Test and Evaluation/Science and Technology Program

Advanced Instrumentation Systems Technology (AIST)

Orientation and Posture TRACking system (TRAC)

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National Defense Industrial Association

2017 Human Systems Conference

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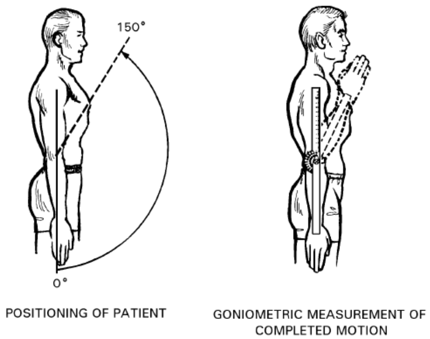
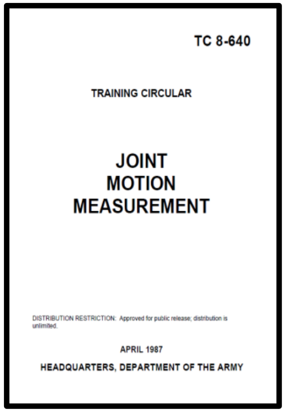
Test Community Need

- Measurements of warfighter posture, head angle, leg + arm positions and weapon orientation are critical to understanding the effectiveness of new equipment and limitations to the warfighter's range of motion.
- Non-line of sight situations create additional challenge in the ability to make these measurements.
- Need to evaluate warfighter range of motion while using new equipment and the effectiveness of their performance in solo and team scenarios.
- Current technology is not adequate to address these measurement needs accurately without influencing the test




TC 8-640

TRAINING CIRCULAR

JOINT MOTION MEASUREMENT

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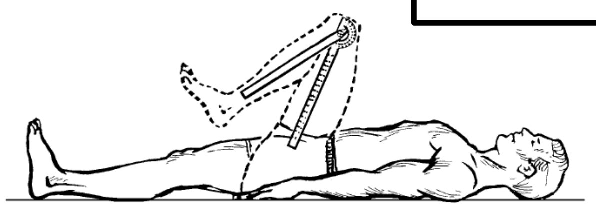
APRIL 1987

HEADQUARTERS, DEPARTMENT OF THE ARMY



Static Conditions

Dynamic Conditions

System Overview

<u>Orientation and Posture TRACking system (TRAC)</u>

- TRAC is a lightweight body shape, head orientation, and posture measurement system
- Enable testing and evaluation of equipment and environmental effects on physiology (range of motion) in tactical (dynamic) scenarios
- Utilize fiber optic shape sensing technology integrated into a bodysuit as a means of providing the positions of the warfighter’s body

System components:

- Fiber Optic Shape Sensors
- Body Suit Integrator
- Portable electronic data acquisition system
- Signal processing software

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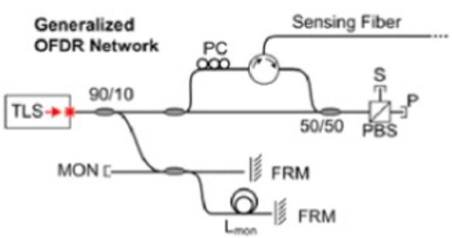
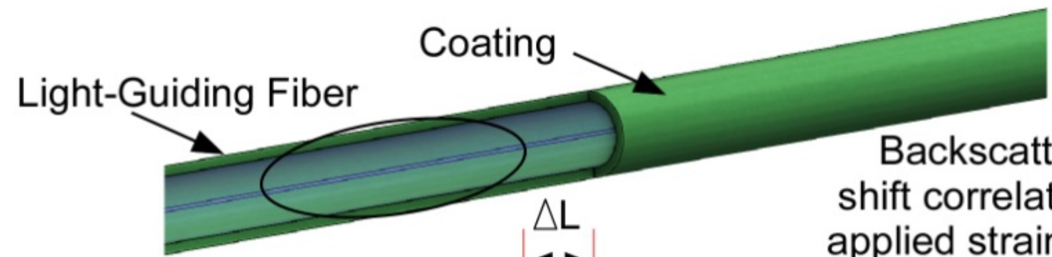
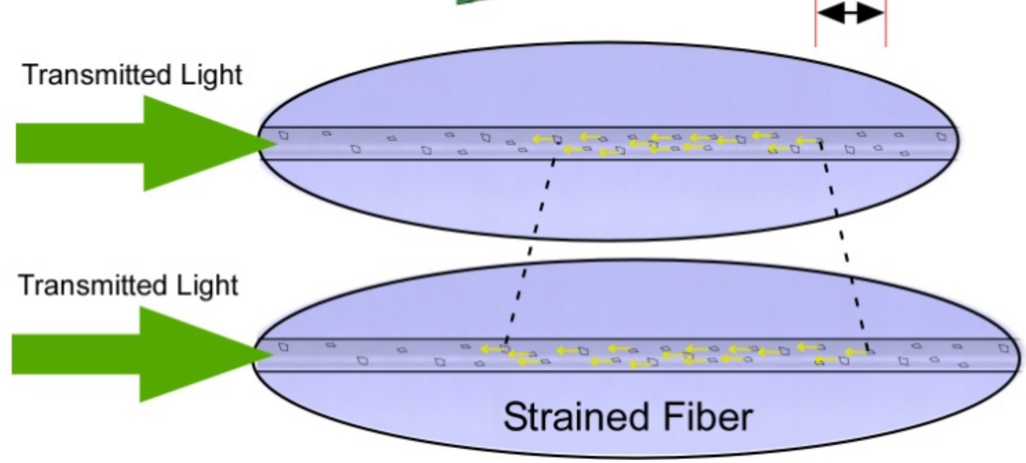
Technical Background – High Definition Fiber Optic Sensing

