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Integrated Self-Sufficient Structurally Integrated Multifunctional Sensors for Autonomous Vehicles

Acellent Technologies Inc.

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Project ID: mat212

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Overview

Timeline

- Project start date – 6/29/20
- Project end date – 3/28/2021
- Percent complete – 100%

Budget

Total project funding

- ✓ DOE share - $199,999
- ✓ Contractor share - $0
- ✓ Funding for FY2020 - $88,888.44
- ✓ Funding for FY 2021 - $111,110.56

Barriers and Technical Targets

- The Department of Energy (DOE) Vehicles Group has identified a need for novel multifunctional composite materials and structures for the automotive industry that have the capability to reduce weight and volume as well as costs of "conventional" structural components by performing engineering functions beyond load carrying.
- Acellent is developing an integrated AUTO-SMART sensor system for the automotive industry that will address this need.

Partners

- Interactions /collaborations – Stanford University, Ford Motor
- Project lead – Acellent Technologies Inc.

Relevance

Impact: The multifunctional sensing system will provide immense benefits to the autonomous and electric vehicle industry including;

(1) Increased safety through real-time detection of impacts,

(2) Rapid pedestrian crash sensing protection,

(3) Novel battery monitoring systems for EV cars,

(4) New advanced sensing that can reduce the cost of vehicle inspection and maintenance.

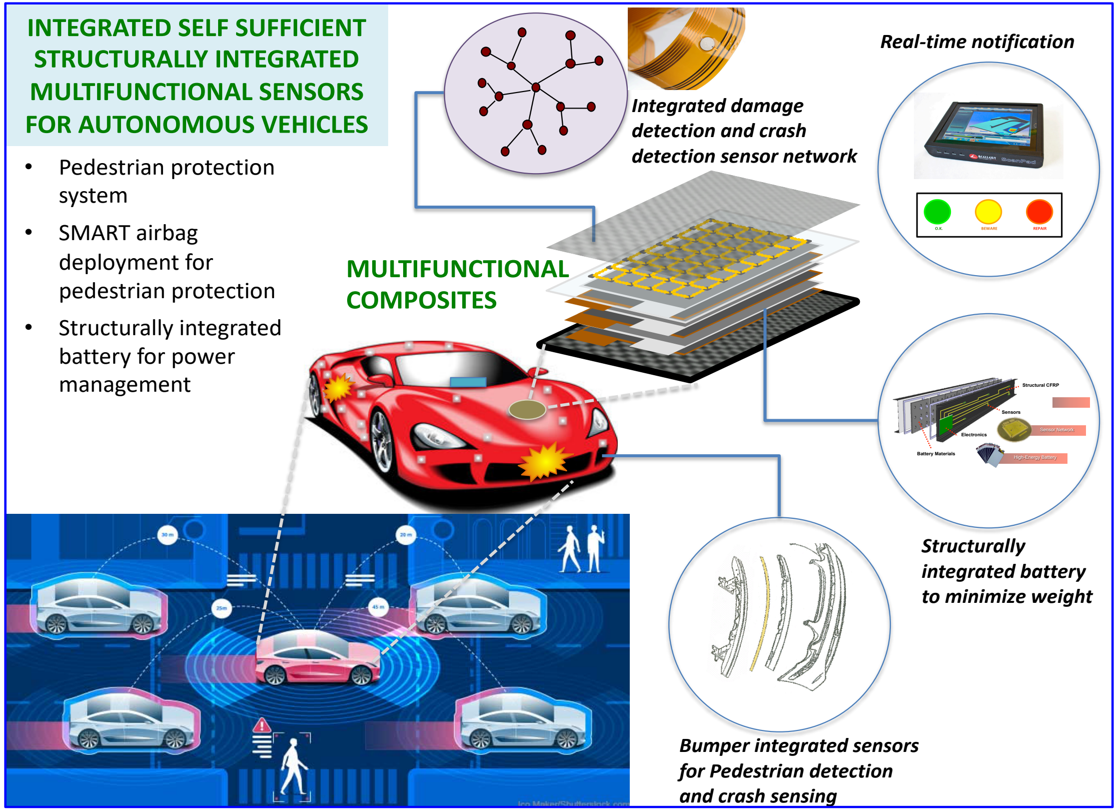
Potential applications include electric and autonomous vehicles, unmanned aircraft, submarines etc.

