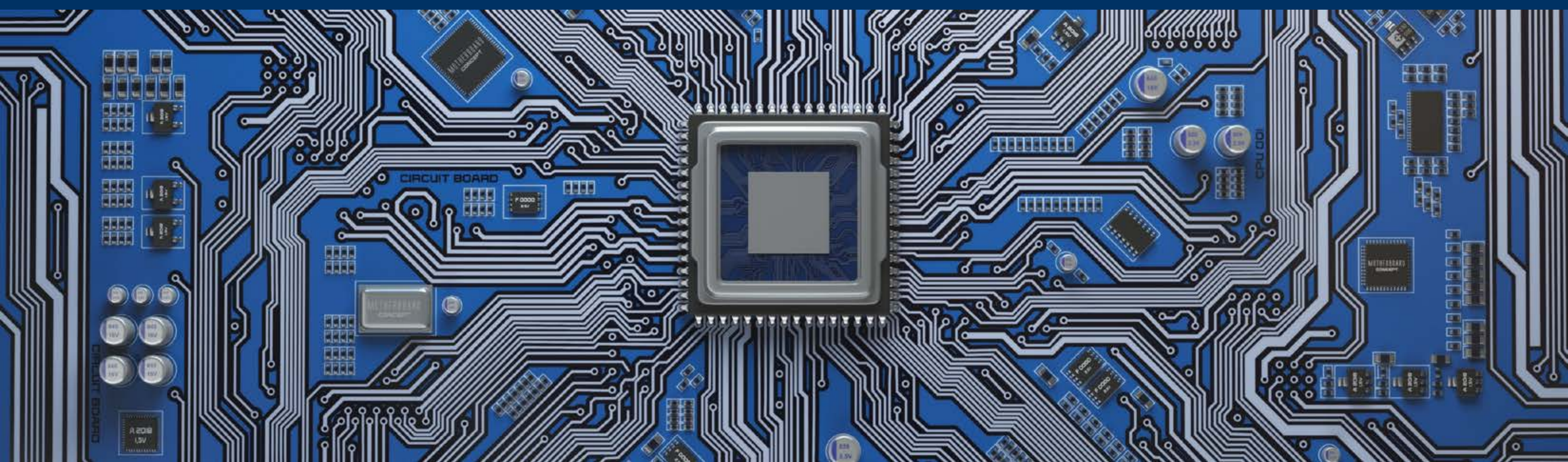
BAAs
RFP/RFQs

Internal Investment

Development

Transition

Production



Micro Weather Sensors (MWS®)

Intellisense Systems offers a variety of true all-in-one weather sensors. We've integrated data storage, wireless communications, batteries, and solar collectors into each unit. No external components need to be connected by wires. The MWS has been deployed in 60+ countries across all 7 continents,

True All-In-One Meteorological Sensors

- Integrated data logging, solar power, and processor
- Two-way Iridium satellite connection
- Integrated panoramic imaging
- Expansion port
- Rugged and portable
- Easy 60 second installation
- Autonomous operations

Weather Data Collected

- Temperature
- Barometric pressure
- Humidity
- Wind speed
- Wind direction
- Compass reading
- Angular tilt
- Visibility
- Dust accumulation
- Lightning distance
- Visual imagery
- Precipitation amount
- Present weather
- GPS location

MWS-M520
Military version features Iridium satellite communications with 12 sensors reporting 27 environmental parameters.

MWS-M620
Military version features Iridium satellite communications with all the features of the M520 plus a 10,000 ft LIDAR ceilometer

MWS-M400
Commercial version features cellular LTE-M communications with 10 sensors reporting more than 20 environmental parameters.

MWS-M500
Commercial version features cellular LTE-M communications with 12 sensors reporting 27 environmental parameters.

MWS-M600
Commercial version features cellular LTE-M communications with all the features of the M520 plus a 10,000 ft. LIDAR ceilometer

Specialty Weather Sensors

Intellisense Systems also offers several specialty meteorological sensors for specific programs and applications.