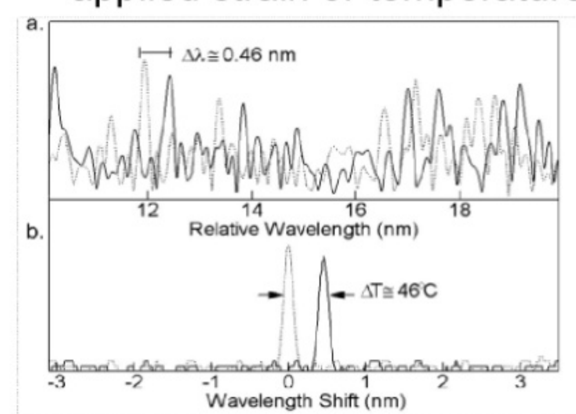
Reflected light from minute differences in the local index of refraction of the fiber core can be used to determine the degree to which the fiber is strained as a result of a thermal or mechanical stimuli.







Backscatter Frequency shift correlates to change in applied strain or temperature



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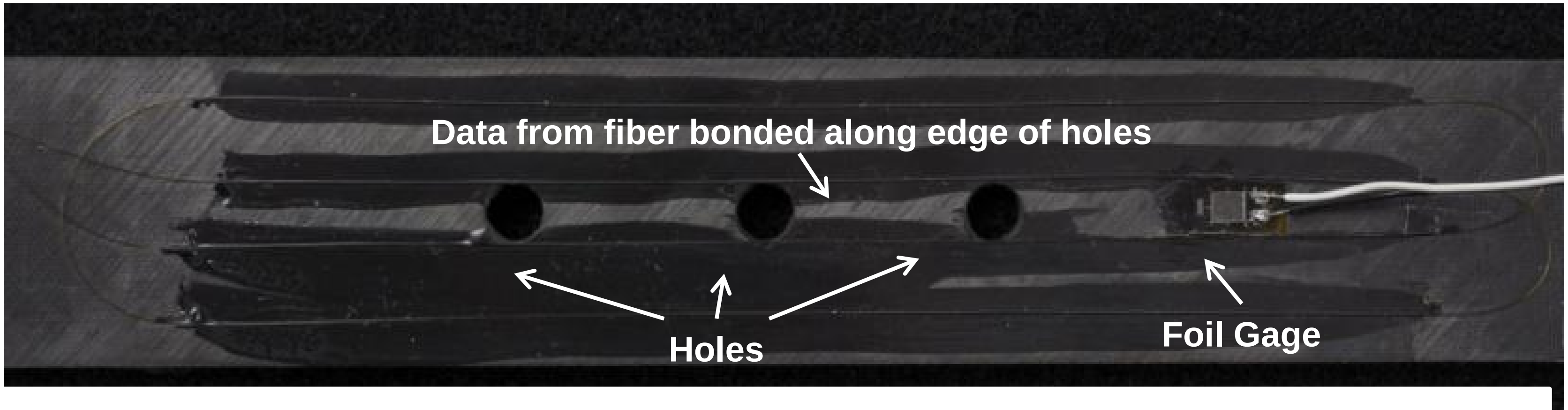
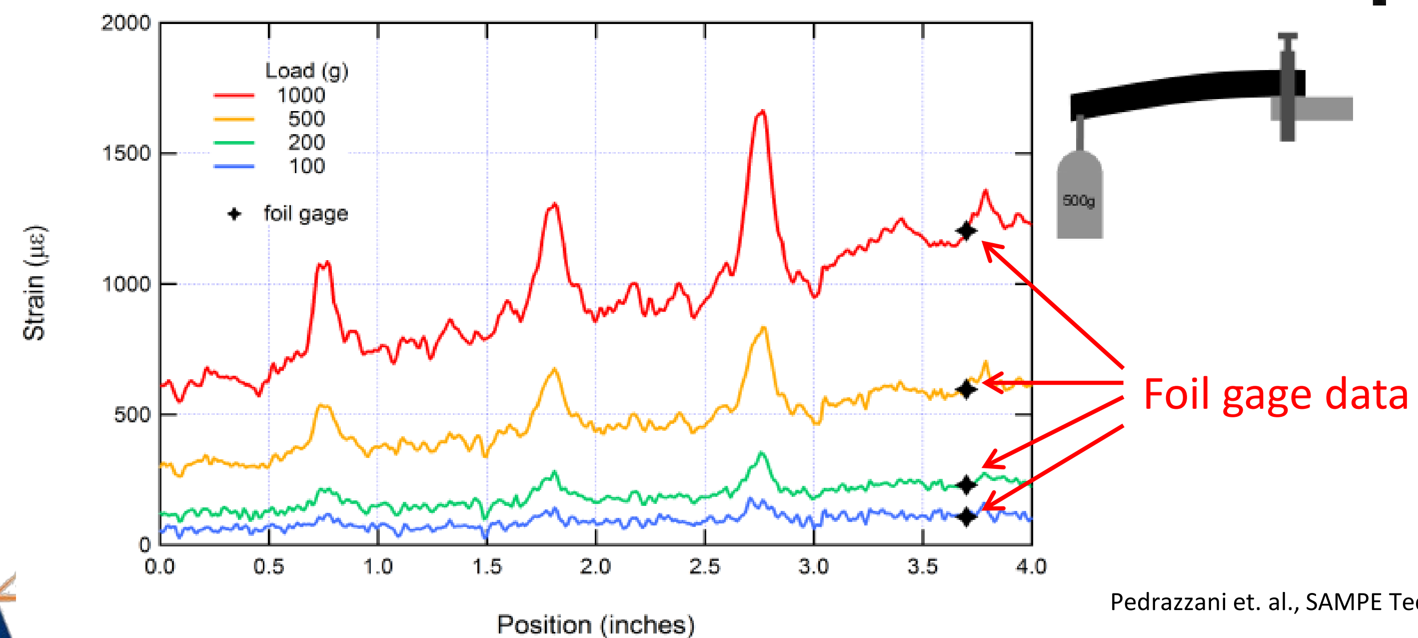
Basic Theory of Operation

