Optically-enabled RFID tracking system

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Overview

- Tracking Hardware
- Tracking Software
- Energy Harvesting
- RFID Circuit
- Present System
- Future Development

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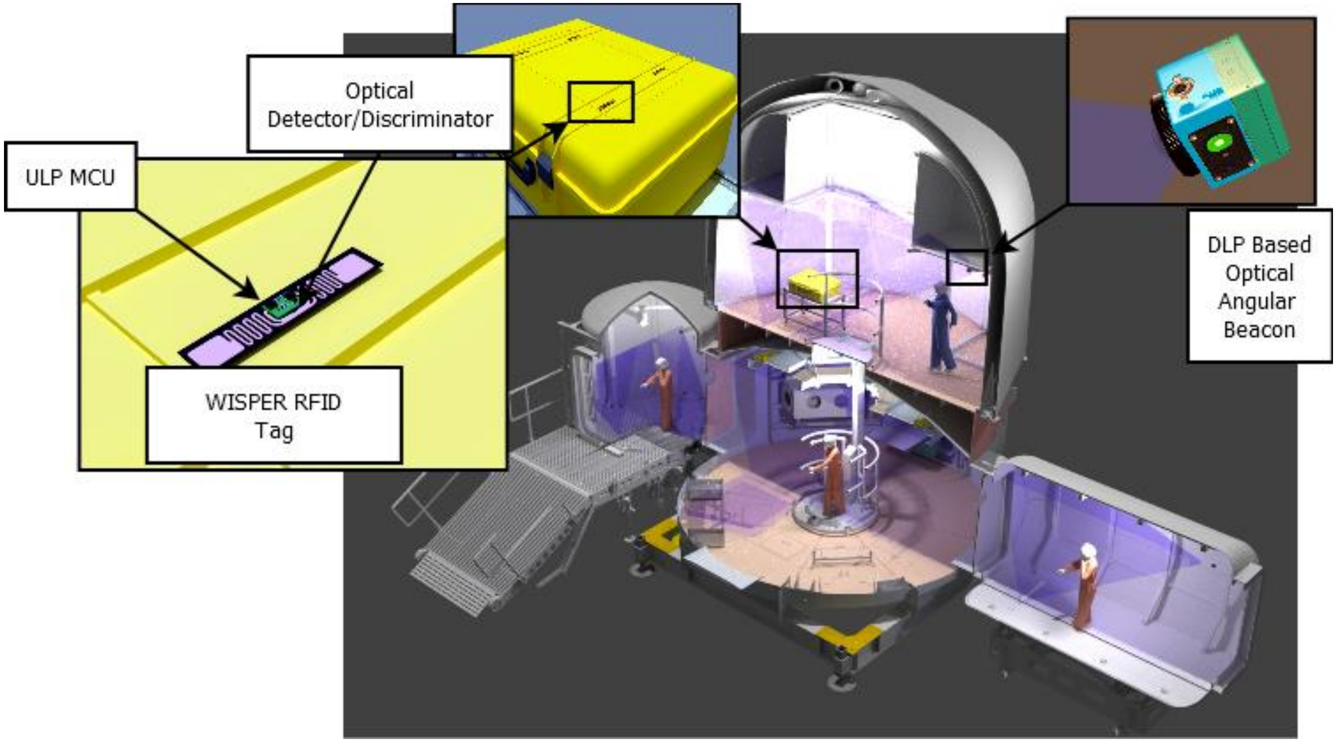
WHISPER Identification of Need

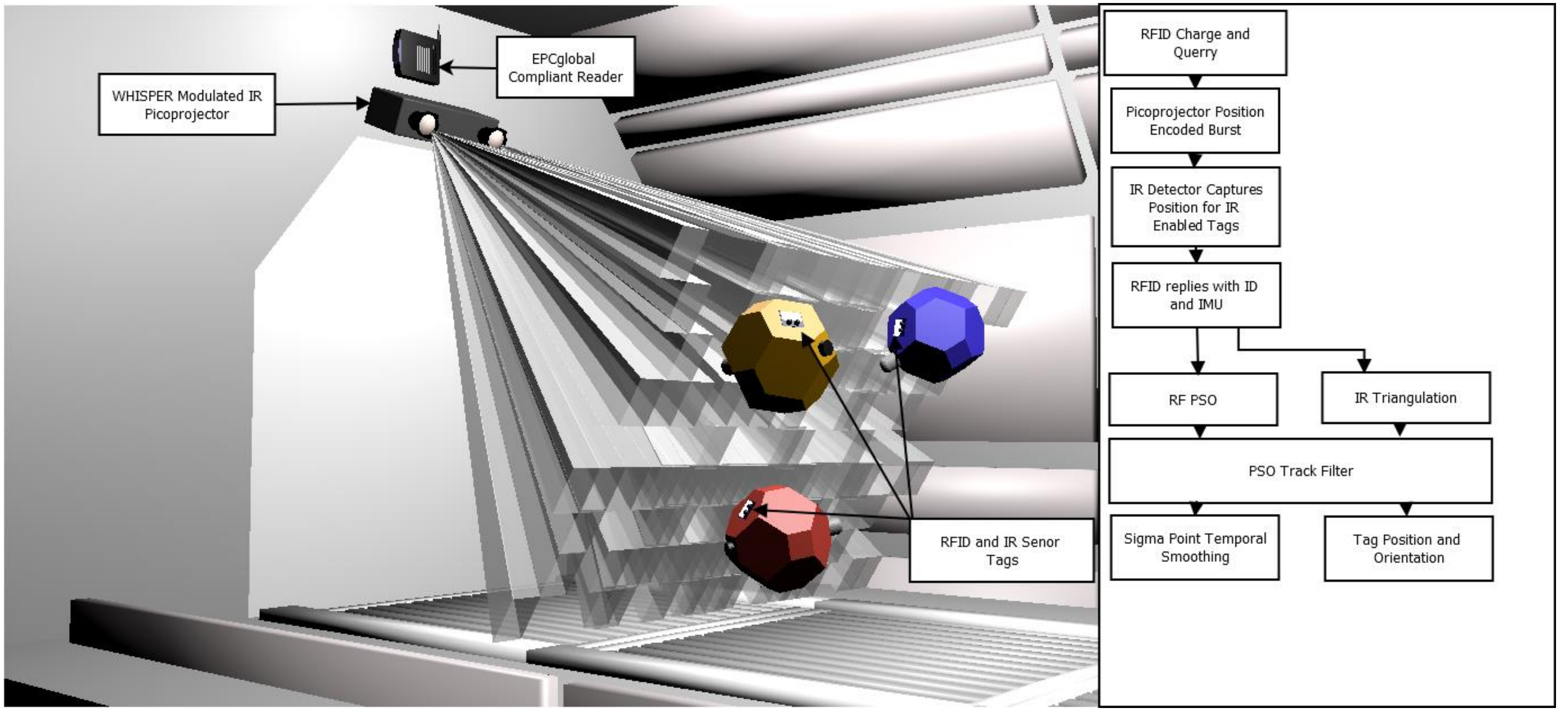
- Locate and Inventory Items on the ISS
  - Presently Very Labor Intensive
  - RFID Considerably Improves Basic Task
  - RFID Alone Cannot Provide Precise 3D Position and Motion Tracking
- Dynamically Track 3D Position and Orientation of Free Floating Objects
  - As Items are Moved About the Station Tracking is needed
  - Unsecured Items need Kinematic Tracking
  - Experiments Such as the AstroBEE Robot System Require Position and Orientation
  - AR Systems and Vestibular Testing

- Track Articulated and Constrained Assemblies
  - Tethered Items
  - Robotic Arms
  - Free Flyers
  - Astronaut Exercise, Biomechanics and Time Motion Studies
- As a result WHISPER provides extensive additional functionality for related work on the ISS justifying already small SWAP-C requirements



WHISPER Operation

- The Whisper System provides high accuracy location and tracking, employing a hybrid optical and EPCGlobal RFID approach.
  - One or more modulated, high speed IR Pico-Projectors operating at kilobit rates transmits a unique binary code for each pixel in the projector.
  - This provides the 2D angle of the tag relative to each projector.
  - The resulting codes are stored in RFID registers which are read out via the EPCGlobal reader.
  - The tags are triangulated, using a probabilistic constraint system. This provides a high level of resiliency against garbled transmissions, occlusion, and sporadic RFID transmissions.



