

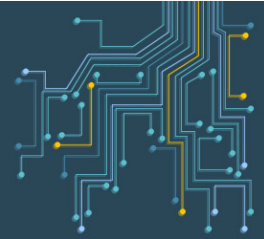
Rapid Prototyping of Wireless Sensor Solutions for Future Applications

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<https://www.dceams.com/>



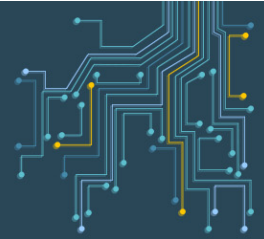
Who is DiPaola Consulting?

Design – Engineer – Fabricate – Share - Lead

Sensors, MEMS, Electromechanical Products, Conservation, Residential Housing



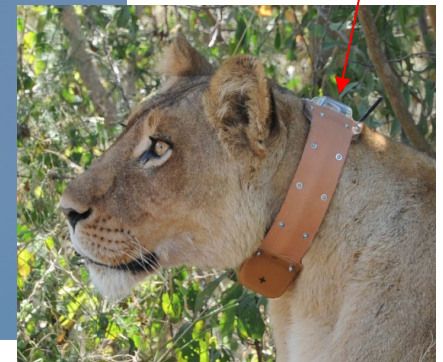
Industries: Automotive, Residential Housing, Heavy Truck and Off Road,
Biomedical Devices, Industrial, Defense and Consumer Electronics



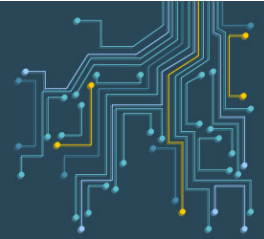
Story in Art - <https://www.storyinart.com/>



Change to
Become
Nonobtrusive

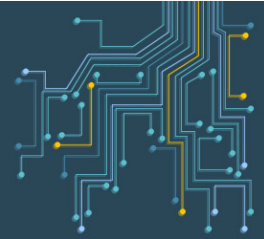


R&D, Photography and Videography to Conserve our Wildlife and Earth



Outline

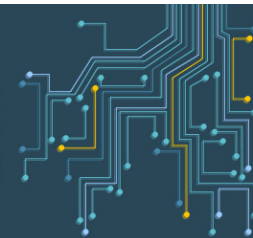
- Need for Wireless Prototypes
- Rapid, High Performance and Reasonably Priced Prototypes
 - Required Hardware
 - Protocols – Wireless and Sensors
 - Software Solutions - Blend of Off-the-shelf and Custom
 - BLE Service
 - Data Storage
 - Limitations – Range, Sample Rate, Bandwidth, Sensor Protocol Speed
- Case Study of a Wireless Medical Sensor



Need for Wireless Prototypes – Smart Herds

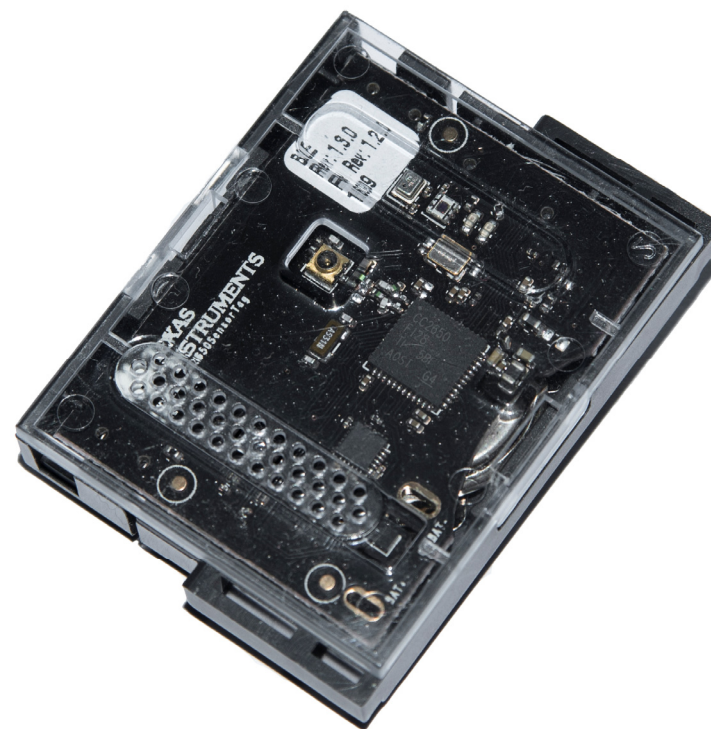
- Smart monitoring of herds for injury, illness, food and water consumption, exercise, location
- Integrated sensors include 9-axis inertial measurement unit, temperature sensor, pressure sensor, humidity sensor, light sensor, microphone, GPS
- Uses multiple wireless interfaces
- Range of 100 / 400 (BLE 5) – 2000 (Sub-1GHz) meters
- Smart algorithms programmed in MCU, data stored in serial flash