Objectives: The following developments were targeted in this program with Phase I focusing on developing a complete design for the AUTO-SMART sensor system:

1. Demonstrating the design for a pedestrian crash sensing system that has the capability to detect any impact event occurring on the front bumper of an automobile within a very short duration and generate the proper response signal to a built-in protection system.
2. Demonstrating the design of a system for improving the ability to monitor the State of Health (SOH) and End-of-life (EOL) of a typical battery packs and Multifunctional Energy Storage Composite Battery (MESC) for use in automobiles. The work on MESC was done in collaboration with Stanford University leveraging an ARPA-E project.
3. The preliminary design developed in Phase I was tested and demonstrated for both the multifunctionalities. The final configuration for installation on a vehicle will be demonstrated in Phase II.

Approach

- The AUTO-SMART sensor system will utilize embedded sensor networks designed for vehicles.
- The goal will be to provide weight savings through integration of materials with sensors, electronics, batteries, etc. to minimize parts counts, create new designs, new manufacturing processes and enable significant cost savings, and enhance pedestrian safety through integration of an impact detection system into the front bumper of a car and battery monitoring system integrated with vehicle batteries.



The innovative *sensor suite is designed, developed and integrated* with structural elements of the vehicle during the manufacturing process itself to create a structurally integrated sensor network.

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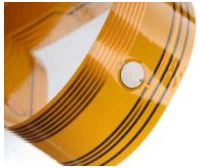
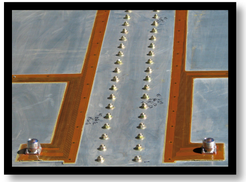
Flexible, easy-to-install sensors

Sensor networks

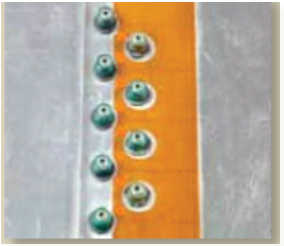
SMART Layer

- **Thin**, dielectric film with embedded pre designed **network** of piezoelectric **sensors/actuators**
- **Flexible and adaptable** to any structure and geometry