Example of High Definition Fiber Optic Sensing of Strain



Carbon composite coupon loaded in cantilever beam configuration



Pedrazzani et. al., SAMPE Tech, 2012

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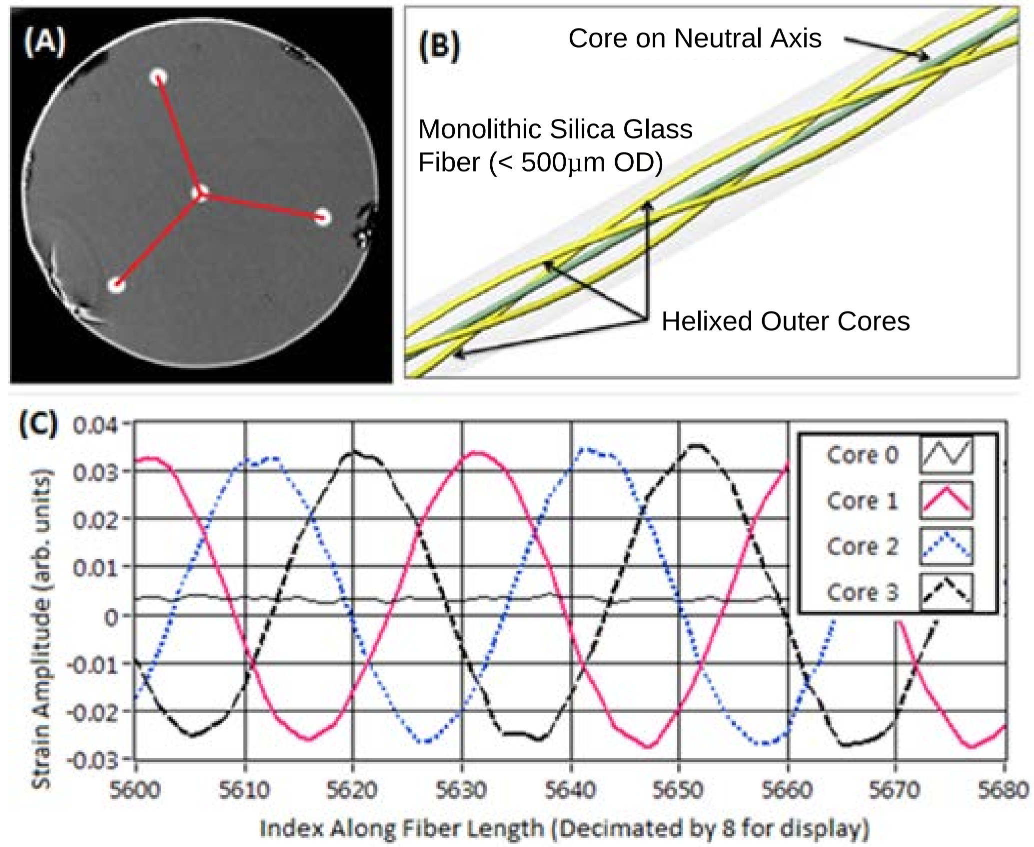
Sensing of Shape using Strain Measurements from Optical Fiber

- **Helical, 4-core optical fiber**
- **Distributed strain measured on each core**
- **Differential strains converted to 3D shape**



- **Under curvature:**
  - Alternating tension & compression on outer cores
- **Under twist:**
  - Common tension or compression on outer cores
- **Under axial strain**
  - All cores experience common tension

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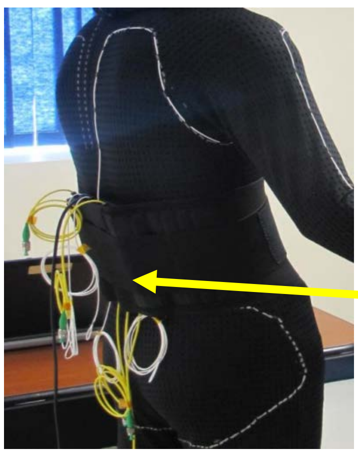
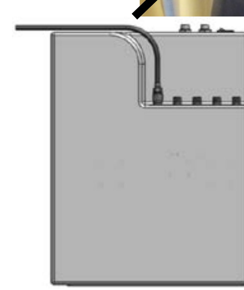
System Level Integration

- Suit is fabricated from a lycra material with mesh that allows the sensors to be routed based on the subjects physiology
- Located on the suit is a box containing the beginning point of the sensor measurement
- Sensors are connected to a battery powered acquisition system located in a pack on the users back



Box containing the sensors has an inertial measurement unit (IMU) to account for rotation of the subject in the global coordinate frame