Vehicle Applications

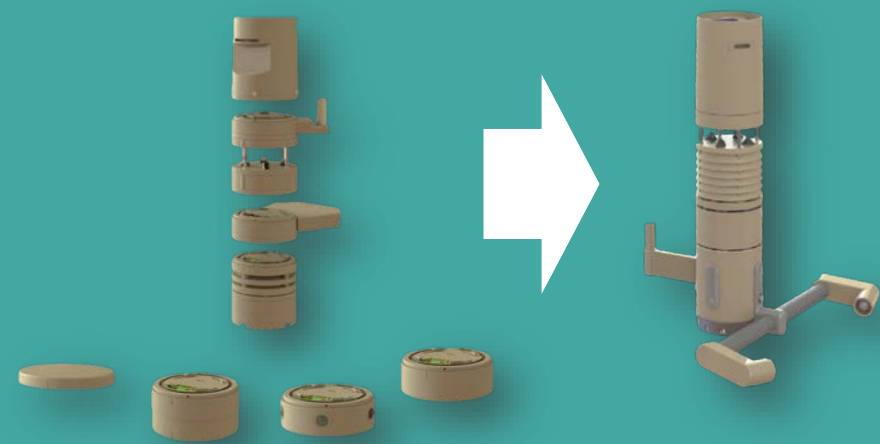
These two meteorological sensors are mounted or tethered to vehicles to provide locational weather data for situational awareness.

SDWS
Submersible-Deployable Weather Sensor
Tethered to submarine for power and communications

BMS
Ballistic Meteorological Sensor
Rugged weather sensor for armored vehicles

Modular Weather Sensor

We are developing a modular weather sensing platform with a range of options including a 25,000 ft LIDAR ceilometer.



Available Modules

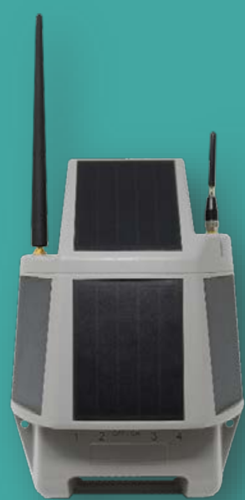
- Temperature
- Barometric pressure
- Humidity
- Wind speed
- Wind direction
- Compass reading
- Angular tilt
- Visibility
- Dust accumulation
- Lightning distance
- Visual imagery
- Precipitation amount
- Present weather
- GPS location

AWARE Flood Sensors

The Advance Warning Equipment (AWARE) Flood system comprises a network of sensor nodes. Each unit is designed to withstand harsh weather conditions throughout all seasons and autonomously monitor water levels and other environmental conditions. The system can automatically send real-time notifications when it detects a flash flood.

Remote, Mesh Network Flood Sensor

- Integrated data logger, solar power, and processor
- Internet of Things (IoT) operations
  - Cellular LTE-M
  - Iridium satellite
- SDI-12 expansion port
- Rugged and lockable
- Optional color imaging camera
- Automatically detects and notifies of flash floods



Transmitted data

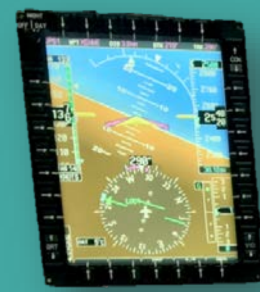
- GPS location, flood depth
- Barometric pressure
- Battery voltage
- Air & water temperature

Rugged Avionics Displays

Our display and visualization products feature cockpit and crew station displays designed for mission support in any aviation environment. They are upgradable and expandable to “smart” display functionality with FACE™ conformant software, including ARINC-661. The electronics are designed to support future growth (higher resolution inputs, touch screen integration, etc.)

Displays that integrate today and support seamless future upgrades

- Form-fit-function replacements
- Open systems modular architecture
- FACE conformant software, including ARINC-661
- Multifunction bezel options
- Touchscreen options
- Support for common avionics interfaces
  - Fiber optic ARINC-818
  - DVI-D
  - RS-422
- Support for common resolutions from VGA to 4K, and many more



MFD
Multifunction Display
6x8 inch
768x1024

VDT
Video Display Terminal
12x9 inch
1024x768
VDT+ (1400x1050, Touch)

CDU
Control Display Unit
8x6 inch and control panel
1024x768

LAD
Large Area Display
20x8 inch
2560x1024

Rugged Wearable Power Manager

The soldier-worn power and data distribution hub provides comprehensive power distribution for air and ground soldiers supporting various alternative power sources including primary cells, vehicle power, solar blankets, fuel cells and wireless power transfer. SMBus device monitoring allows intelligent charging. The status of each connected device is transmitted over USB and displayed on the touch screen of an Android end user device using Intellisense's ISPDS-C or Nett-Warrior-compatible Android app.

Features

- Dual 14 V / 28 V conformal wearable battery
- Alternative Power Source (APS) 10-36 VDC
- OV, OC protective circuits
- Built-in maximum power point transfer (MPPT) for APS
- Wireless power transfer compatible up to 100 W+
- Available in 7-port or 2-port versions