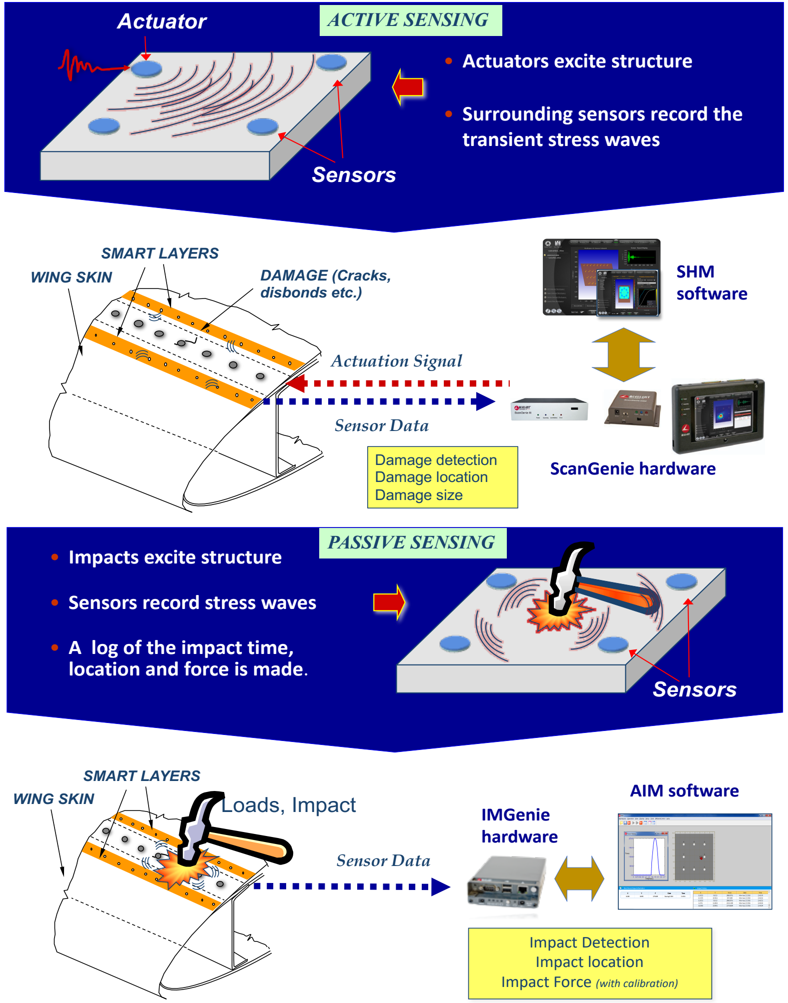




***Installation:** Surface mounted on metal or existing composite structures*



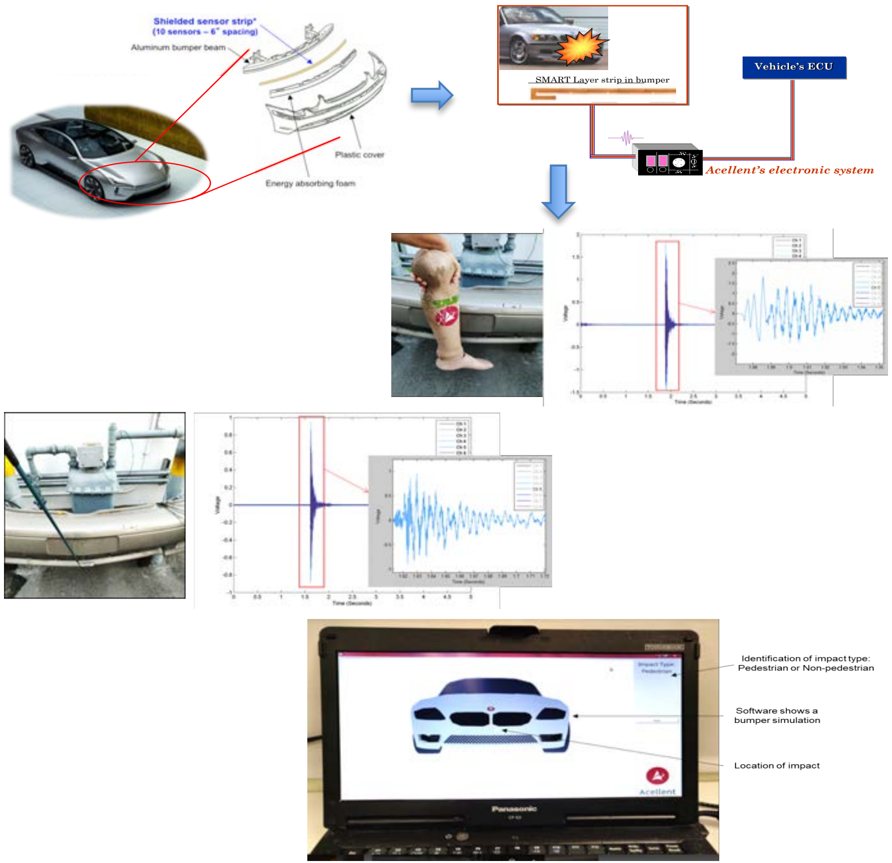
HOW DOES THE SYSTEM WORK?



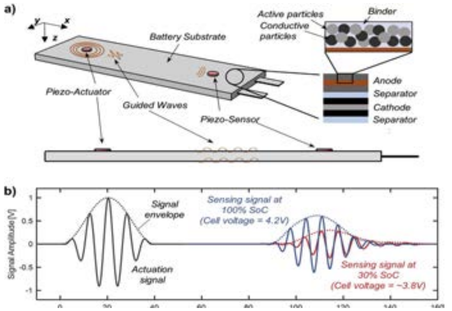
Technical Accomplishments & Progress

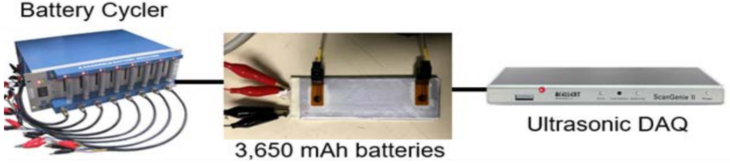
Phase I focused on demonstrating the following 2 major multifunctionalities

1. Pedestrian protection system (PPS)

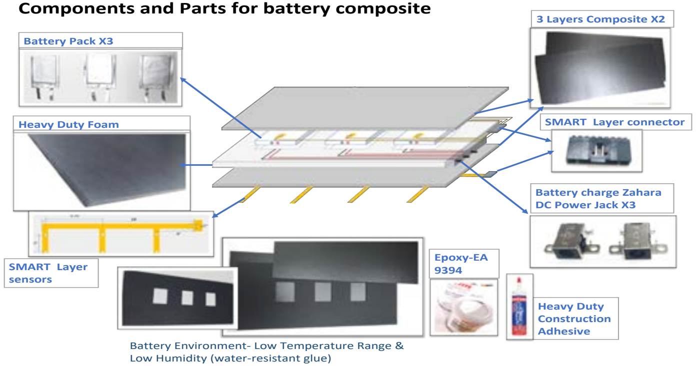


2. Battery monitoring system (BMS)





Components and Parts for battery composite



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Technical Accomplishments and Progress

