NeXafe - Final Design Review

ME 482 – Team 20 | March 14th 2019

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Agenda

1. Background
2. Final Prototype and Specification Verification
3. Sub-System Development
   - 3.1 Actuation
   - 3.2 Sensing
   - 3.3 Packaging
4. Project Management
5. Symposium Showcase Plan
6. Conclusion

1. Background

Background

One in four Americans aged 65+ falls each year [1]

Geriatric falls lead to whiplash associated injuries to the head and neck

"A need exists to dissipate energy from a fall to minimize the severity of whiplash to the head and neck"

[1] "Falls Prevention Facts", National Council on Aging, 2018. [Online]. Available: https://www.ncoa.org/news/resources-for-reporters/get-the-facts/falls-prevention-facts/. [Accessed: 21- May- 2018].

Project Summary

ME 481

ME 482

Research

- Fall - Causes
- Specifications

Brainstorm

- Solution Concepts
- Design Plan
  - Iterations
  - Modelling
  - Resources

Develop

- Analyzed
  - Concepts & Feasibility
- Divided into sub-systems
  - Actuation
  - Sensing
  - Packaging

Test

- Sub-system level testing
- Integrating systems
- Upcoming Tasks

Goal

- Functioning **Proof-of-Concept Prototype**
- Successful **Public Presentation**
- Learning Experience