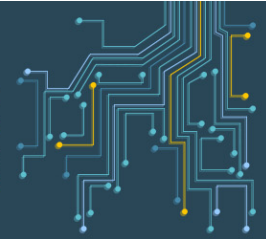


Prototypes – Rapid, Performance, Cost

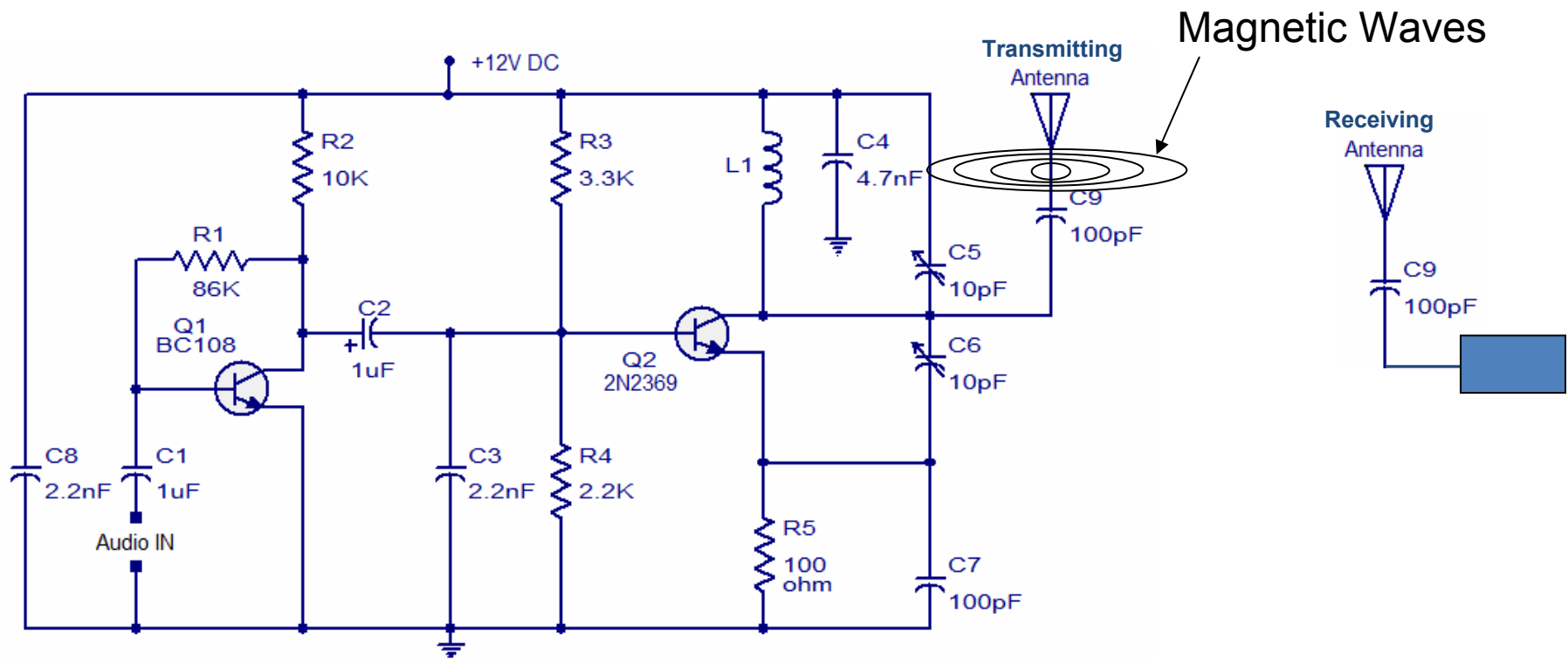
- Rapid Prototypes: 2 weeks to 4 months (depending on complexity)
- High Performance: Various sensors with strong capability come built-in to wireless prototype solutions but custom add-on development packs with new sensors greatly increase performance for specific needs
- Custom programming possible
- Reasonably Priced Development: Thousands to tens of thousands of dollars (not hundreds of thousands)
- Ultra-low power consumption, low product cost (relative) and small physical size
- Start collecting data to demonstrate proof of concept to Investors / management