Phase I accomplishments

- Identified two primary multifunctionalities for vehicles – pedestrian protection system and battery monitoring system
- Developed the requirements for the PPS and BMS systems
- Designed the sensor layout for car bumpers and identified potential low cost materials
- Manufactured sensors and tested and demonstrated a complete PPS for use in identification of non-pedestrian vs pedestrian impacts
- Worked with Stanford University to manufacture and test laboratory based batteries and State of Health (SOH) and End-of-life (EOL) of the batteries for automotive applications
- Designed a test bed with a sandwich of composite and batteries for use in complete battery monitoring. Testing will continue into Phase II.

This is the first year that the project has been reviewed

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Collaboration and Coordination with Other Institutions

Collaborators *(Phase I and Phase II)*

- **Stanford University** *(Phase I and Phase II)*

  Under an ARPA-E funded project, Stanford is developing "Multifunctional Energy-Storage Composites (MESC)" for the energy efficient design of light-weight electric vehicles. The focus of the ARPA-E program is on development for aircraft platforms. Stanford is collaborating with Acellent to develop and test the BMS system for automobiles.

- **Ford Motor Company** *(Phase II and beyond)*

  Ford will work with Acellent in Phase II to provide bumpers, test car, coupon testing in selected environmental conditions specific to cars and guidance during the project.

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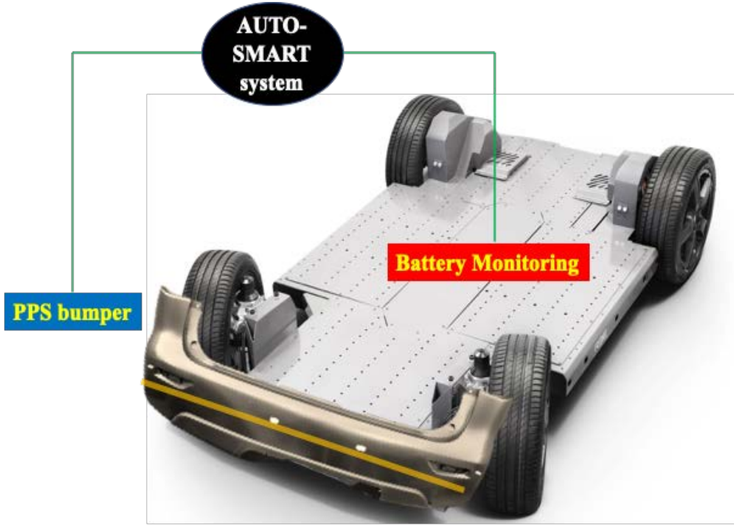
Proposed future research

Future tasks *(to be conducted in Phase II)*

In Phase II, the program proposes to completely develop multifunctional systems for cars. The two systems – PPS and MESC battery monitoring, will be developed using a unified architecture for implementation of both multifunctionalities in a vehicle design.

1. Design, develop and test a complete prototype of the Pedestrian Protection System (PPS)
2. Design, develop and tested a complete prototype of the Battery monitoring systems (BMS)
3. Design the architecture of a unified multifunctional sensing system for cars
4. Develop commercialization plans and cost targets with Ford and other automotive companies for the PPS and BMS



Proposed implementation of system

Any proposed future work is subject to change based on funding levels

Summary

The primary focus of the program is on how multifunctionalities in vehicles can impact their design to provide increased pedestrian safety, weight savings and structural efficiencies. During Phase I, Acellent developed an innovative *sensor suite that was designed, developed and integrated* with automotive vehicle structures during the manufacturing process itself to create a structurally integrated sensor network.

The focus was primarily on demonstrating the following two multifunctionalities:

1. A pedestrian protection system (PPS) that is critically important for driverless cars.
2. A battery monitoring system (BMS) for (1) typical battery packs and (2) a structurally integrated battery developed by Stanford University and licensed exclusively by Acellent leveraged for use in power delivery and management.

In Phase I, Acellent successfully demonstrated a complete PPS in a laboratory environment. Sensors were designed for installation on a bumper. The system was tested for impact detection using a non-pedestrian object (golf club) and a pedestrian leg. The signals due to impacts with each were clearly discernable. During the Phase I effort, Acellent received interest from the Ford Motor Company for the development of the PPS concept. The results of the Phase I effort showed that Acellent's proposed concept for the PPS was at a very high Technology Readiness Level (TRL). Ford agreed to collaborate with Acellent during a Phase II effort for the potential commercialization of the technology.