System located in a backpack

Human Factors and Durability Testing

Two days of testing were performed at Aberdeen Test Center to evaluate the durability and impact of the system on test subjects under relevant conditions

- Results from this testing are being used to improve the overall system design and integration
- 2 Army test subjects and 1 Luna representative were fitted with the suits and representative sensors
- Testing used standard telecom fiber in lieu of shape fiber
- Enabled durability to be assessed after each exercise by scanning with a reflectometer
- Range of Motion (ROM) study conducted to determine degradation
- Tactical Mobility Performance and Compatibility studied through 2 mile march, obstacle course, and weapons compatibility

Human Factors Test

- Baseline range of motion (ROM) was assessed with the test subjects wearing ACU
- Second baseline with ACU and Improved Outer Tactical Vest (IOTV)
- Repeated for both cases with the TRAC unit as well

- A loss of ROM greater than 20° was considered significant.
- ROM measurements results showed a consistent loss in ROM for shoulder flexion and knee flexion with the TRAC suit.
- The ROM data showed instances of anomalies, for TPN 1 in particular, where the results were not as expected. For example, a gain in ROM when a loss was expected.

	TPN 1						TPN 2					
Measurement	ACU	ACU TRAC	Loss/ Gain	ACU IOTV	ACU TRAC IOTV	Loss/ Gain	ACU	ACU TRAC	Loss/ Gain	ACU IOTV	ACU TRAC IOTV	Loss/ Gain
Shoulder:												
Flexion	176	152	-24	141	[a] 92	-49	168	141	-27	151	131	-20
Extension	72	80	8	80	61	-19	88	83	- 5	64	70	6
Abduction	146	132	-14	121	91	-30	163	140	-23	124	108	-16
Adduction	153	119	-34	112	95	-17	108	113	5	97	95	- 2
Elbow flexion	139	123	-16	140	115	-25	133	134	1	139	117	-22
Hip:												
Flexion	107	112	5	89	91	2	93	90	- 3	85	77	- 8
Adduction	48	57	9	41	40	- 1	47	52	5	45	51	6
Abduction	75	78	3	74	61	-13	67	68	1	61	61	0
Knee:												
Flexion	125	117	- 8	[a] 90	119	29	102	101	- 1	90	97	7
Extension	90	69	-21	90	72	-18	96	73	-23	90	73	-17
Trunk:												
Extension	73	[a] 38	-35	72	73	1	53	41	-12	48	54	6
Flexion	89	69	-20	90	77	-13	84	93	9	82	76	- 6
Head:												
Flexion	72	59	-13	84	69	-15	56	55	- 1	64	61	- 3
Extension	75	54	-21	64	49	-15	82	70	-12	79	62	-17
Rotation	88	73	-15	70	61	- 9	79	63	-16	60	60	0
Lateral	61	54	- 7	55	43	-12	49	36	-13	40	37	- 3

Human Factors Test

- Tactical Mobility Performance and Compatibility
  - 2-mi road march
  - Soldier Systems Test Facility (SSTF) portability course
- Static weapons compatibility trial with the M4.

- General comments were that the system was easy to don/doff
- Feedback from the testing concluded that the subjects did not feel much restriction wearing the suit
- Data collected on shock/vibration using accelerometers

TABLE B-2.2-3. MISSION ACTIVITIES EVENT RATINGS

Mission	TPN 1 Fit and Comfort	TPN 1 Soldier Performance	TPN 1 Compatibility/ Interference	TPN 2 Fit and Comfort	TPN 2 Soldier Performance	TPN 2 Compatibility/ Interference
ACU and TRAC						
Target acquisition:						
Standing	5	5	5	5	5	5
Kneeling	5	5	5	5	5	5
Prone	4	4	4	5	5	5
Foot march	3	4	4	3	3	4
Obstacle course	3	4	4	2	3	3
ACU, TRAC, and IOTV						
Target acquisition:						
Standing	5	5	5	5	5	5
Kneeling	5	5	5	5	5	5
Prone	2	4	4	5	5	5
Foot march	2	4	4	3	4	4
Obstacle course	2	4	4	3	5	4

Poor: Very	Poor: Slightly	Neutral	Good	Excellent
1	2	3	4	5

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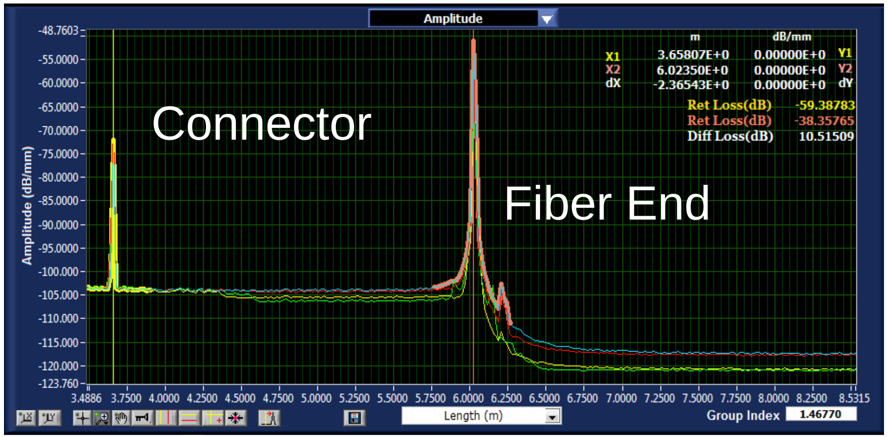
Durability Test



Data from Sensor T7 used to determine the length of the sensor at different test intervals.