Unique WHISPER Advantages

- The Whisper System is unique as an active tracking system due to its combination of features:
  - Low Latency : Necessary position information is received directly by the tags on an object and can be rapidly processed.
  - Very Low Power Consumption: Only requires an optical detector/discriminator operating on demand with the UART segment of an Ultra Low Power (ULP) Processor
  - High Reliability due to multiple beacons and probabilistic constraints. Multiple tags and projectors allow for position and orientation to be determined in the presence of occlusions.
  - Flexible and scalable: Multiple projectors can be employed in tiled configurations to cover arbitrary volumes

WHISPER Overview

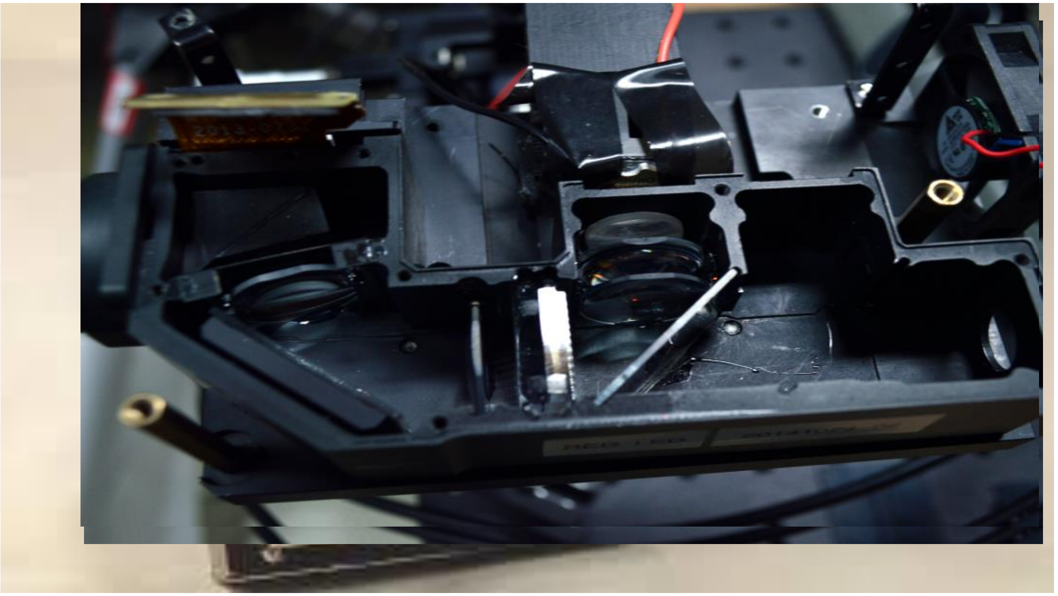
- System Overview
  - Beacon Subsystem
    - Wide Angle Picoprojectors
    - Modulated IR LED system
    - Synchronization system
  - Optical Receiver Subsystem
    - Detector
    - Amplifier/Discriminator
    - Processor
  - RFID Subsystem
    - RFID chip
    - Antenna
    - RFID Receiver
  - Tracking Subsystem
    - CODEC Software
    - Probabilistic Analysis
    - Manifold Compliant Particle Swarm Optimization (MCPSO)

Present Beacon Subsystem

In this program Picoprojector PRO4500 was selected as the beacon module

Its use requires substantial modification of the module optical train. This includes

- Replacing the RGB LED light sources with near IR LED
- Complete redesign of the optical train
- Use of fisheye optics



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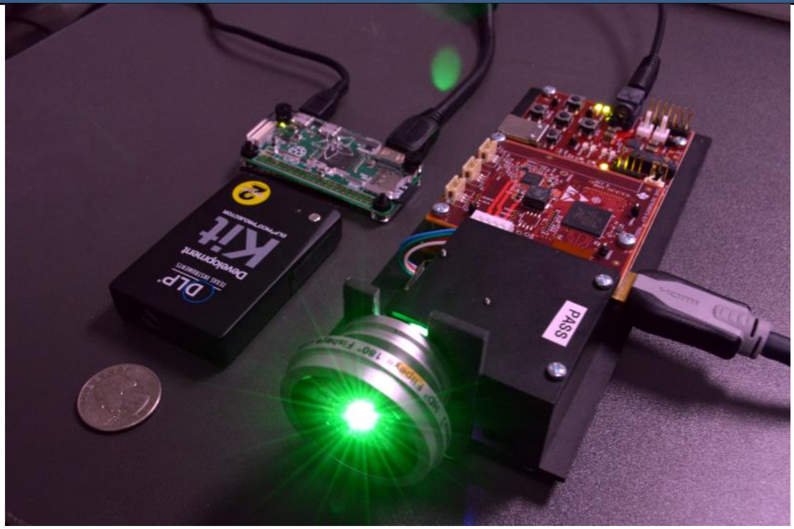
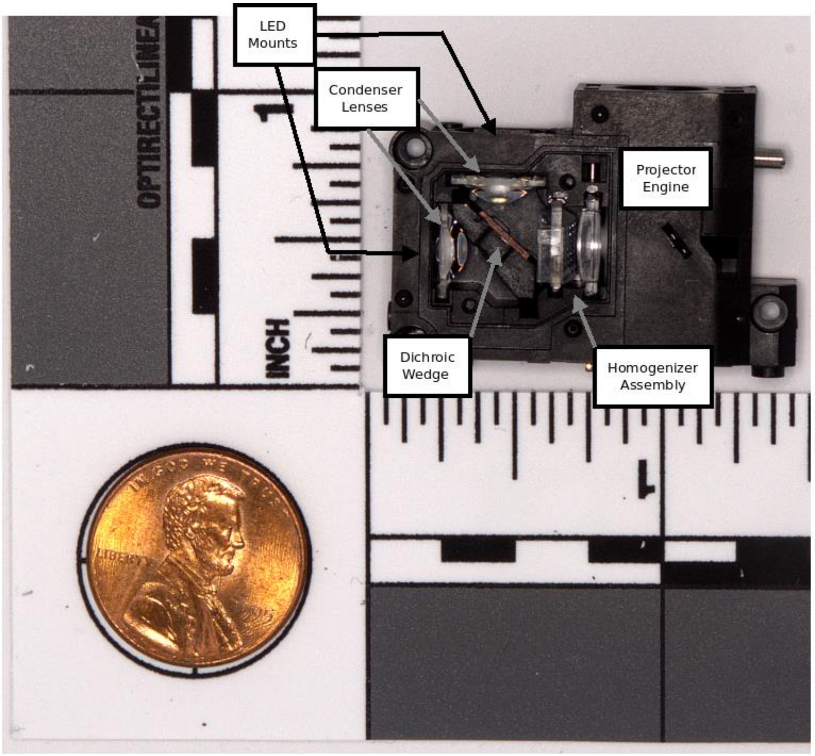
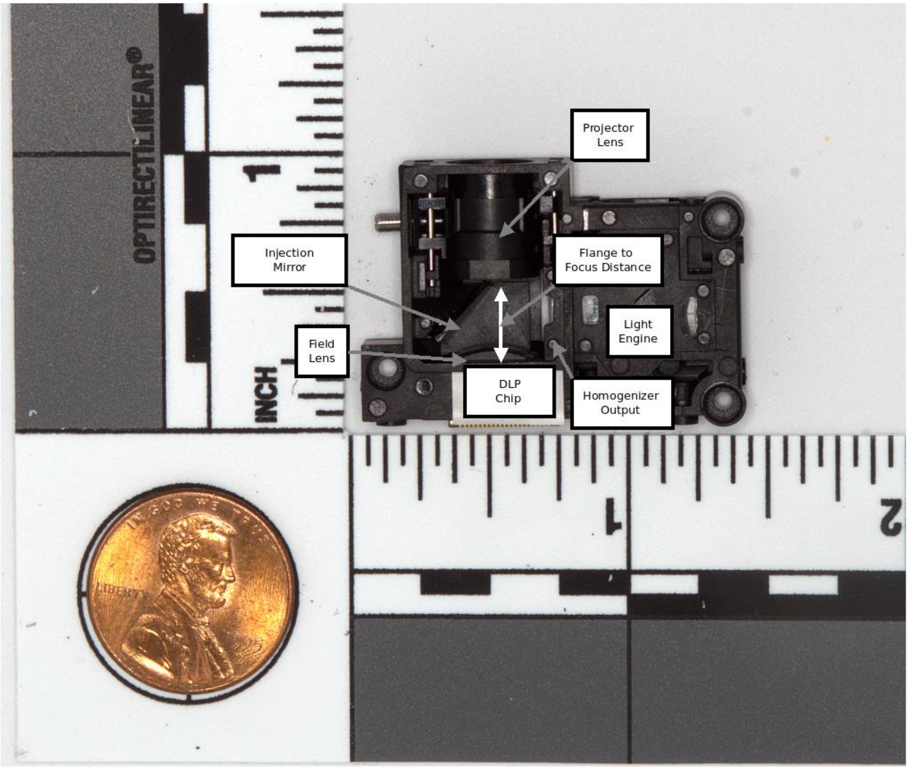
Beacon Subsystem Upgrade Path

While the Lightcrafter 4500 is intentionally large, to simplify modification, much smaller picoprojector designs can be used.