In collaboration with Stanford, Acellent also demonstrated the ability of using piezoelectric transducers to accurately monitor the State of Charge (SoC) and End-of-Life (EOL) for battery cells, both independently and when embedded inside a composite structure. A testbed for testing in Phase II using practical usage design was created and manufactured.

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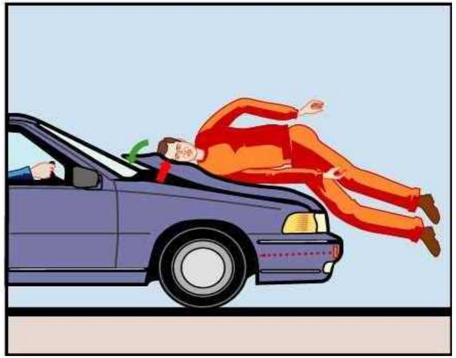
TECHNICAL BACKUP SLIDES

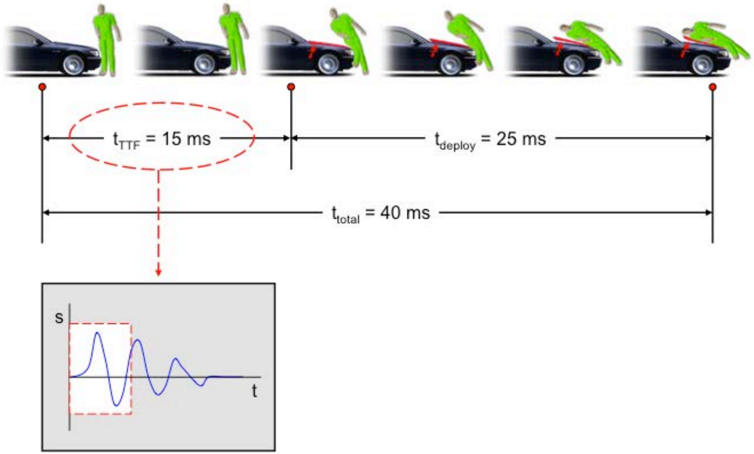
PPS requirements

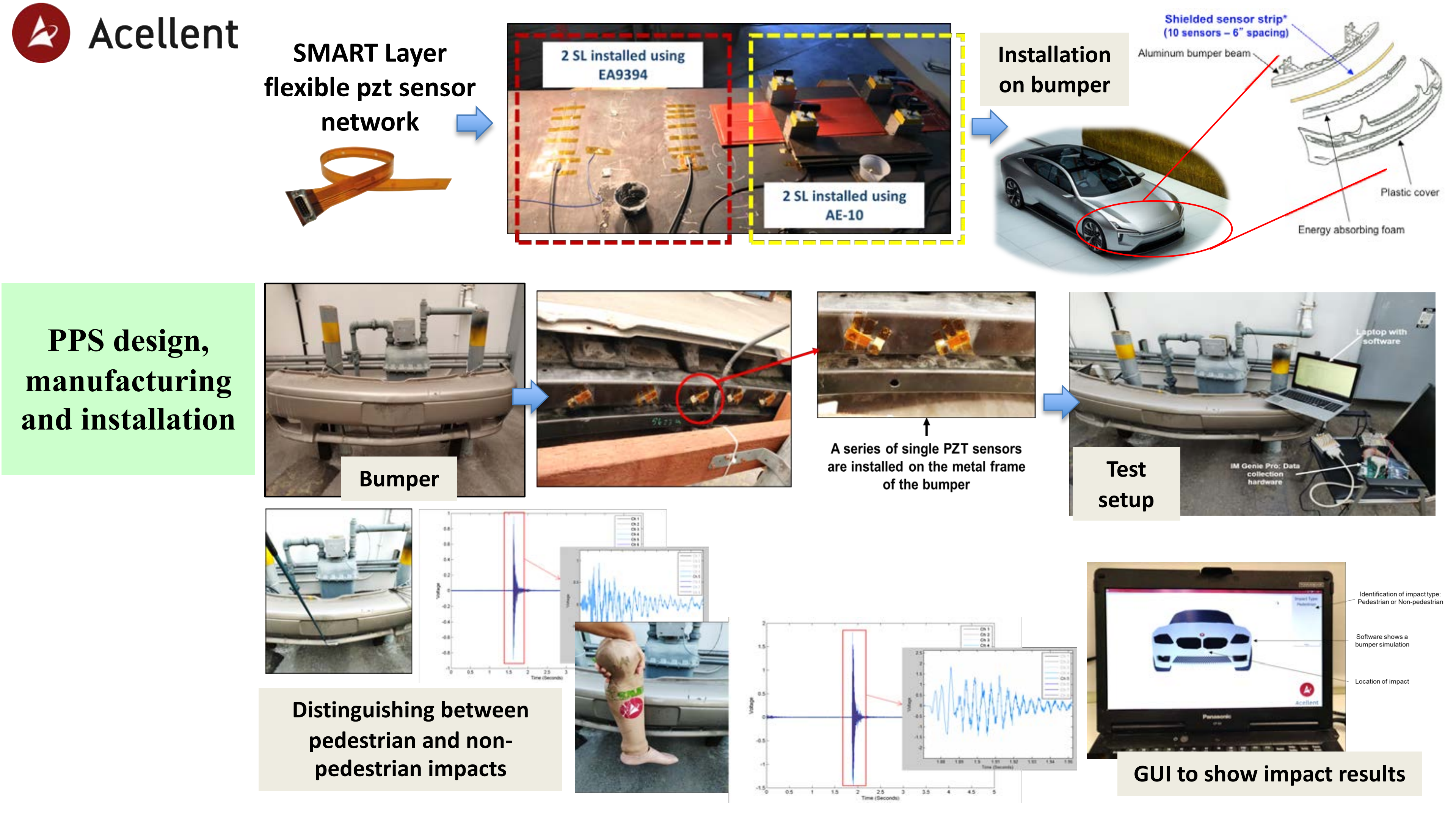
- NEED: Develop a pedestrian crash sensing system that has the capability to detect any impact event occurring on the front bumper of an automobile within a very short duration and generate the proper response signal to a built-in protection system.
- A primary challenge is to design and develop an impact event detection technique that can work efficiently even for complex structures with local property variation.
- Conventional impact detection systems have long response times because of the slow response of traditional sensors.