Example: TI Sensor Tag



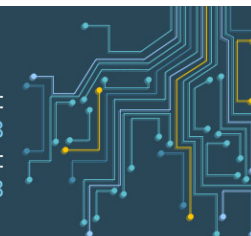
Radio Frequency (RF) Wireless Signal



FM transmitter circuit

www.circuitstoday.com

- Oscillation of RC circuit is tuned and transferred to antenna producing magnetic waves that have long range transmission that are received by receiving antenna

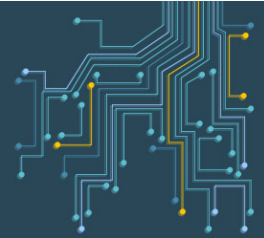


Wireless Protocols (not all inclusive)

	Bluetooth Low Energy (BLE)	Bluetooth Low Energy (BLE) 5.0	Zigbee	WIFI
Live Sample Rate	133 Hz	133 Hz	100 + Hz	1000 Hz
Actual Pay Load Transfer Rate	2667 bytes / s	21,336 bytes / s	2500 bytes / s	12 M Bytes / s +
Range	10 - 30 meters	40 - 1500 meters**	70 - 150 meters	10 - 100 meters
Power Consumption (Battery Life)	Months to 2 years	Months to 3 years	Months to 3 years +	Days
Frequency	2.4 GHz	2.4 GHz	2.4 GHz (ISM band), 784 MHz (China), 868 MHz (Europe), and 915 MHz (USA)	90 MHz 2.4 - 5 GHz
Network Topology	Device to Hub / Mesh	Device to Hub / Mesh	Mesh	Internet
Standard	Bluetooth SIG*	Bluetooth SIG*	IEEE 802.15.4	IEEE 802.11
Typical Uses	Wearables / Personal Electronics Connected to Smart Device	Various	Smart Home Devices, Mesh Networks	Various

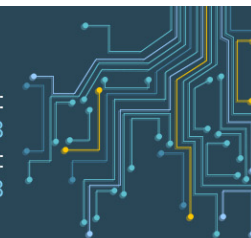
*Bluetooth Special Interest Group (SIG)

**New LE 2M PHY, as well as the original LE 1M PHY, are both called Uncoded PHYs since they use a 1-symbol representation per bit of data (in comparison to the new LE Coded PHY which uses a 2-symbol or 8-symbol representation per bit of data - with data rate going down to 125 kbps for the latter)



Required Hardware

- TI SensorTag (others include Silicon Labs, Cypress Semiconductor, etc.)
 - Wireless chip supporting multiple protocols (Bluetooth Low Energy, Zigbee, WIFI, Sub-1GHz radio interface)
 - Sensors: 9-axis inertial measurement unit, temperature sensor, pressure sensor, humidity sensor, light sensor, microphone, GPS (optional)
 - Built in Antenna on PCB, Single coin cell battery (CR2032)
 - Serial flash for data storage
- Development packs
 - Module (Debug Devpack) that plugs into back of SensorTag allowing custom programming
 - Custom development packs can be made to add new sensors to the device
- USB dongle and PC (dongle enables PC to receive bluetooth low energy (BLE) signal) or bluetooth enabled device such as mobile phone, tablet or Raspberry PI
- CC Debugger used to communicate and program USB dongle (firmware updates)
- All of the SensorTag design / fabrication files are available for download and modification
- Multimeter and Total Phase I²C and SPI Level Shifter programmer / reader