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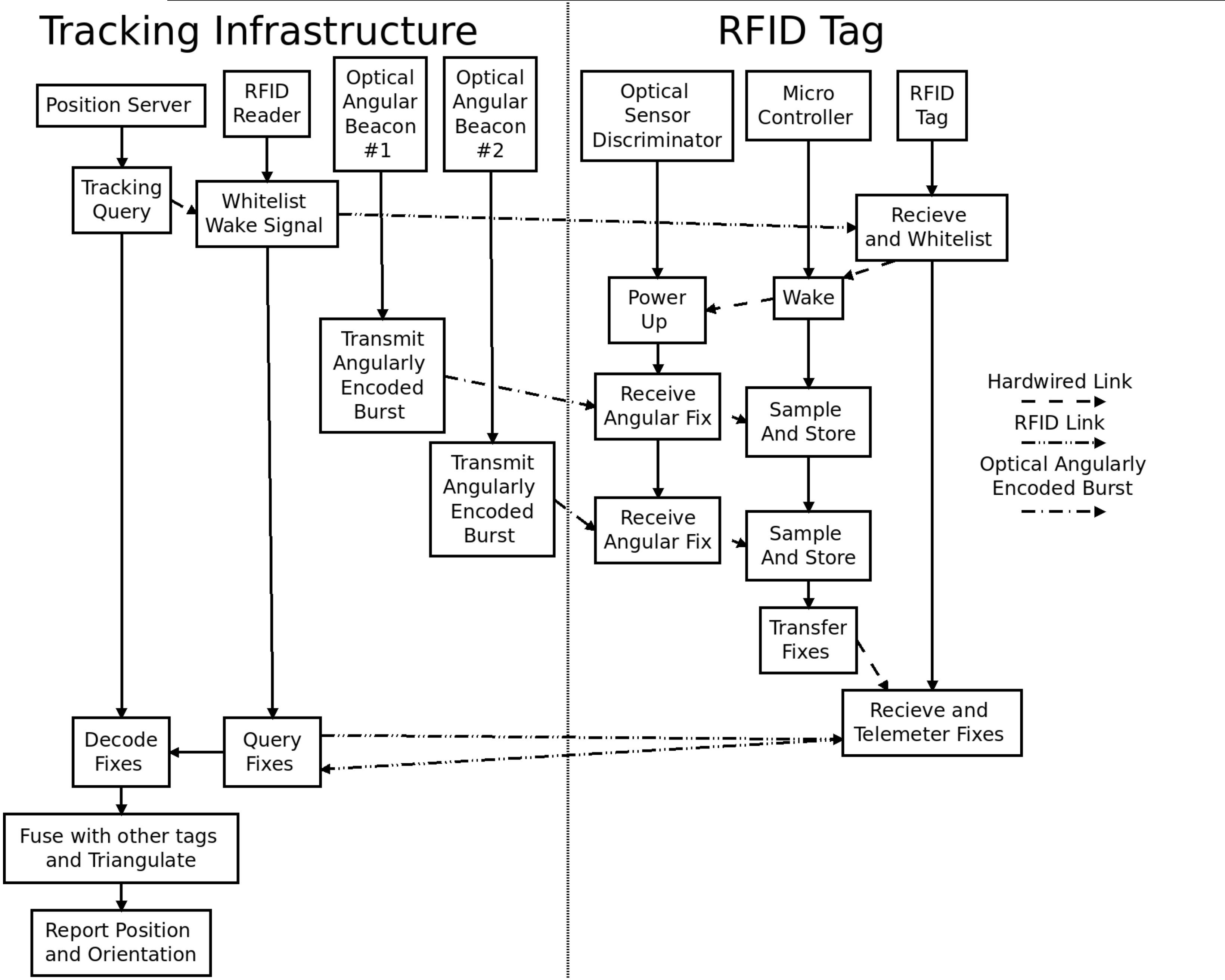
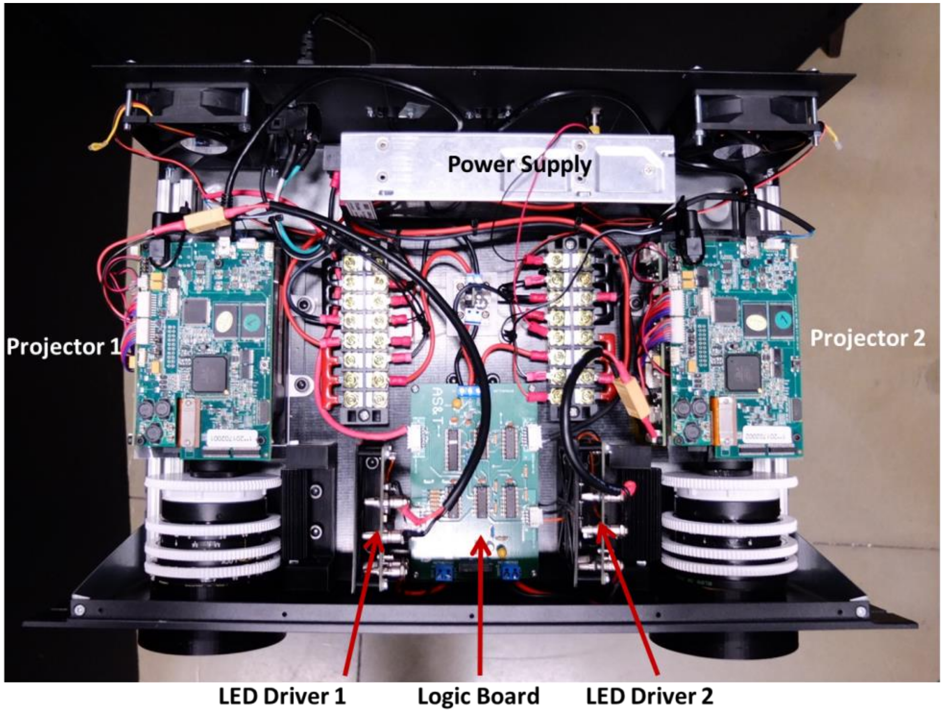
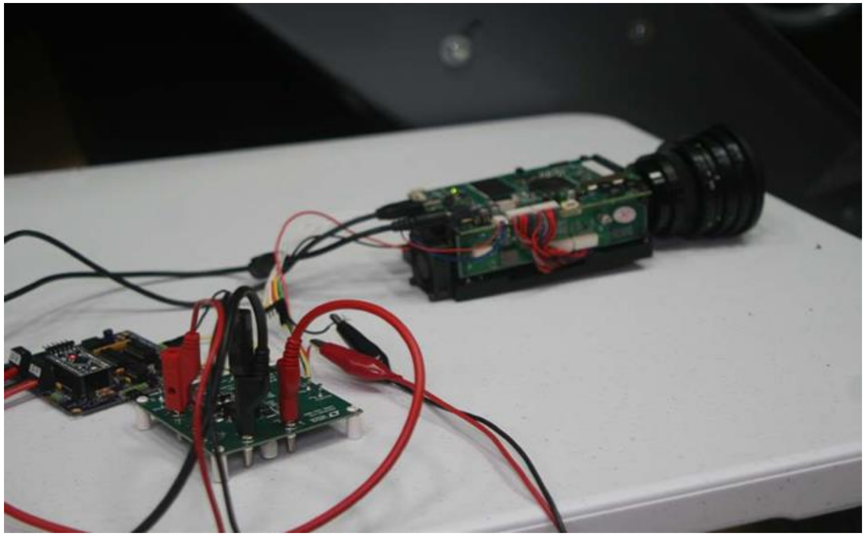
Whisper System Operation sequence