- The proposed system utilized PZT sensors to generate the impact signal immediately after the impact event happens. By doing this, the passive safety systems (such as air bags and pyrotechnic restraints) can be activated in time to save life.

- External protection device (pop-up hood) is deployed to protect pedestrian from head and neck injuries.



- Crash sensors identify impact with pedestrian leg.

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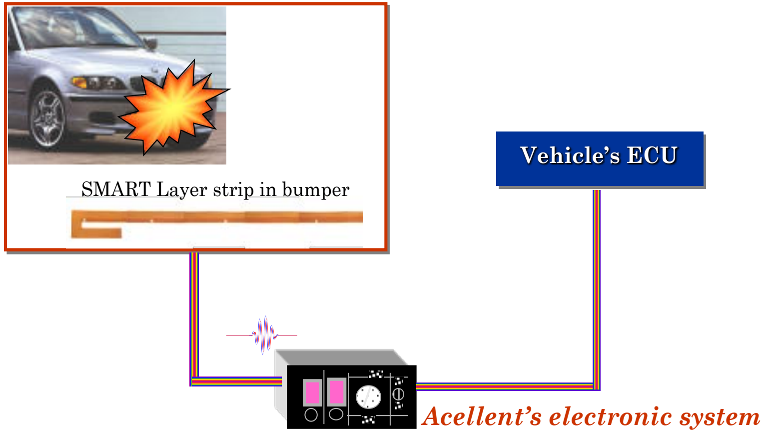
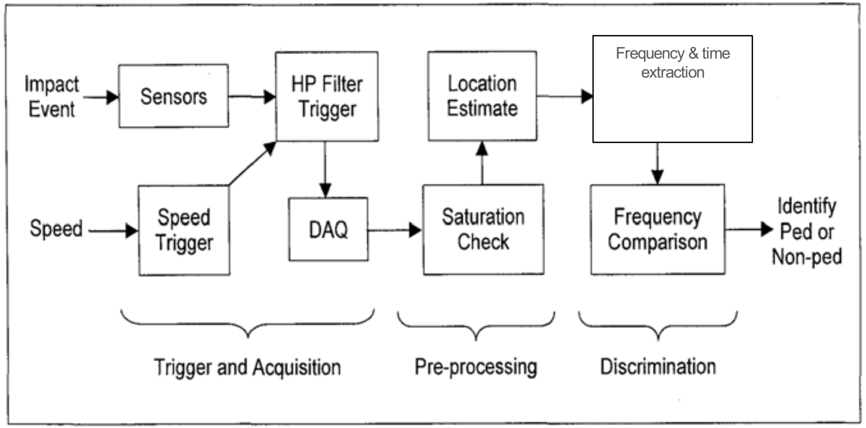
SMART Layer flexible pzt sensor network
2 SL installed using EA9394
2 SL installed using AE-10
Installation on bumper
Shielded sensor strip* (10 sensors – 6" spacing)
Aluminum bumper beam
Plastic cover
Energy absorbing foam
PPS design, manufacturing and installation
Bumper
A series of single PZT sensors are installed on the metal frame of the bumper
Laptop with software
IM Genie Pro: Data collection hardware
Test setup
Distinguishing between pedestrian and non-pedestrian impacts
Voltage
Time (Seconds)
Identification of impact type: Pedestrian or Non-pedestrian
Software shows a bumper simulation
Location of impact
GUI to show impact results