TI SensorTag

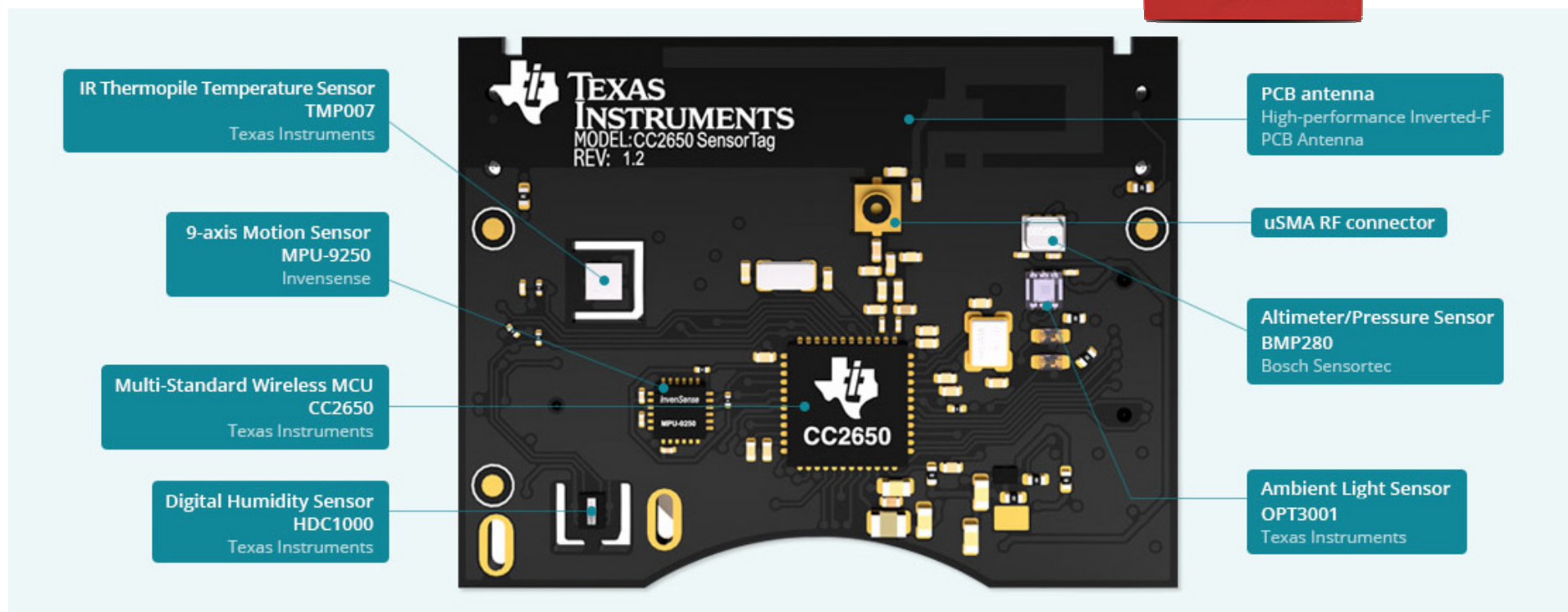
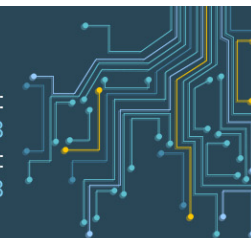


Photo Courtesy of TI



TI SensorTag



CR2032 Battery Clip

Buzzer

DevPack
Expansion Connector

JTAG Debug/Programming
Interface

4M Serial Flash

Required for:

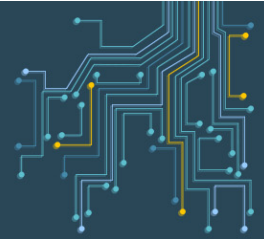
- Offline Data Storage
- Multi-Protocol Support
- Over-the-air (OTA) upgrade of full software stacks