Beacon Subsystem Progress

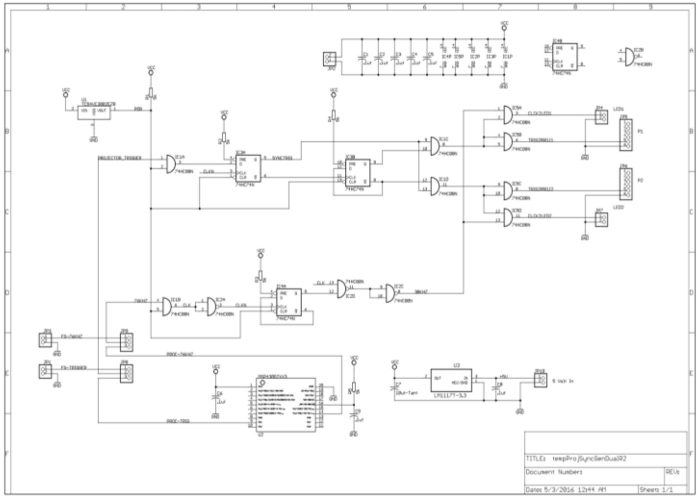
- Wide Angle Picoprojectors
  - LightCrafter 4500 Successfully in Turnkey Operation
  - Correct Trigger Operation
  - Peleng 8mm Lenses
    - Successful Hyperfocal Operation
    - Successful Distortion Compensation
    - Can be replaced with C-Mount or M12 lenses

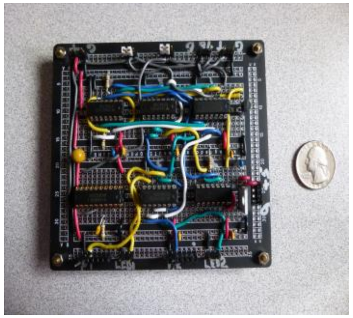


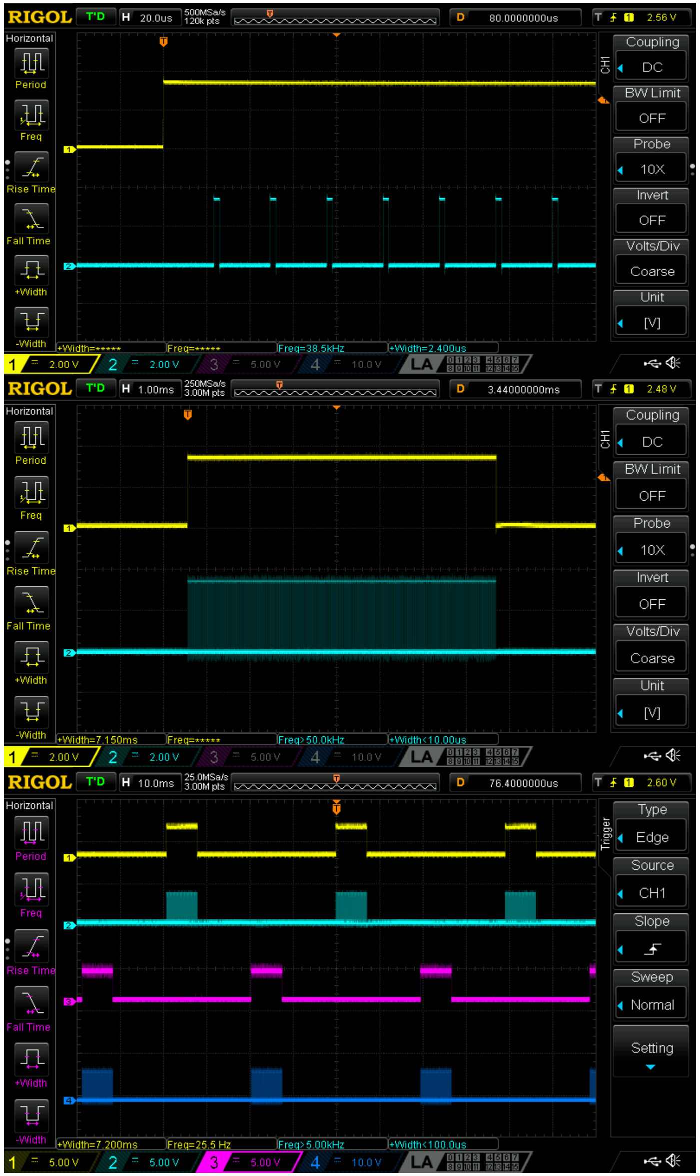


Beacon Subsystem Operation

- Modulated IR LED
  - High Efficiency IR LED Retrofit
  - Modulator Circuit Successfully Operating
- Synchronization Circuit
  - Synchronous "Round Robin" Operation of Projectors
  - Successful Triggering of Projection Sequence Illumination Pulse