Table 1: Sensor lengths at various key stages of testing.

Sensor Number	Initial Length	Suit Removed (Day 1)	Suit Donned (Day 2)	After Obstacle course with Body Armor	After Obstacle course without Body Armor	Upon Returning to Luna
T7	2.365	2.365	2.365	2.365	2.365	2.365
T5	2.384	2.384	2.384	2.384	2.384	2.384
T8	2.402	2.402	2.402	2.402	2.402	2.402
T4	2.347	2.347	2.092	2.092	2.092	2.092
T9	2.566	2.566	2.566	2.566	2.566	2.566
T1	2.420	2.420	2.420	2.420	XX	2.420
T2	2.347	2.347	2.347	2.347	2.347	2.347
T3	2.420	2.420	2.420	2.420	2.420	2.420
T6	2.402	2.402	2.402	2.402	2.402	2.402
T10	2.329	2.329	2.329	2.329	2.329	2.329

- Fiber durability was checked by measuring its length after each test
- Only one of the sensors, T4 located on the Left Arm of Subject 2, experienced a failure during the test.
- This failure was 30 cm from the end and would align with the subject’s elbow.
- The remaining 9 sensors survived all of the studies as well as remaining installed into the suit as it was taken on and off twice.

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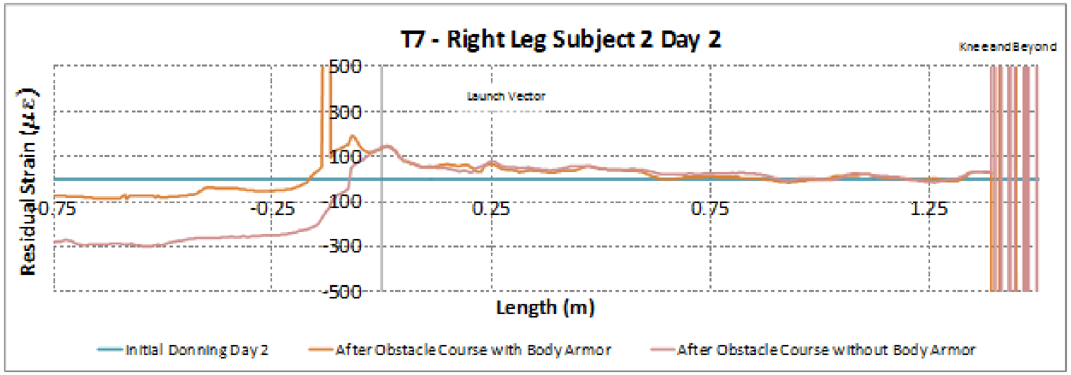
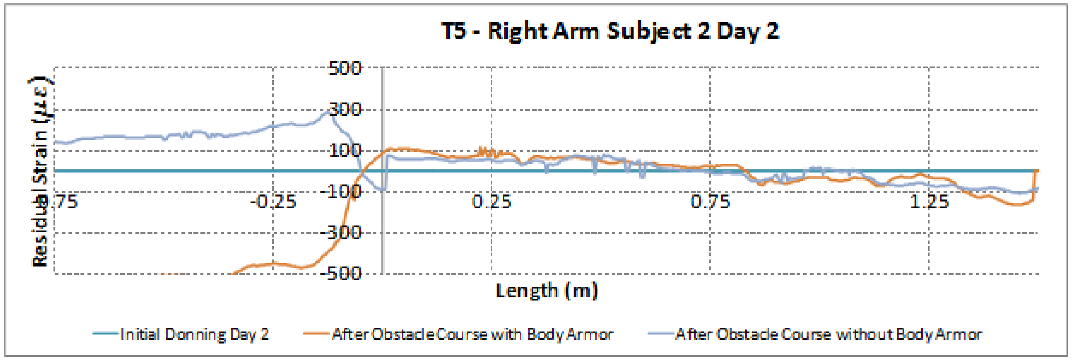
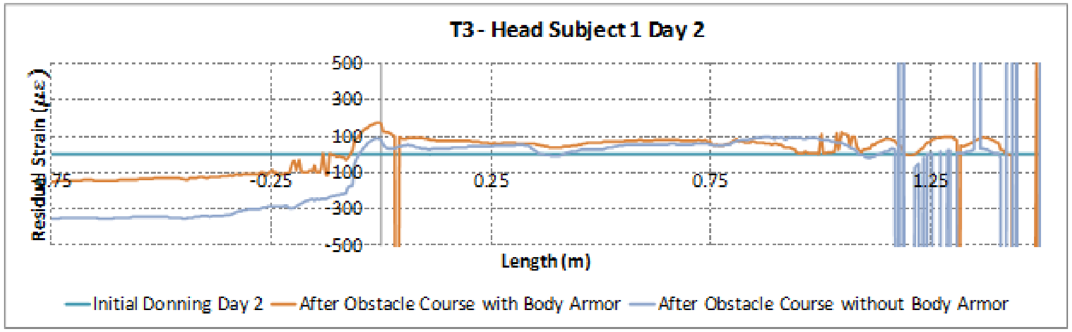
Residual Strain as a Result of Test Activities

- Residual strain was calculated using the backscatter pattern in the fiber
- Data aligned to where the shape measurement would begin
- 100 με or less residual stain was observed in the region of the sensor that would be used for shape sensing
- This level of residual strain is unlikely to significantly affect the shape measurement accuracy