Project Management

Timeline | Budgeting | Work Breakdown | Deliverable Tracking

FDR Focus

ME 481

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ME 482

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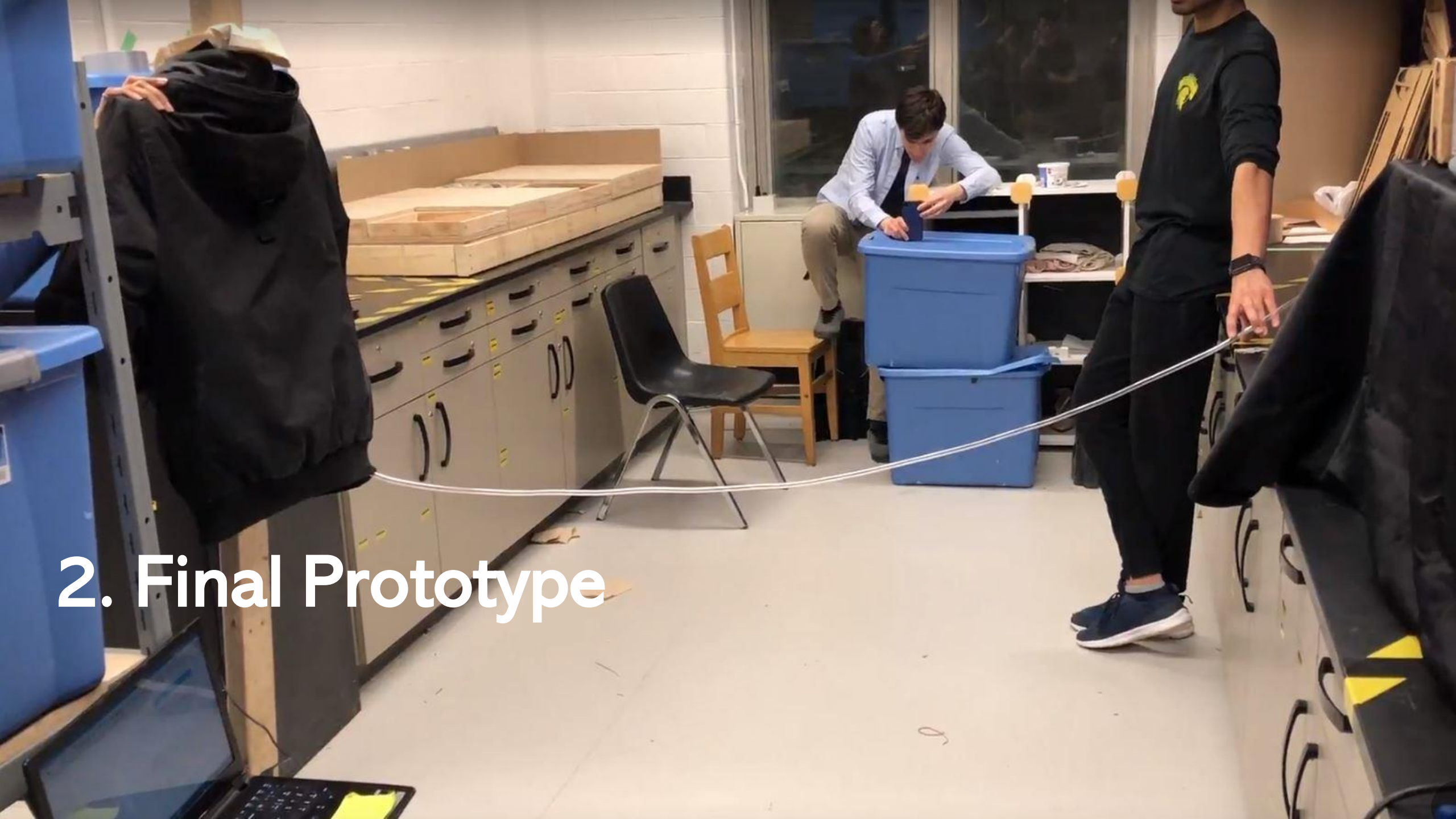
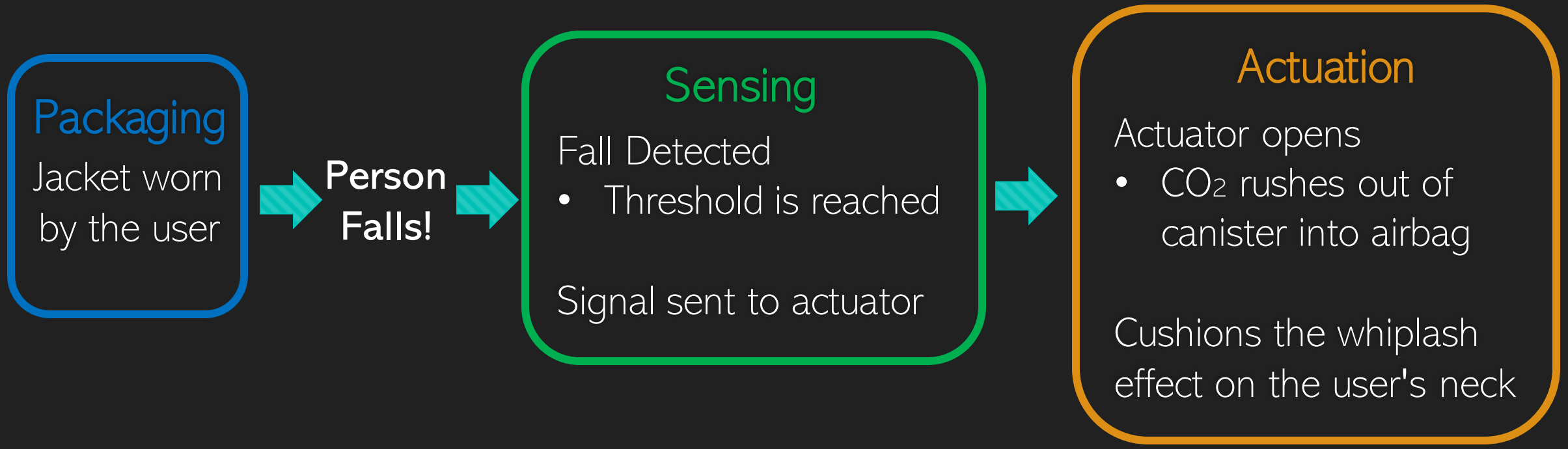