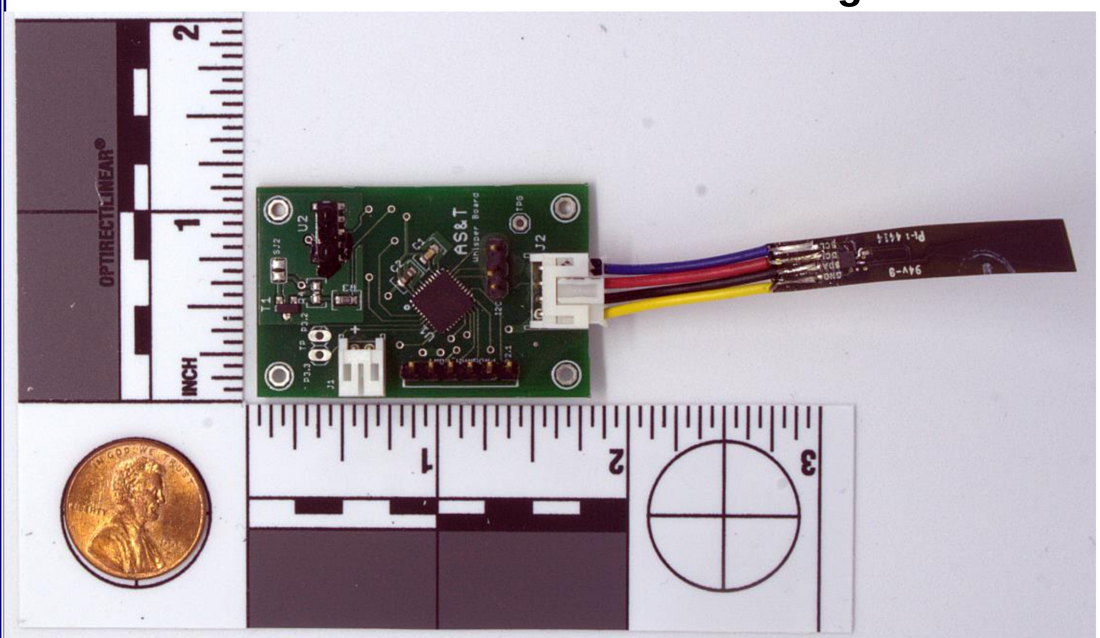


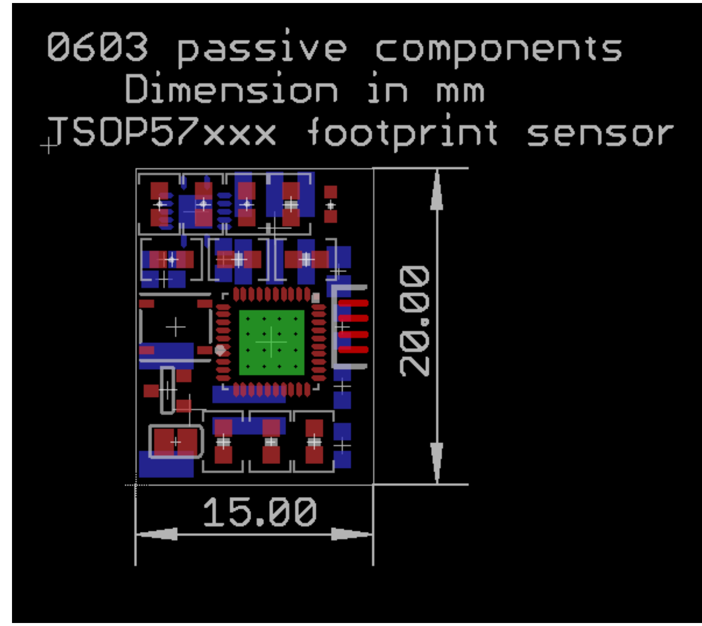


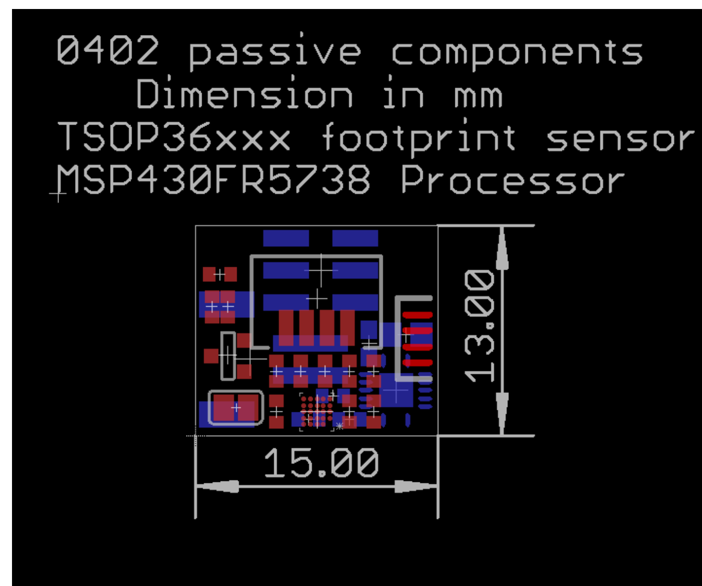


Optical Receiver Subsystem

- **Detector**
  - **Standard Vishay Detector-Discriminator TSOP 37138: AGC-2 Product**
- **Dector-Discriminator**
  - **TSOP chips provide a small chip scale Transimpedance dector- discriminator that will link to arbitrary PIN-diodes This allows us to reduce the SWAP of the receiver while enhancing optical filter selectivity.**
- **Processor**
  - **MSP430FR5739**
  - **Retaining Compatibility to MSP430FR5738 for small form factor DBGA configuration**







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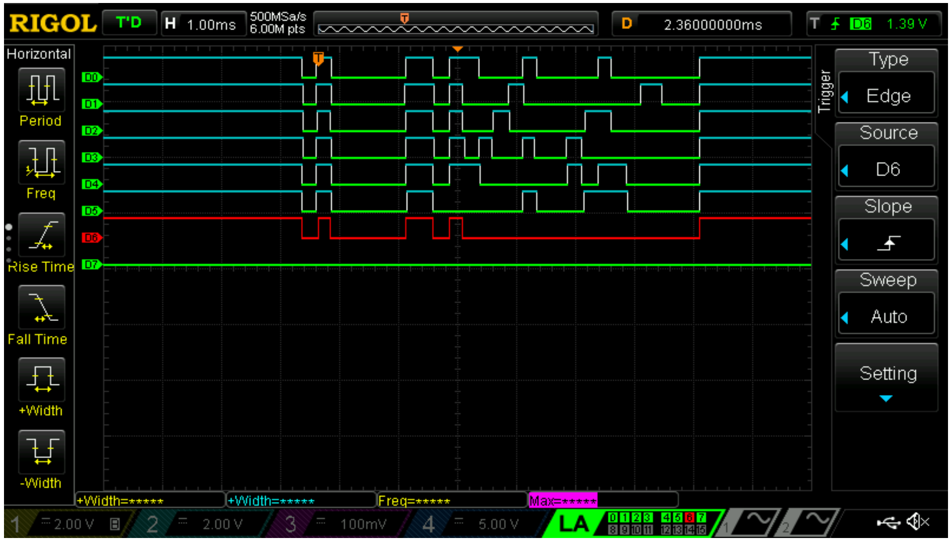
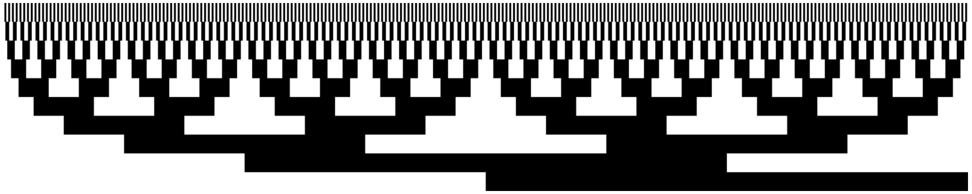
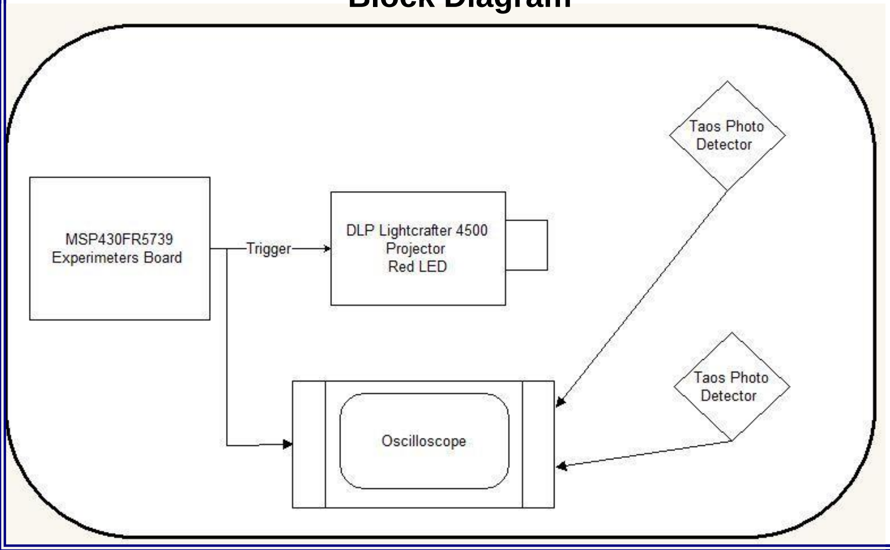
Tracking Subsystem

- CODEC Software
  - Encoding employs Morton Order Gray Code for optimal close to distant range operation
  - Tests of redundancy reduce and/or cull occasional garbling of the position signal
- Probabilistic Analysis
  - The majority of positional data is accurate, but a small portion is subject to jitter and garbled data. As a result, consistency testing and averaging are used to extract accurate positions. This is coupled with appropriate kinematics