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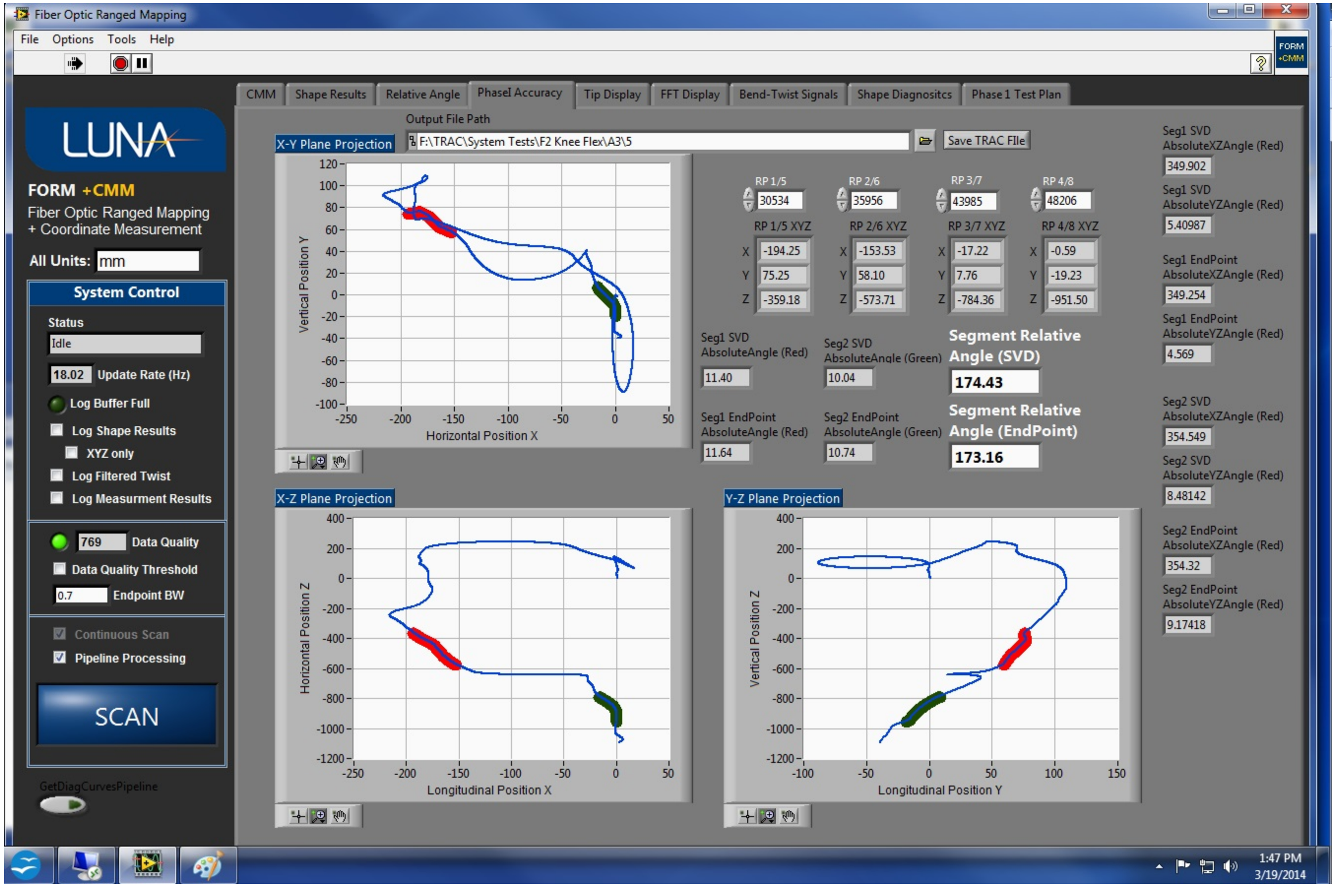
Laboratory Testing

Interpretation of Shape Data

- Data is output in the form of coordinates x,y,z along the length of the fiber which enables heading, pitch, and roll of defined segments
- Shape is typically displayed as a projection in three planes

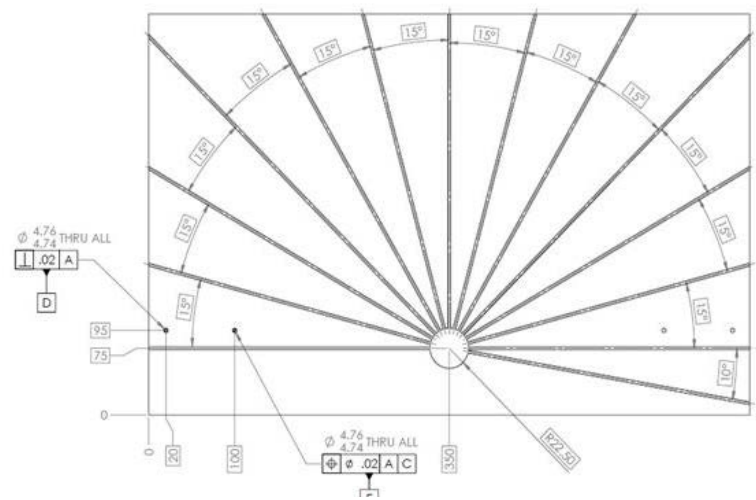
- Specific regions of the fiber can be selected and the angle between them calculated
- Enables differential measurements of heading, pitch, and roll