PPS system





The PPS will be able to make a decision in much shorter time than existing front bumper systems. By using multiple sensors, Acellent's PPS can provide a faster response than the other systems. Impact on the car can be picked up quickly by the closest sensor. Currently used PPS that rely on a single sensor have to wait for the impact wave to travel to the sensor. Such a short time difference can be very critical. An energy summation circuit can pick up the impact quickly from the sensors, provide the trigger signal quickly, and provide sufficient data to discriminate between different types of impacts, i.e. pedestrian versus non-pedestrian objects.

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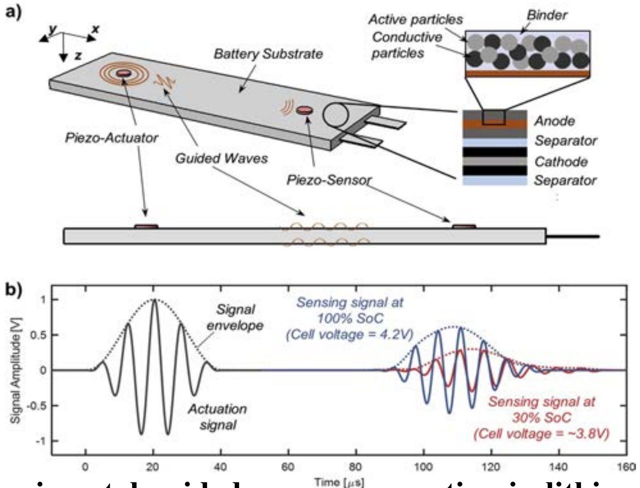
BMS system



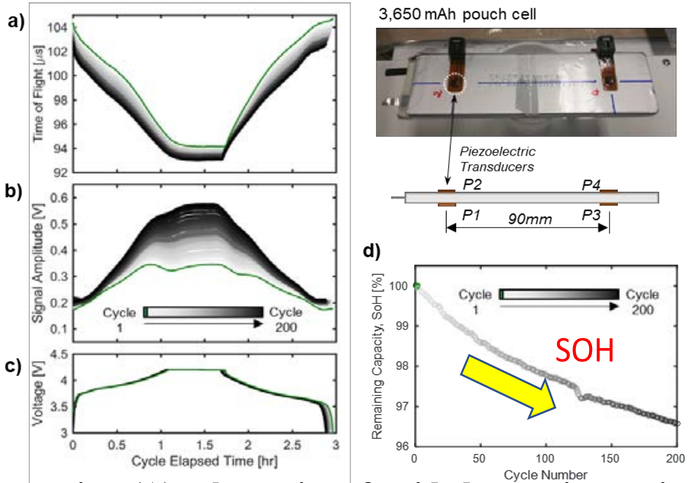


Figure : (top) experimental guided wave propagation in lithium-ion batteries. (A) schematics of guided wave inspection setup; (B) representative signals at two SoC (bottom) indicative results from 3650 mAh pouch cells which underwent cycle life aging

Future EV and autonomous vehicles require a new concept for safe and structurally integrated advanced battery monitoring. To optimize battery performance, lifespan, and most importantly, safety, a battery management system (BMS) is required to perform battery condition monitoring, charge/discharge control, thermal management, cell balancing, and fault mitigation. The BMS must be able to accurately monitor the batteries' critical internal states, which primarily include state of charge (SoC) (the charge remaining in the battery with respect to the fully charged capacity, or the equivalent of a fuel gauge) and End-of-Life (a degree of degradation in battery health).