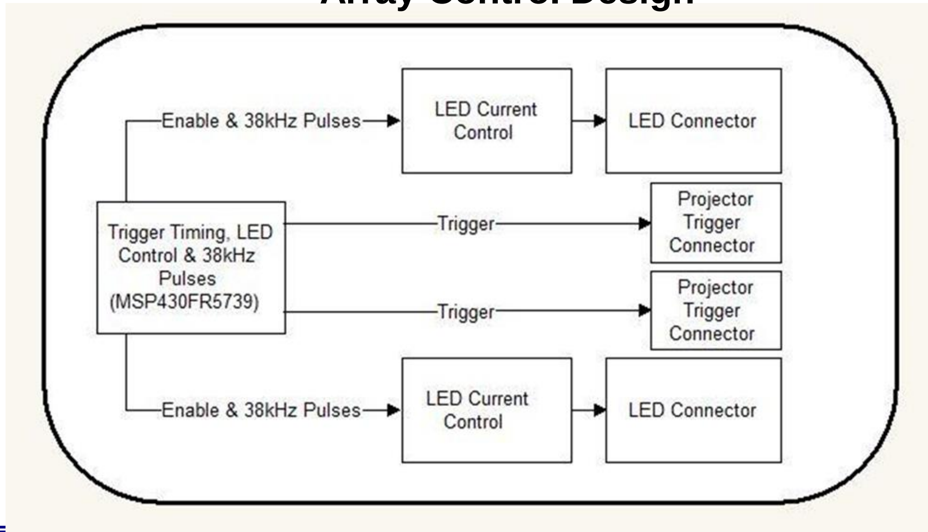




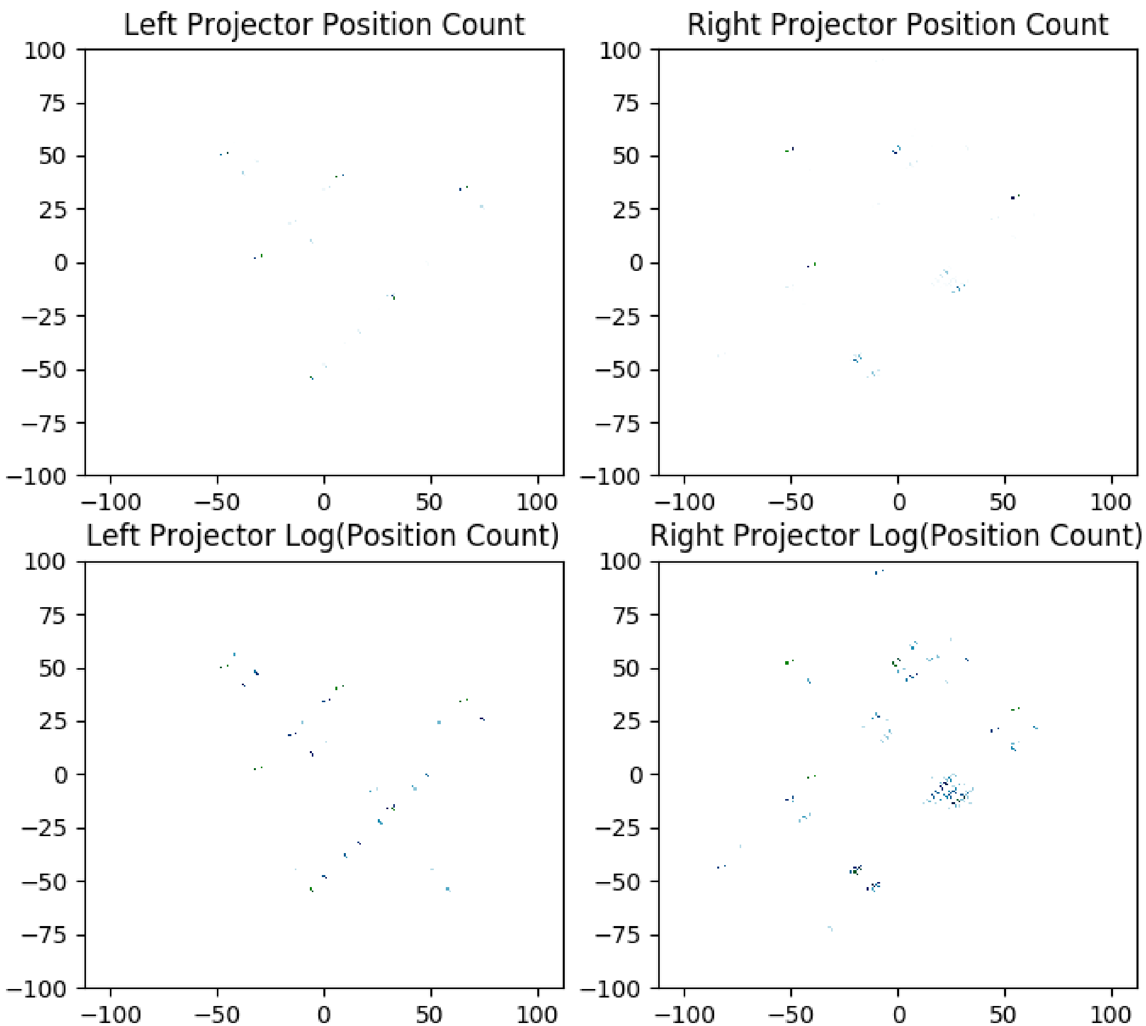
Timing and Synchronization Rig Block Diagram



Array Control Design

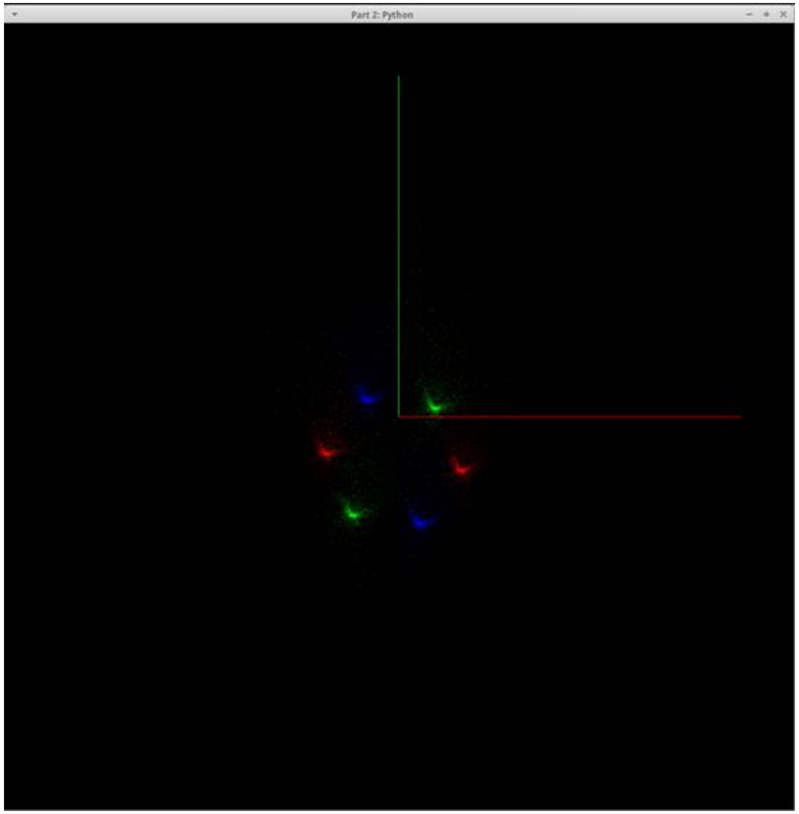


Tracking Statistics



Manifold Compliant Particle Swarm Optimization

- When multiple tags are constrained (for example by the rigid body constraint) MCPSO algorithms allow for the filtering of constrained systems position and orientation in the presence of non gaussian noise.
- This allows for the determination of position and orientation.
- In addition, this confers considerable resilience to occlusion, as constraints allow, for tags visible to different projectors, in order to combine estimates.
- Manifold Compliance recasts constraints as a Lie Manifold, allowing for the use of log-exponent mapping to “bake in” the geometry, reducing the search space to only physically realizable configurations.
- A fully operational MCPSO has been implemented in OpenCL (Open Compute Language) a platform independent language for Heterogeneous Multi-Processing. This allows operation on Nvidia, AMD, Intel, ARM Mali, and Various other Graphical Processing Units, as well as Altera FPGA architectures, allowing for fast and efficient processing of estimates.



Example of Particle Swarm Optimization of 262,144 Particles in Real Time

Whisper Analysis Software

- Written in Python:
  - Rapid development
  - Efficient integration with OpenCL
  - wxPython allows rapid graphical user interface development
  - Strong integration with scientific computation packages as well as visualization with VTK (Visualization Toolkit), OpenGL and pygame
- Solution of tracking problem: Particle Swarm Optimization (PSO)
  - Generative approach to data fusion: Model state measurement process, and find the state for which modeled measurements best match actual measurements
  - Multidimensional optimization (location x,y,z, orientation q1,q2,q3,q4: 7 numbers): Use PSO, implemented in OpenCL for highly parallel solution on GPU
  - Approach can be ported to FPGA as well as to low-power mobile processors