Magnet Sensor
MK24
Meder

Digital Microphone
SPH0641LU
Knowles

Solder point for AAA battery pack

Photo Courtesy of TI



TI SensorTag Development Pack

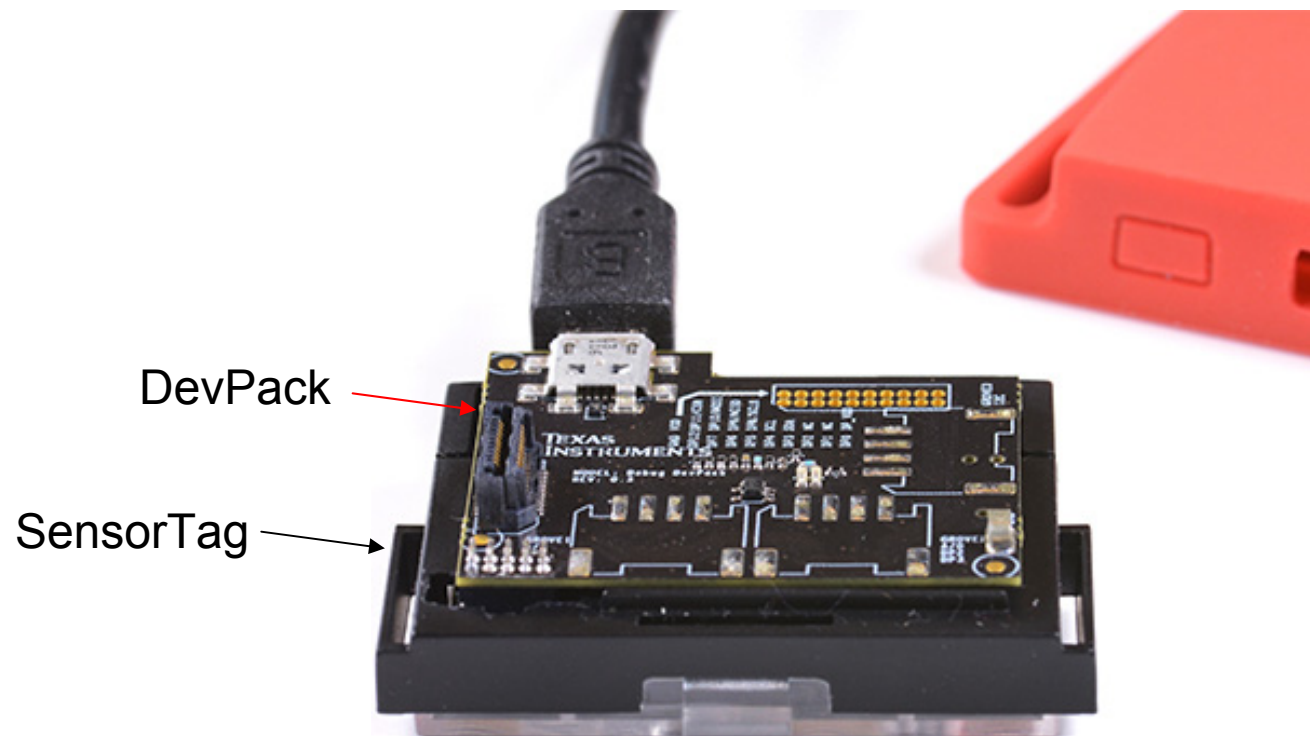
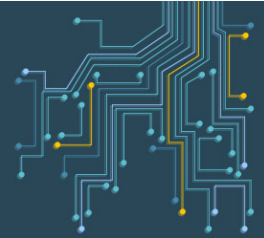
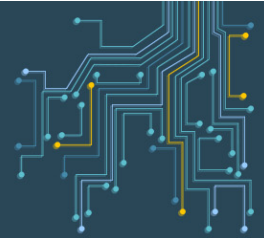


Photo Courtesy of TI



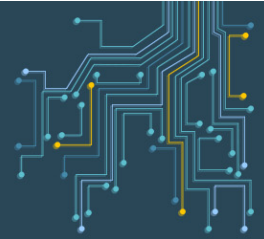
Software Solutions - Overview

- Software solution typically a blend of off-the-shelf and custom
- TI provides off-the-shelf firmware in C programming language that can be downloaded and modified to meet desired need (over 30,000 lines of code in over 100 files)
 - Once modified the new software is downloaded to the SensorTag via a Debug Devpack that plugs into an expansion slot on the SensorTag
 - Firmware update files for USB Dongle and SensorTag are provided by TI periodically
- The addition of a new sensor using a development pack requires adding a service in firmware to enable the SensorTag to communicate the output of the sensor via Bluetooth Low Energy to a laptop computer, Raspberry Pi, tablet, phone or other Bluetooth enabled device
 - Development of the service firmware is not entirely from scratch as other similar sensors can be used as a template to expedite programming and error resolution (TI also provides training)
 - C Programming is performed in Code Composer Studio by TI
- Additional programming maybe needed:
 - If sensors are sampled at a rate greater than 7.5 milliseconds, the data can be stored in flash memory and transmitted during a communication cycle after data collection has stopped
 - Data is stored and transmitted less often to conserve battery life
 - Algorithms are added to increased functionality of the system