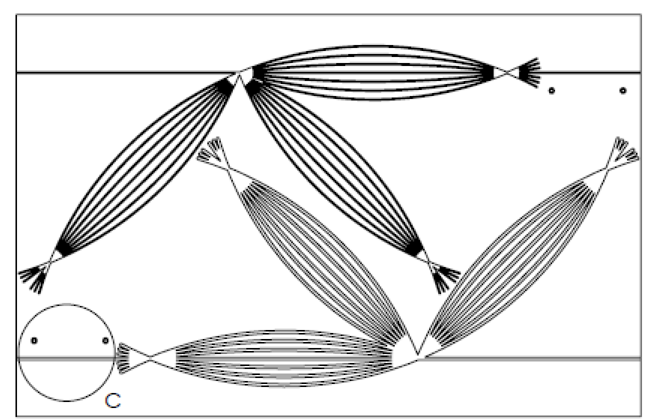


Characterization Testing

2 plates were manufactured with patterned grooves to test the accuracy and repeatability of the sensors

- Range determined from MIL-STD-1472G, TABLE XXXVI. Range of human motion
- Shoulder Flexion: Upper Limit of 190º
- Hip Adduction: Lower Limit of 15º
- Both plates have both 1/8” and 1/16” grooves to accommodate current and future sensor designs
- General procedure to insert the sensor into the groove defined in the test matrix, make the measurement, and remove and repeat 7-9 times
- Plates verified using Faro Arm





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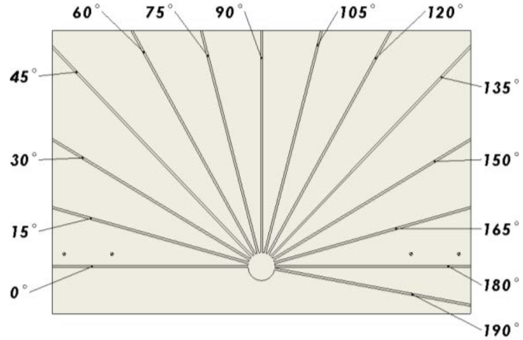
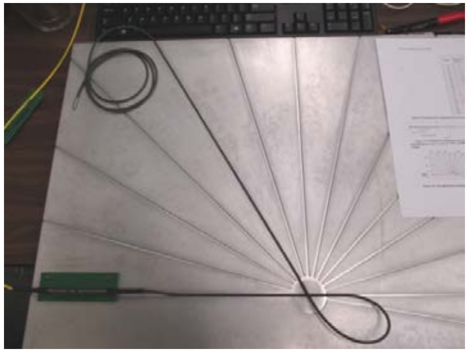
2D Angular Accuracy

- Relative accuracy refers to the angle between two segments
- Absolute accuracy refers to the angle from the start of the sensor

2D Relative Angle Test			
Sensor ID:	B129-02		
System ID:	G3-2B		
Zone:	2/3		
Basic Angle, Degrees	Mean Measured Angle, Degrees	Standard Deviation , Degrees	Error, Degrees
15	14.9	0.1	0.1
30	29.8	0.2	0.2
45	44.8	0.2	0.2
60	59.9	0.3	0.1
75	74.7	0.1	0.3
90	89.8	0.2	0.2
105	104.9	0.2	0.1
120	119.9	0.2	0.1
135	134.9	0.3	0.1
150	149.9	0.2	0.1
165	165.0	0.1	0.0
180	179.9	0.2	0.1
190	190.0	0.3	0.0

2D Absolute Angle Test			
Sensor ID:	B129-02		
System ID:	G3-2B		
Zone:	3		
Basic Angle, Degrees	Mean Measured Angle, Degrees	Standard Deviation , Degrees	Error, Degrees
15	14.9	0.2	0.1
30	29.9	0.1	0.1
45	44.9	0.2	0.1
60	59.9	0.1	0.1
75	75.0	0.1	0.0
90	90.0	0.0	0.0
105	104.9	0.1	0.1
120	120.0	0.1	0.0
135	134.9	0.2	0.1
150	150.0	0.2	0.0
165	164.9	0.2	0.1
180	180.0	0.1	0.0
190	190.1	0.1	0.1





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Integrated Suit Testing

- Mannequin was fitted with an early generation suit and sensors
- Reference points were located on the suit to determine spatial and angular position.
- FARO arm was used as a comparison and results tabulated for each position tested

Relative angle (error in degrees)

Test angle	*mean error*	*standard deviation*	*95% CI (±)*
A1.a	0.34	0.19	0.3705
A1.b	0.37	0.31	0.6045
A1.c	0.37	0.29	0.5655
A2.a	0.51	0.28	0.546
A2.b	1.83	1.07	2.0865
A2.c	0.37	0.29	0.5655
E1.a	1.02	0.76	1.482
E1.b	0.26	0.27	0.5265
E1.c	0.32	0.26	0.507
H1.a	0.97	0.65	1.2675
H1.b	0.75	0.68	1.326
H1.c	0.95	0.26	0.507
H2.a	0.23	0.22	0.429
H2.b	0.36	0.21	0.4095
H2.c	0.26	0.12	0.234
H5.b	0.48	0.2	0.39
H5.c	0.29	0.16	0.312
F2.a	0.69	0.39	0.7605
F2.b	0.27	0.18	0.351
F2.c	0.95	0.26	0.507