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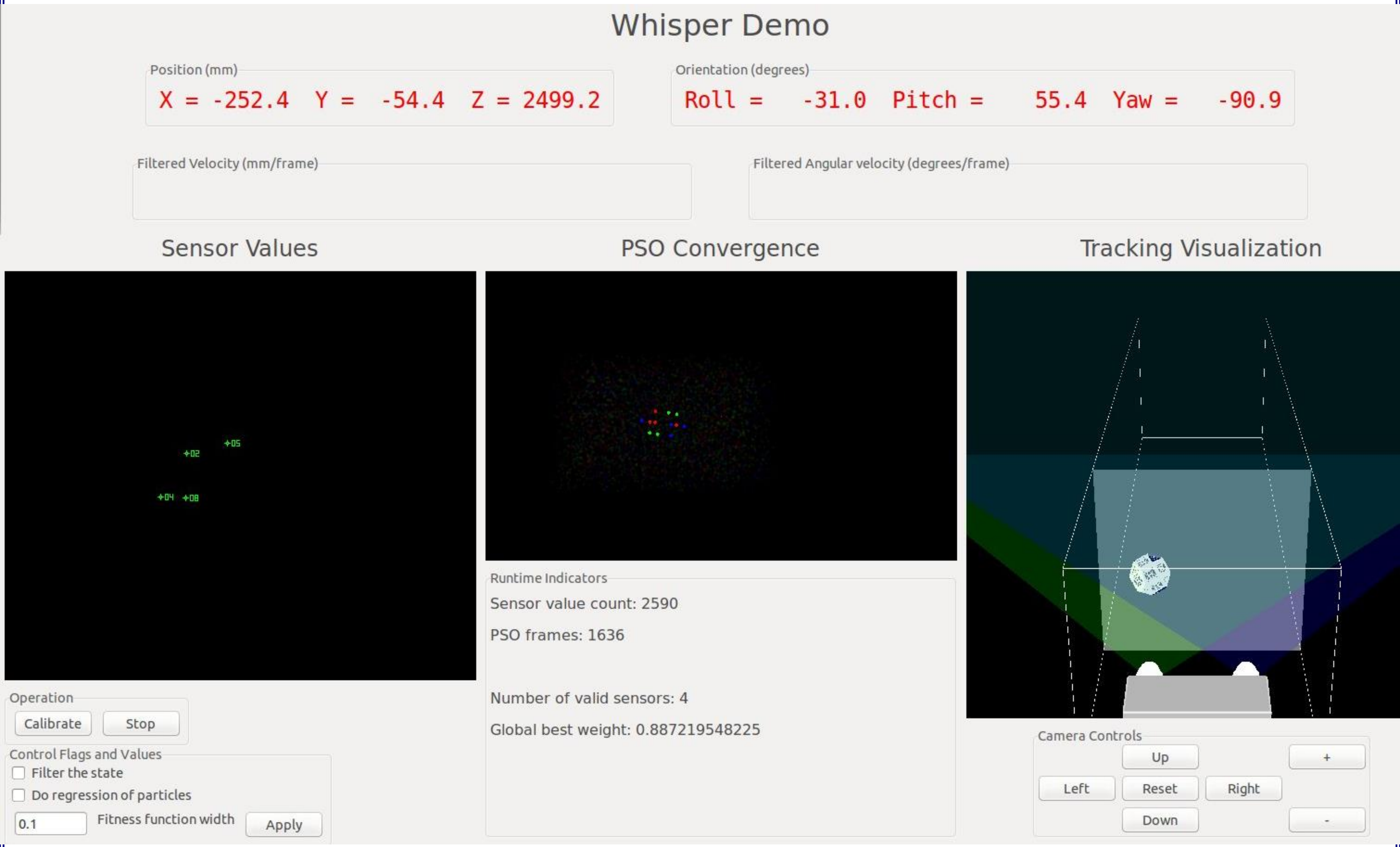
Whisper Analysis Software: User Interface



Whisper Analysis Software 2

- Whisper sensors communicate with computer via RFID/BLE/WiFi
  - Standard interface
  - Sensor values are encoded as printable text
  - Each sensor reports 4 numbers:
    - Validity code; Projector code; x, y (pixel location detected)
- Solution to tracking problem:
  - One projector gives data at each timestep
  - Solution for target position, orientation is found which maximizes the overlap between actual and modeled sensor values. Invalid data are ignored
  - Particle cloud (in effect, probability distribution function) for the state at each measurement is used as initial guess for next timestep. Particles optionally propagated using time derivatives (velocity and angular velocity)
  - Stereo from two projectors is improved by use of sigma point (unscented) filter which provides smoothing of results

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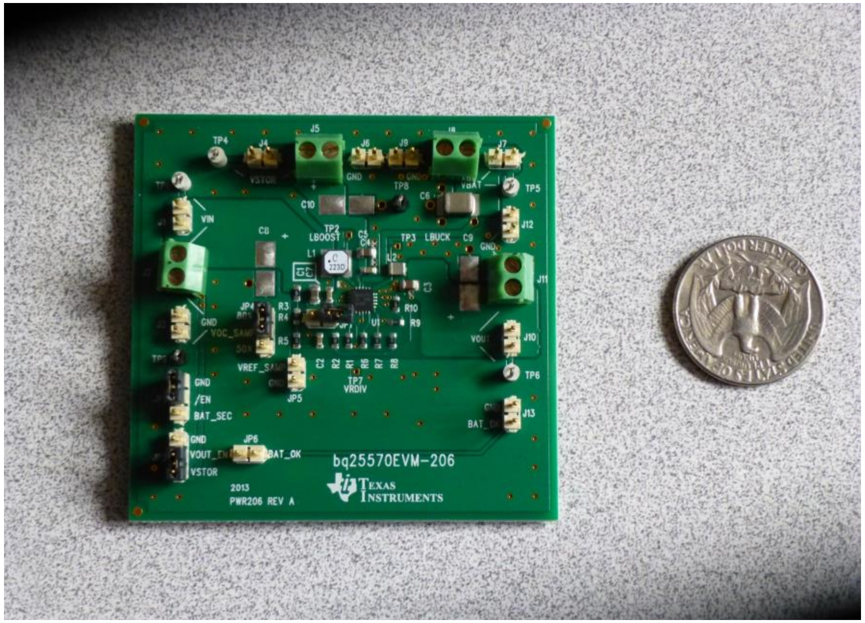
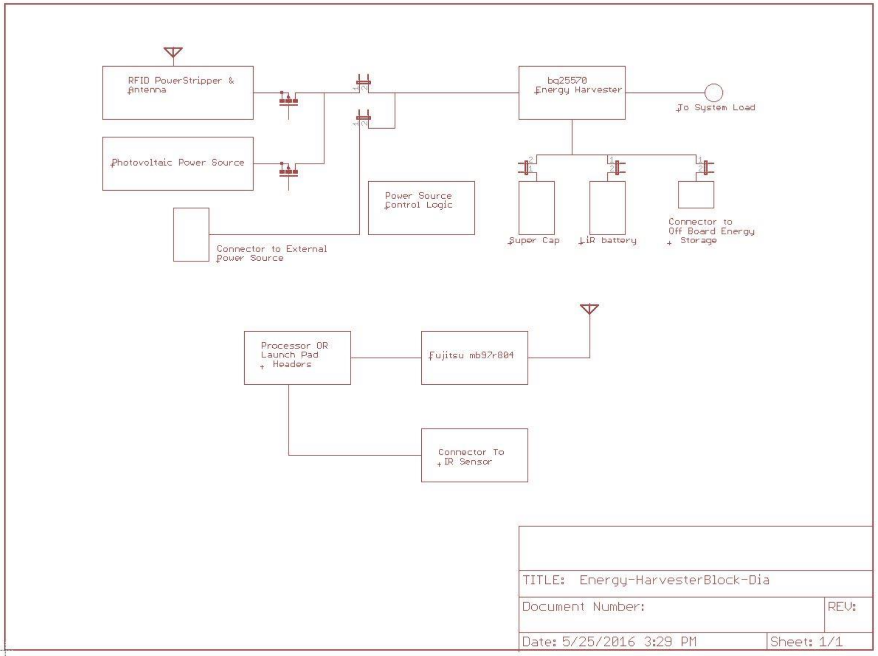
Energy Harvester Subsystem Progress

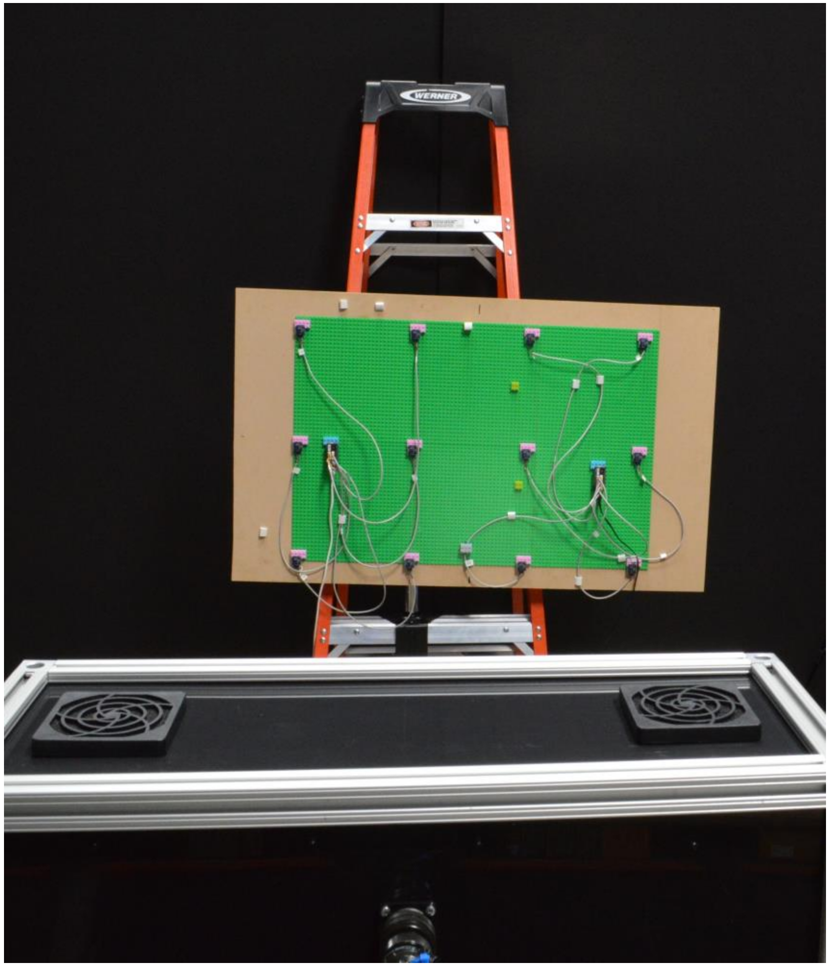
- ❑ Harvester Circuit
  - ■ Texas Instruments BQ25570 Nanopower Buck/Boost Converter
  - ■ Designed to extract microwatts from high impedance PV/RFID without collapsing the sources.
- ❑ Supplementary RF Antenna
  - ■ Twinned with Selected RFID module.
- ❑ Optional Photovoltaic (PV) Cell
  - ■ Printed Thin Film units
  - ■ Watch style PV cells.