2. Final Prototype

Overview | Prototype Function



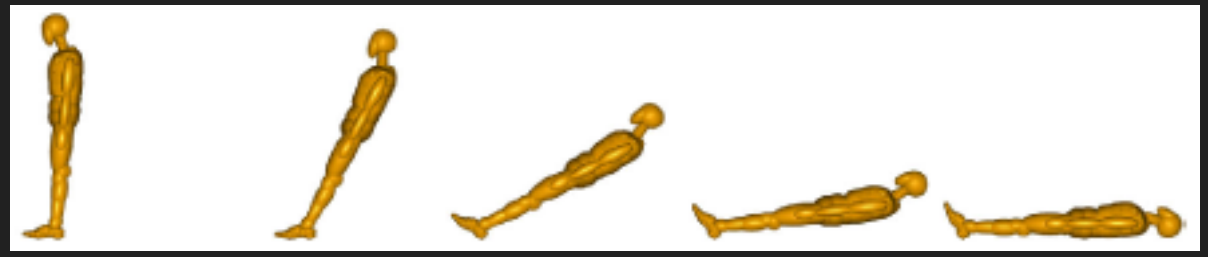
Final Prototype | Video Review

Final Prototype | Specification Summary

Specification	Target	Recorded	Verification Method
Total Actuation Time	< 0.75 sec	Achieved	Analysis / Test
Coverage of Critical Zones	C1-C7	Achieved	Test
Weight	< 750 g	38 g Above	Test
CO_2 Cylinder Safety	WHMIS Spec.	Achieved	Demonstration
Reusability	Airbag, Canister, Batteries	Achieved	Demonstration
Adjustability	80th Percentile Human	Achieved	Demonstration

Specifications | Total Actuation Time

- 'Simple' backwards fall, no hip bending
- Total fall duration: 0.75 - 1.25 seconds
- Experimental validation using controlled falls and test fixture
- Recorded activation before impact



Model "person"

M. Hajiaghamemar, M. Seidi, J. R. Ferguson, and V. Caccese, "Measurement of Head Impact Due to Standing Fall in Adults Using Anthropomorphic Test Dummies," Annals of Biomedical Engineering, vol. 43, pp. 2143–2152, Sept. 2015. [Accessed: 06-July-2018].

Specifications | Total Actuation Time

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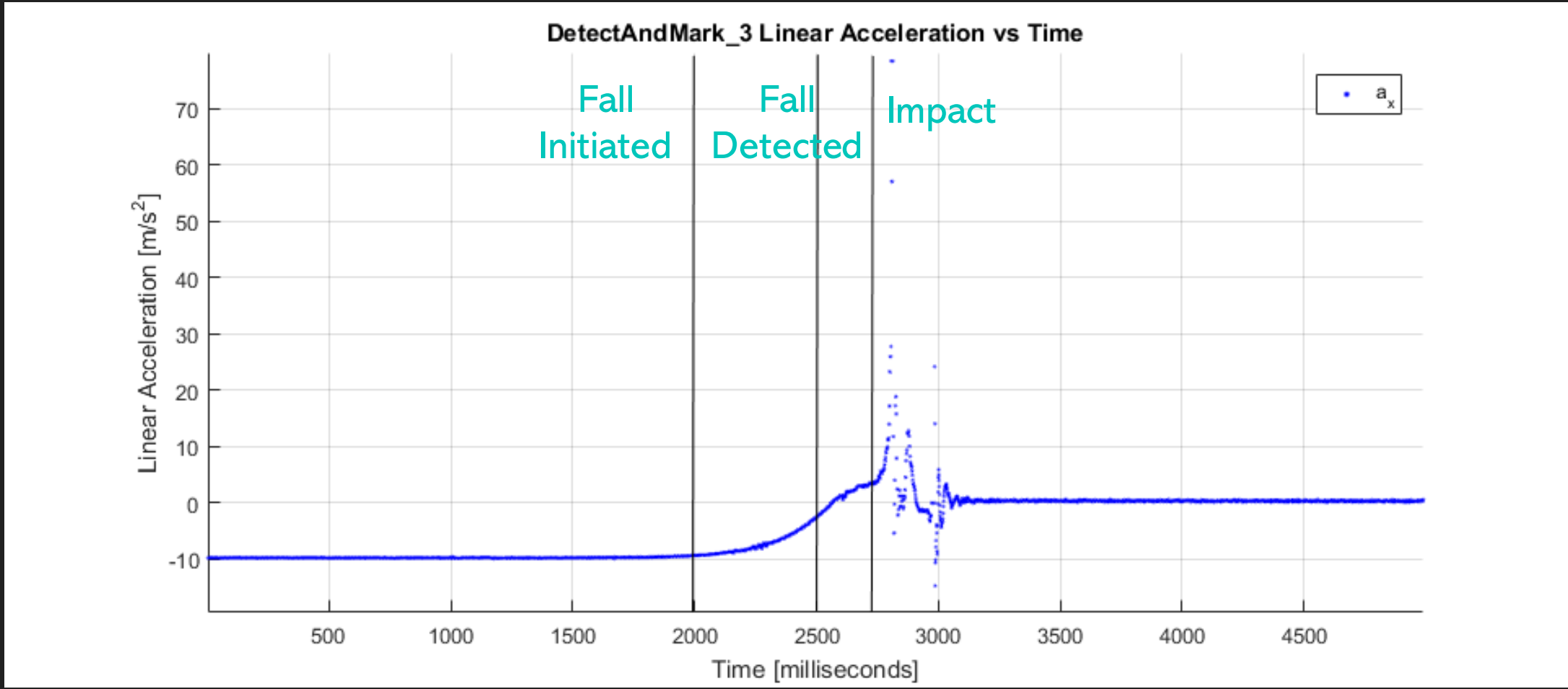
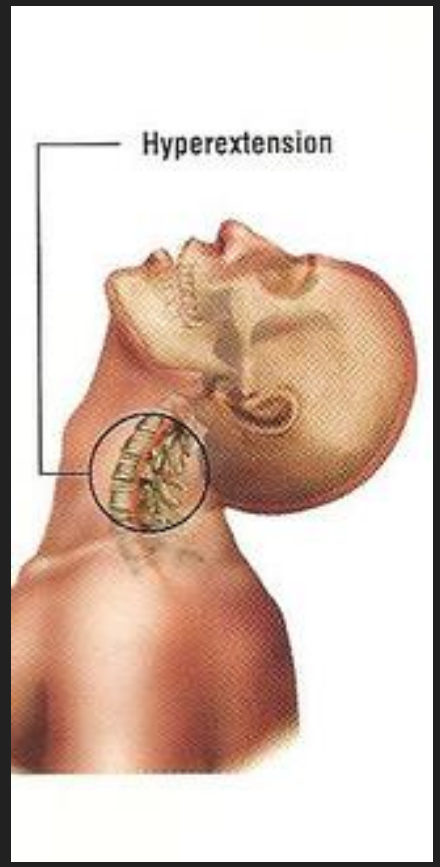