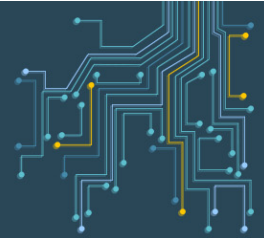
Software Solutions – BLE Service

- The Attribute Protocol (ATT) implements the peer-to-peer communication between an attribute server and an attribute client
 - ATT client sends commands, requests, and confirmations
 - ATT server sends responses, notifications and indications to the client
- The Generic Attribute (GATT) Profile specifies the structure in which data is exchanged. This structure defines basic elements, such as services and characteristics, used in an application.
 - Bluetooth SIG has defined several Profiles to ensure interoperability
- A Service is a collection of characteristics
 - Characteristics are made of several Attributes and a Declaration
 - Attribute - the smallest addressable unit of data used by ATT and GATT (Handle, UUID, Value)
 - Declaration - comes before the value attribute and describes whether the value attribute can be read or written, contains the UUID of the Characteristic and the handle of the Characteristic Value's attribute
- To complete a service, 6 program files are generated (>2000 lines of C code developed, compiled and debugged), ~10 additional program files are modified for a single sensor



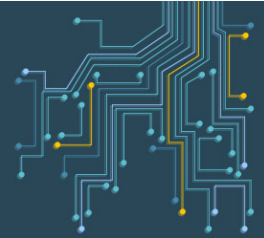
Software Solutions – Tools

- Code Composer Studio: Viewing existing firmware and C programming of SensorTag
- SmartRF Studio 7: Update firmware of USB Dongle
- Smart RF Flash Programmer 2: Update firmware of SensorTag
- Device Monitor: Log and monitor data from TI SensorTag
- *All programs and firmware are free to download from TI's site*



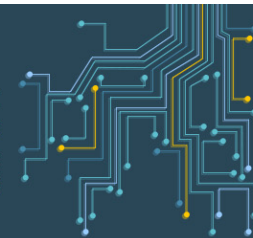
Limitations

- Range of SensorTag is about 30 ft indoors. If this is a problem, you can use the dual band SensorTag that uses Sub 1-GHz communication and bluetooth to increase range to 2 Km unobstructed.
- Live sample rate is limited to 133 Hz. This can be problem for some applications. To overcome this, you can collect data faster and store in serial flash memory and then transfer data during a down period.
- Data transfer rates are slow at 2667 bytes / s. This can be a problem if down time is limited and sample rate is high. In this case you can use a WiFi based sensor to show proof of concept or utilize BLE 5.
- Some sensors have limitations on I²C sample rate at 400 KHz (max I²C speed with SensorTag). The SensorTag also uses SPI (serial peripheral interface) and this can sometimes eliminate this constraint.



Case Study of a Wireless Medical Sensor

- Wireless medical sensor is used to detect injury and monitor recovery
- Developed with world renown orthopedic surgeon, Dr. Lanny Johnson, MD
- Clinical study currently being performed at The Rothman Institute in Philadelphia led by Dr. Gerald Williams, MD
- Initial results showed highly trained orthopedic surgeons small movements not previous seen
- Prototype system was developed in 3 weeks and is currently in use in the clinical study (works with 3 mouse clicks)
- Clinical study expected to be completed early next year



Prototype System



← SensorTag

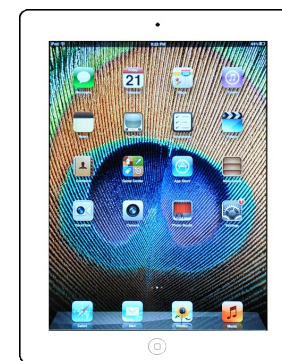


PC w/ USB Dongle

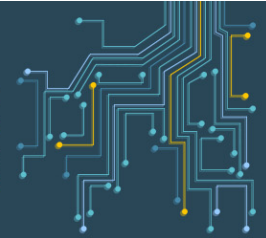
Or



Or



Tablet /
Smart Phone



Device Monitor Software

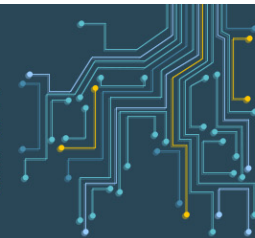
The screenshot displays the Device Monitor Software interface for a CC2650 SensorTag. The interface is divided into several sections:

- Event Log:** A list of events with timestamps and sensor status messages, such as "Optical sensor PASSED", "Pressure sensor PASSED", "Gyro/Accel PASSED", "Magnetometer PASSED", "External Flash PASSED", and "OAD support detected".
- Services:** A tab labeled "CC2650 SensorTag" showing various sensor configurations and status indicators.
- Sensors:** Multiple sensor modules are visible, each with a set of controls and data fields:
 - IR Temperature:** Includes "IR local temp." and "IR target temp." controls.
 - Humidity:** Includes "Humidity" and "Humidity temp." controls.
 - Gyroscope:** Includes "Gyro X", "Gyro Y", and "Gyro Z" controls.
 - Magnetometer:** Includes "Mag X", "Mag Y", and "Mag Z" controls.
 - Accelerometer:** Includes "Accel X", "Accel Y", and "Accel Z" controls.
 - Barometer:** Includes "Pressure temp." and "Pressure" controls.
 - Light Sensor:** Includes a "Light" control.
 - Buzzer:** Includes "Buzzer on" and "Buzzer off" controls.
 - LED:** Includes "Red LED", "Green LED", and "LED off" controls.
- BLE Network:** A table showing connected devices:

Device	Address	RSS	Status
Host	D4:F5:13:09:1...	-56	Connected
CC2650 Sens...	B0:B4:48:BE:8...	-56	Connected
- Mode:** A section with "Test" and "Monitoring" radio buttons.
- Buttons:** "Run", "Stop", and "Clear" buttons are present.
- Options:** Checkboxes for "Wake On Motion", "Log Enable", and "Abort on Error".
- Status:** A message at the bottom indicates "11:31:44.487 : Enabling notifications ... done".

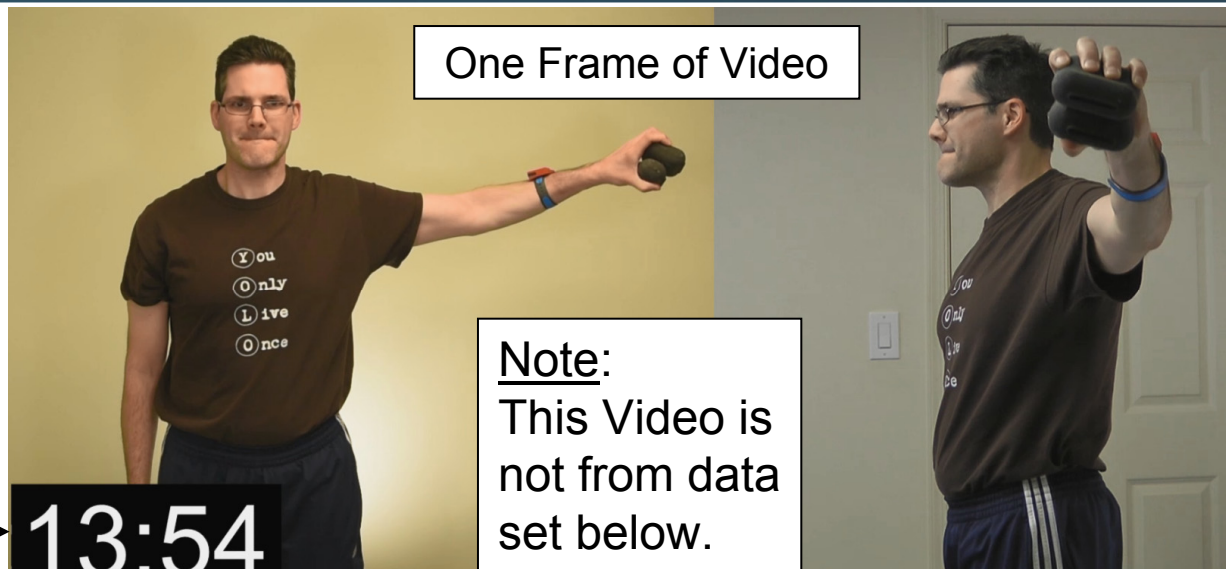
A bracket on the right side of the interface groups the sensor configuration panels under the label "Device Data".

At the bottom left, a "SensorTag Connected" message is displayed with an upward arrow pointing to the "CC2650 Sens..." entry in the BLE Network table.