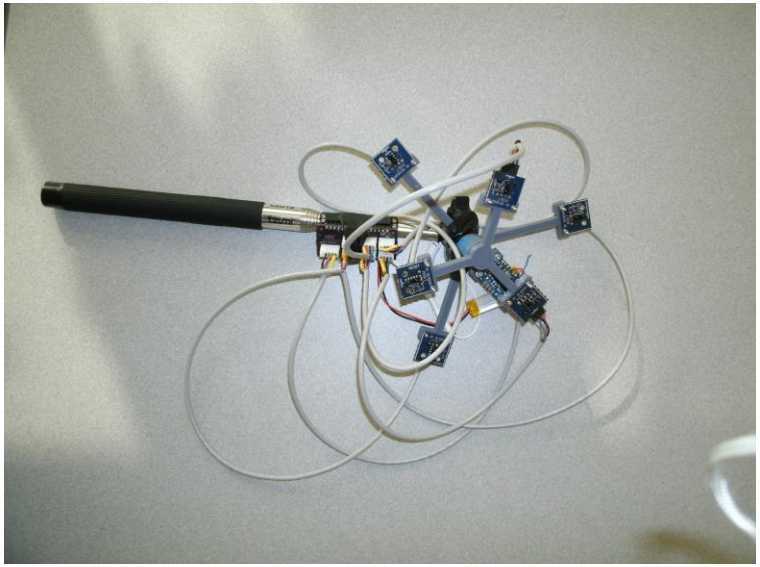




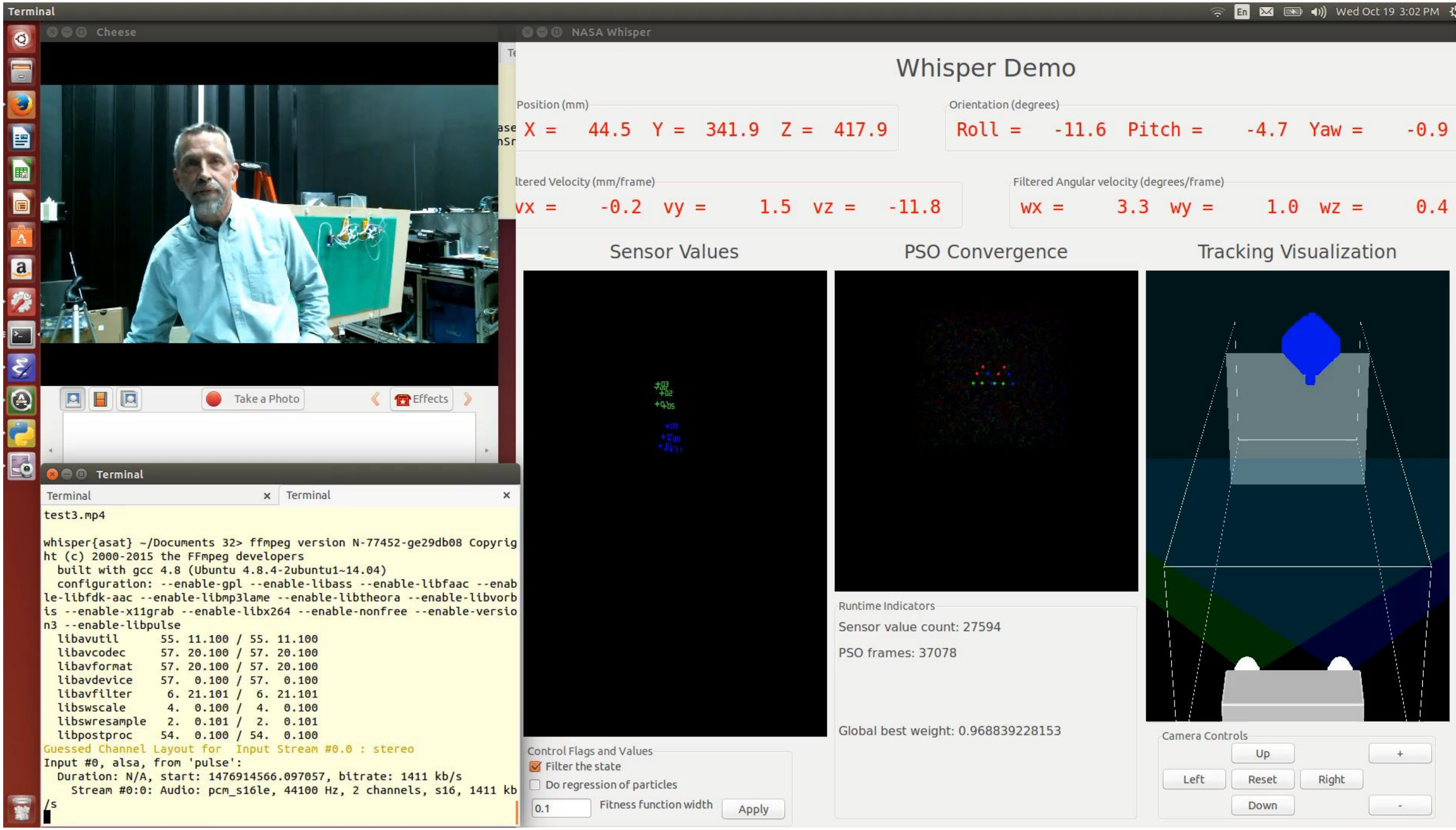
Interim Evaluation Unit

- Due the need for simultaneously developing optical tracking, MCPSO software, RFID and energy harvesting, our interim evaluation unit has employed BLE and WiFi enabled stand in channels for RFID, as these systems are developed.





In House Performance Demo



Accomplished

- What we have accomplished:
  - Full Pico Projector Based Synchronous Multiple Beacon System
  - Detector/Discriminator Reception/Synchronization/Decoding
  - Full MCPSO tracking implemented in OpenCL allowing for cross platform operation with all GPU platforms including mobile processors as well as FPGA based solutions.
  - Compatible Impinj Monza X implementation
  - Primary integration of Power Harvesting based on TI BQ25570 chip

Way Forward

- The path ahead
  - Integration of IMU
    - Already implemented in hardware, requires software integration
  - Full integration of power harvesting and FRAM based RFID
    - Alternate implementation via direct modulation via MSP430 or Minimal rewrite Monza X
  - Miniaturization of Beacon Projectors
    - Present Design is Picoprojector Based but employs bulky optics for easy modification
    - Retaining the same .45” pico DLP and transitioning to a non-telecentric optical engine in conjunction with COTS M12 fisheye leads to a “deck of cards” or less scale projector.
  - Integration of “Monocular” Simultaneous Location And Mapping (SLAM) for setup and calibration.
    - The primary components of such an approach, MCPSO tracking and Data Association, are fully resolved.
    - Integration of Low Rank Factorization required to realize SLAM. Multiple sources of existing code from the field of Probabilistic Robotics.
    - Graphical Constraint System is the final goal.
  - Full Miniaturization of Tags
    - Chip Scale and Dense Ball Grid Array Components
    - Flexible PCB implementation
    - Printed PV cells.

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