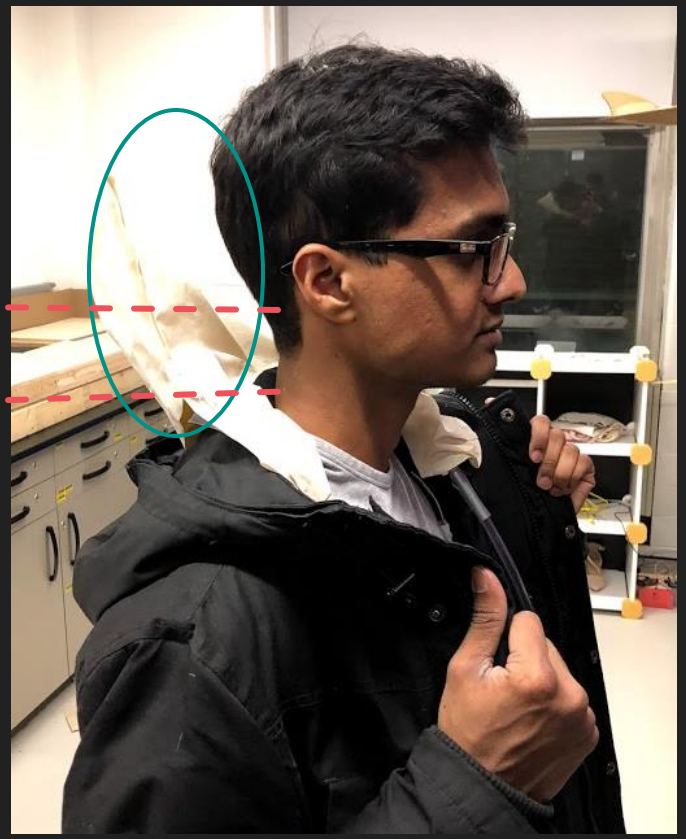
Specifications | Critical Zone Coverage

- C1-C7 vertebrae: prone to hyperextension during whiplash
- Needs to be braced by airbag during impact
- Average human neck: 102-112 mm C1-C7 distance



M. Paul J. Slosar, "Cervical Vertebrae", *Spine-health*, 2019. [Online]. Available: https://www.spine-health.com/conditions/spine-anatomy/cervical-vertebrae. [Accessed: 21- Jan- 2019]
"Whiplash Trauma", *Differentiating head pain*, 2019. [Online]. Available: https://atsuheadpain2014.weebly.com/trauma.html. [Accessed: 13- Mar- 2019]