Parameter (Definition)	Phase 1 Criteria	Achieved	Results from Testing
Shape Accuracy as a function of length	5%	1.64%	0.43 ± 0.68 % length (Component) 0.95 ± 0.69 % length (System)
Relative angle accuracy	±1º	1.27º (max)	0.11º ± 0.39º (Component) 0.58º ± 0.69º (System)
Absolute angle accuracy	±1º	1.13º (max)	0.11º ± 0.27º (Component) 0.58º ± 0.55º (System)

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System Demonstration

Video of the suit with the IMU Integrated

Conclusions and Future Development

Conclusions

- Luna has developed a system that will enable range of motion studies in a dynamic environment
- The feasibility and durability of the system has been demonstrated
- Environmental loads have been characterized that have been fed into the design to ensure that the system meets performance requirements

Future Development

- Data acquisition system is being designed for increased reliability
- Modifications to the suit design are being conducted to implement the feedback from the Human Factors Test
- Once complete, additional testing will be used to verify the system

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Acknowledgement and Disclaimer

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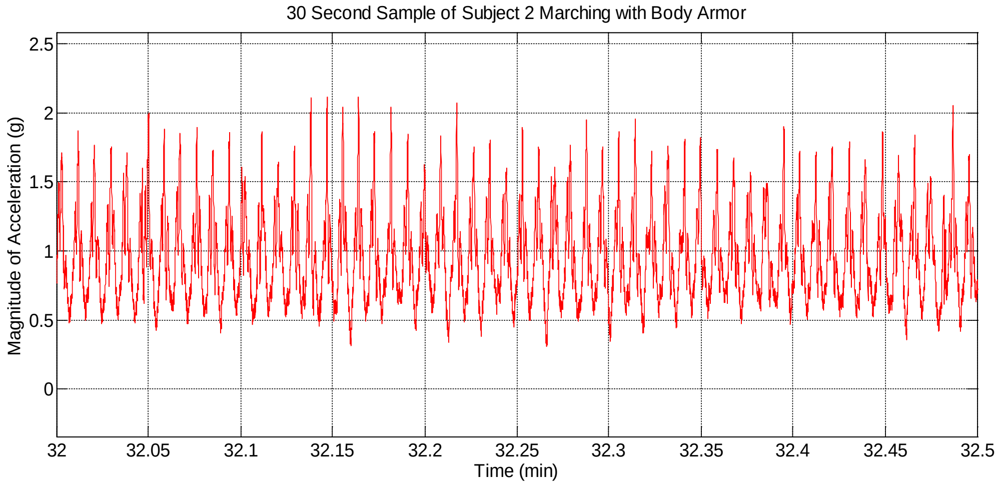
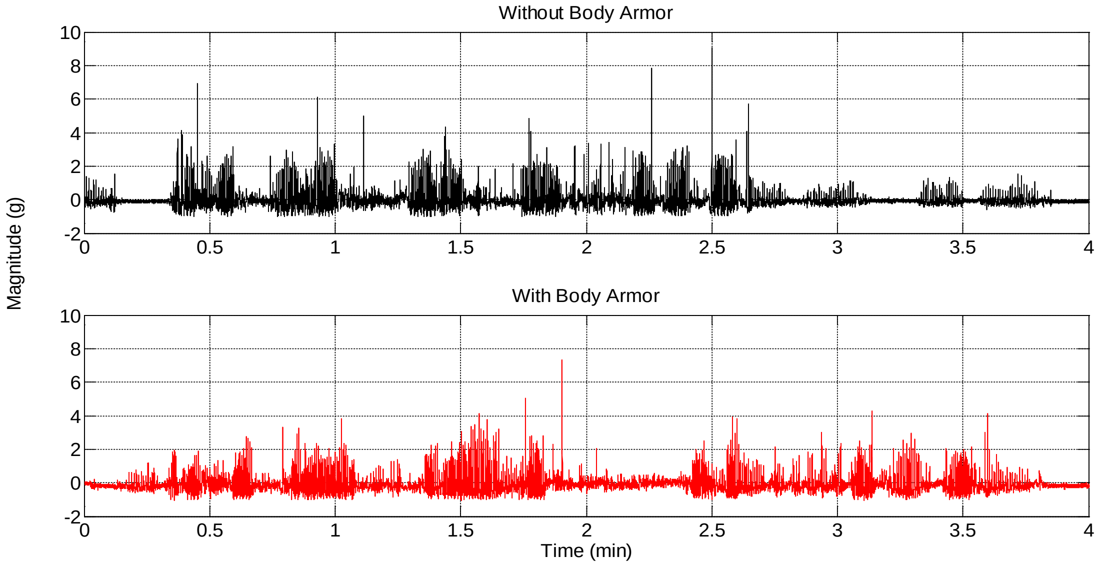
Backup

Temperature, Shock, Vibration

- Vibration/shock data to be used to harden future design and packaging
- Maximum pk-pk shock without body armor of 8.5g which was higher than the 7g measured with the body armor.
- In general, most of the shock loads fell at or below 4g.
- The largest shock had a duration of 0.12 seconds while the bulk of the frequency content fell below 5 Hz.
- Performance objective of the system is to provide data at 5 Hz



1.5 g's measured during standard road march



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Temperature, Shock, Vibration

- Live fire test using 7.62 NATO, 5.56 NATO and .45 ACP
- Accelerometer was located on the data acquisition system in the backpack.
- During the pistol test the accelerometer was firmly strapped to the forearm
- The lower caliber had a much higher magnitude over a shorter time than the larger 7.62 round achieving on the order of 20g's and settling in 0.03 seconds.
- The 7.62 round only achieved a magnitude on the order of 6-7 g's over a timespan of 0.12 seconds.