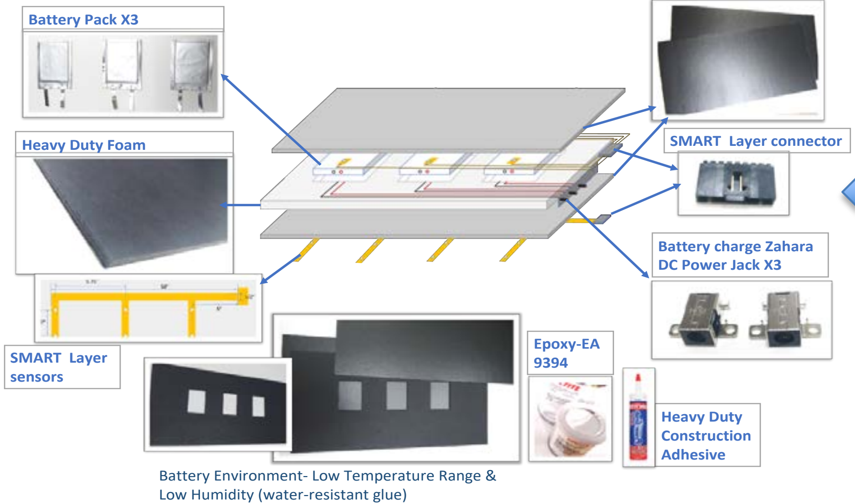
Testing was conducted by Stanford to demonstrate SOH and EOL[1]. The testing was conducted on a Li-ion pouch cell, as shown in the Figure, which is equipped with Acellent’s single sensor SMART Layer PZT’s which can serve as actuators and sensors. One of the piezoelectric discs can be chosen as an actuator to generate acousto-ultrasonic guided waves. The other piezoelectric disc then serves as a receiver to record the transmitted guided wave signals. These guided wave signals from piezoelectric sensors can be corelated with battery SOC/EOL through both experiments and analysis.

Ref 1- Purim L., Fotis K., Chang, F. K., Estimating state of charge and health of lithium-ion batteries with guided waves using built-in piezoelectric sensors/actuators, Journal of Power Sources,Volume 384, 2018

BMS system

- Under an ARPA-E funded project, Stanford is developing "Multifunctional Energy-Storage Composites (MESC)" for the energy efficient design of light-weight electric vehicles. The MESC constitute a multifunctional structural battery system which embeds Li-ion battery materials into high-strength structural composite materials. **Acellent has an exclusive license to this technology from Stanford and is also a commercialization partner for the ARPA-E project.**
- During this SBIR Phase I, Acellent designed a complete sensing system for the MESC batteries that incudes installing sensors on the battery directly and on the composite. A design for the MESC with the embedded sensors was created and a complete test bed manufactured to test the sensors for use in SoH and EOL determination. Testing is currently ongoing.

Components and Parts for battery composite



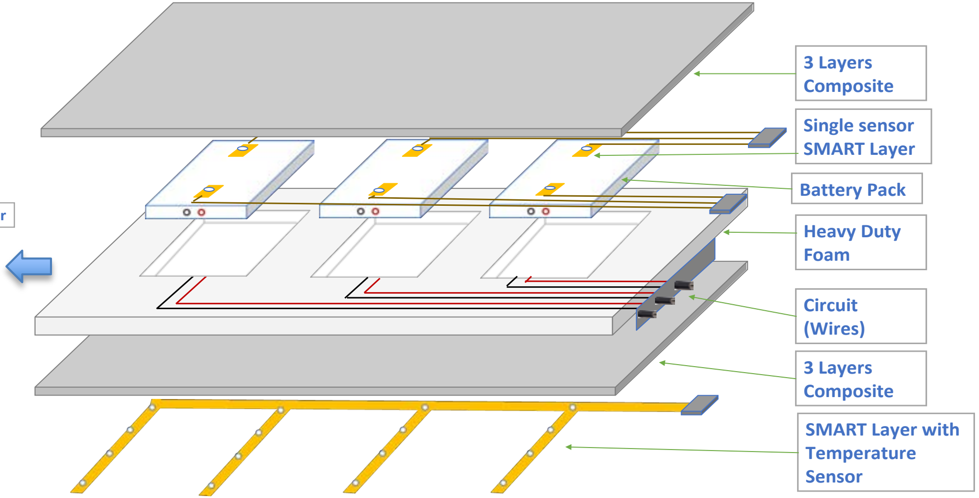


Figure: Structurally integrated battery monitoring test bed