Specifications | Critical Zone Coverage



Specifications | Weight

- Critical for user comfort
- Benchmarked popular 'Hövding" inflatable helmet at **650g** [2]
- Hit-Air Inflatable Vest: **1.7kg** [3]
- Selected **750g** as feasible middle-ground target (excluding jacket weight)
- Validated via subcomponent measurement

[2] "Hovding 2.0", Kennedy City Bicycles, 2018. [Online]. Available: https://www.kennedycitybicycles.cc/accessories/hovding-20. [Accessed: 09-Jul- 2018].
[3] "Hit-Air Inflatable Vest MLV-C in Black Size L by Hit-Air", Hit-Air, 2019. [Online]. Availablehttps://www.amazon.ca/dp/B007OW1N3U/ref=as_li_ss_tl?psc=1&slotNum=0&pd_rd_i=B007OW1N3U&_encoding=UTF8&pd_rd_wg=e83D&pd_rd_w=MTqTl&refRID=3P1W8RHVEZP431YGTVDV&pd_rd_r=3P1W8RHVEZP431YGTVDV&linkCode=g12&linkId=80a5f2eac6381217ba578c05b1e0fb35&imprToken=QjNmXMSLUzNoJa71ip6NxA&creativeASIN=B007OW1N3U&tag=watchyourse04-20

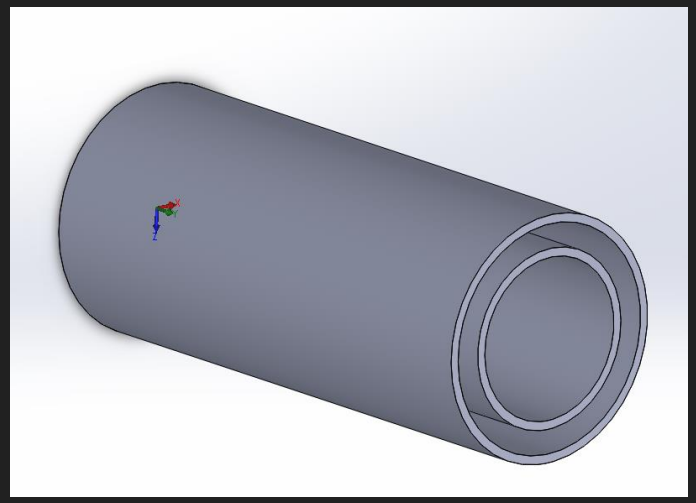
Specifications | Weight

Target weight: 750g	
Components	Weight (g)
Battery enclosure	44
AA batteries	192
Battery case	20
IMU Enclosure	106
Solenoid Enclosure	93
Solenoid	143
Tubing (¼")	147
Push fittings	42
Total	787

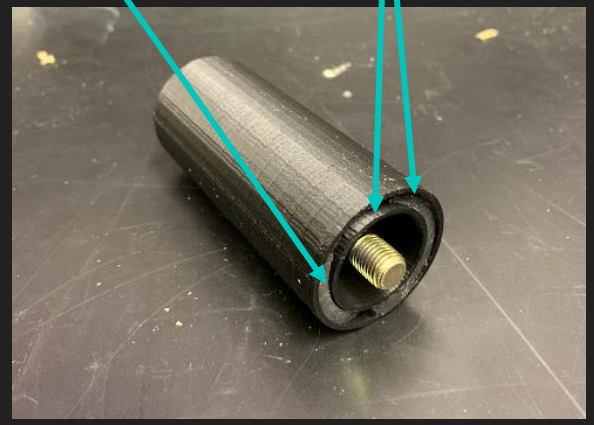
Specifications | CO_2 Cylinder Safety

- Weakest location: front seal / inflator neck
- WHMIS guidelines:
  - Use appropriately-rated regulator
  - Protect cylinder neck from impact
  - Isolate cylinder with noticeable temperature drops