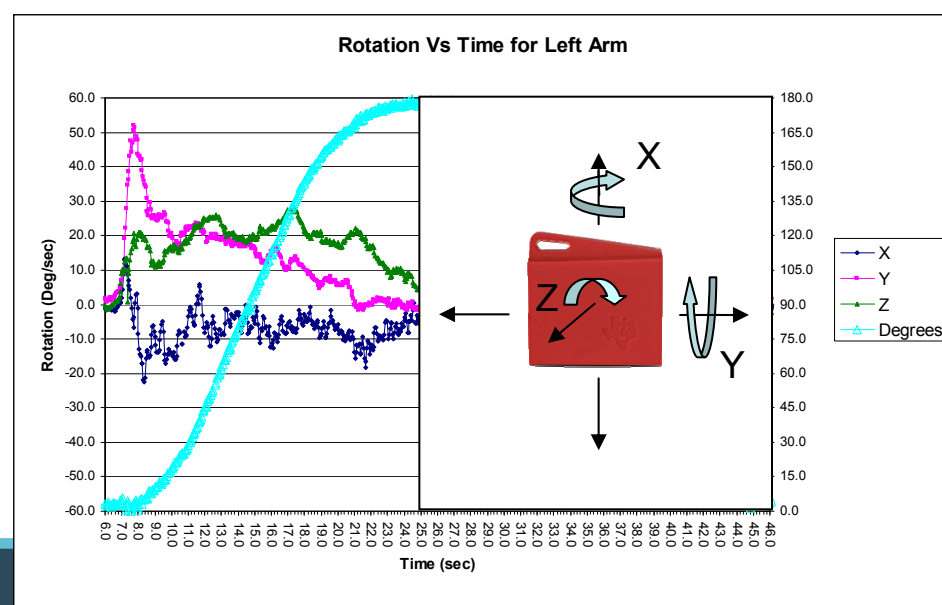
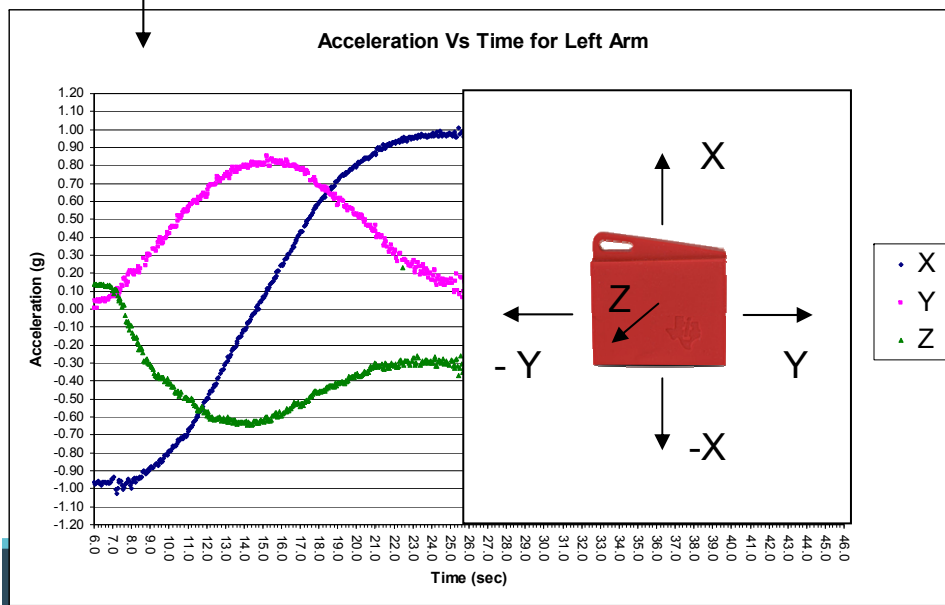
Data

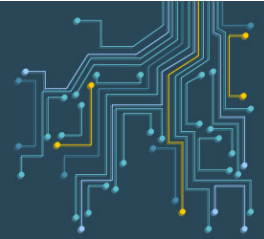
- In application video is synced w/ sensor data (example shown is not synced – two separate sets of data – demo only)



Sensor Data

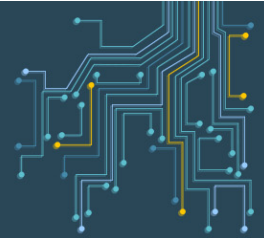
Time → **13:54**





Potential of System

- Use algorithms to detect injury and monitor recovery
- Give Physician more insight to problem and path to healing
- Detect issues before the point surgery is needed
- Monitor patient recovery without an office visit
- Quantify effectiveness of specific surgical procedures
- Better monitor the effectiveness of physical therapy through monitoring small changes
- Lower cost to patients / lost time
- Detect fake injury by patients to collect workers compensation



Call to Action

- Wireless sensor solutions are feasible and within reach at low cost for development and prototypes
 - If you have an idea, get the prototype complete and start collecting data for investors and management to see capability of the product
 - Simultaneously conduct market research to prove market viability
- There are various solutions to the limitations of the technology
- The algorithms behind the hardware hold tremendous potential for intellectual property and revenue growth
- Companies like TI that make the development process easier are grabbing market share
- If the initial complexity is daunting, we are here to help and happy to discuss you ideas