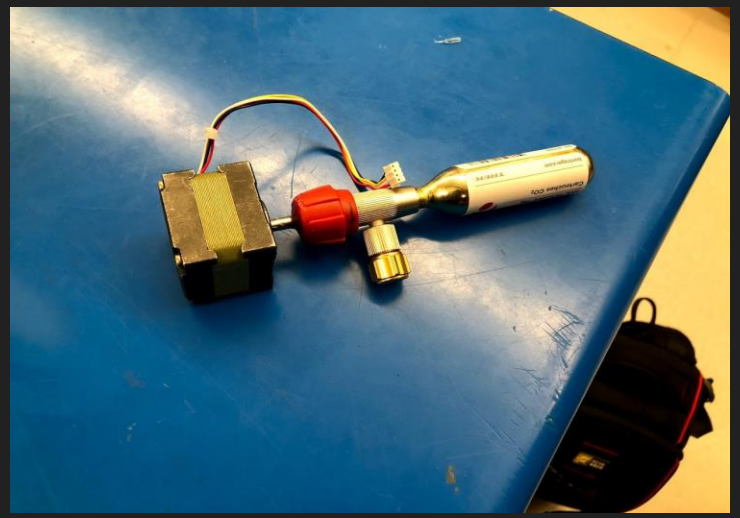
Specifications | CO_2 Cylinder Safety



Enclosed Canister CAD



Enclosed Canister



Canister with inflator

Specifications | Reusability

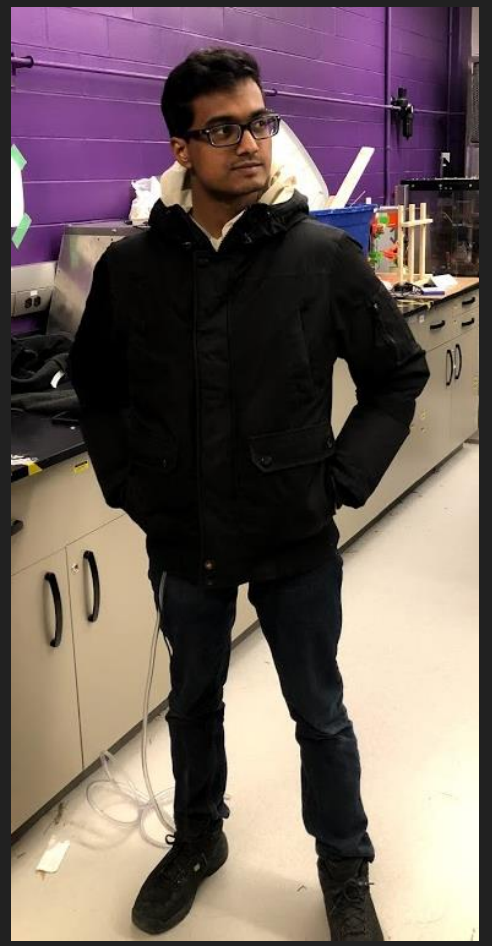
- Reusability important for ease-of-use
- Validated via demonstration

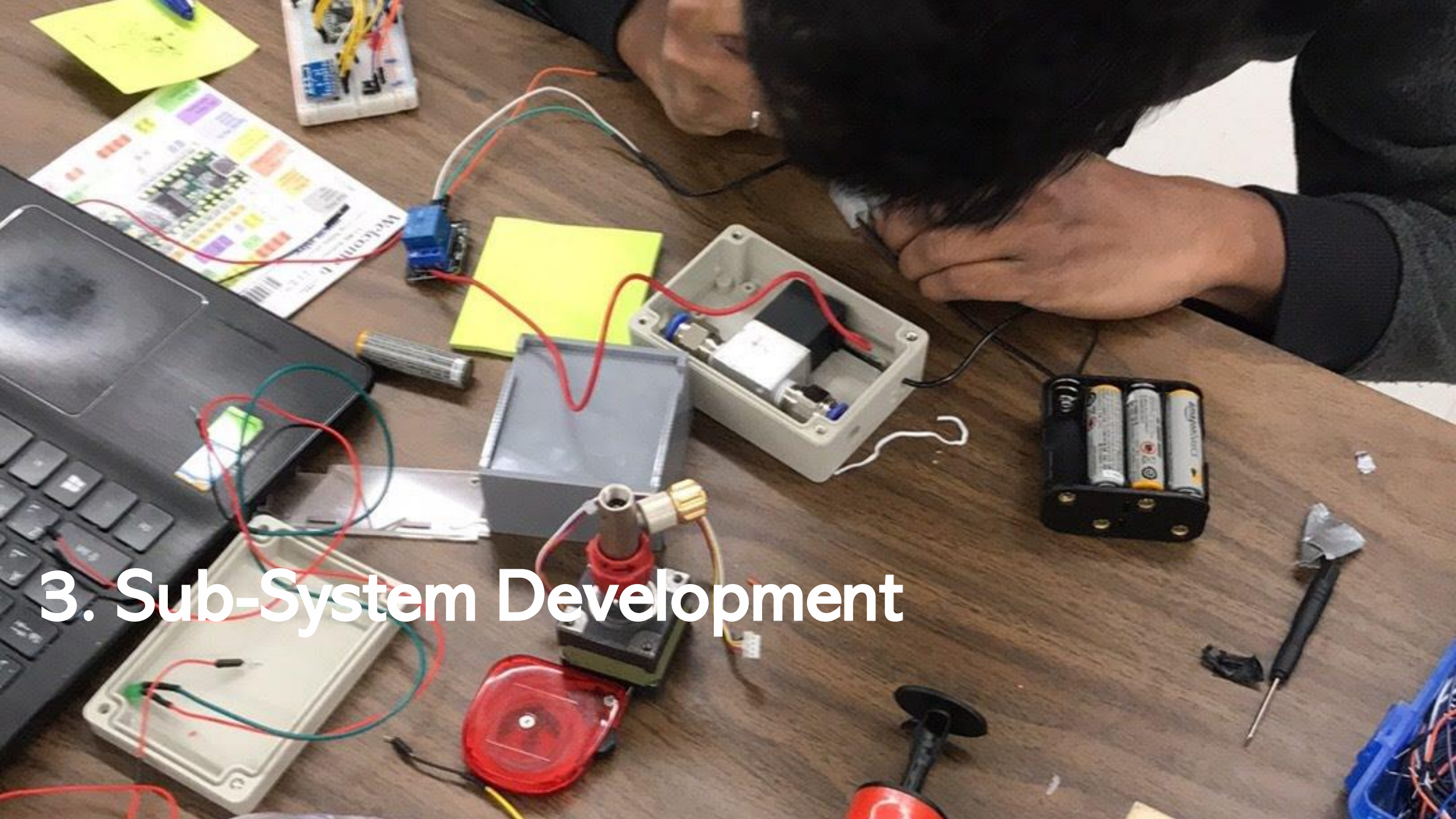
Specifications | Adjustability

- System integrated into winter jacket
- Modularized for flexibility regardless of jacket size

Internal jacket pocket (left)

Internal jacket pocket (right)





3. Sub-System Development

Sub-System Breakdown

Actuation

- Pneumatics
- Hardware
- Airbag

Sensing

- Microcontroller / IMU
- Algorithm

Packaging

- Canister Enclosure
- Solenoid Enclosure
- Electrical Enclosure
- Jacket

3.1. Actuation

Actuation | Iterative + Experimental Design

Experiment
- Procedure
- Apparatus

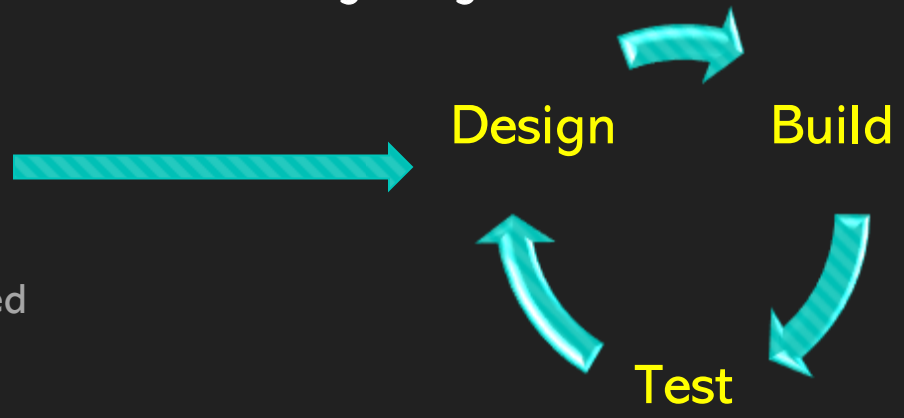
Airbag Designs

Setup
- Pneumatics – canister, fittings
- Hardware – solenoid, battery
- Electrical – cables, boards, PC

Fabricate Airbags

Goal / Vision

Canister releases air
1. Solenoid controlled
2. Motor controlled



Working Subsystem

Gather Useful Information
- Time
- Pressure
- Volume

Select Actuation Method

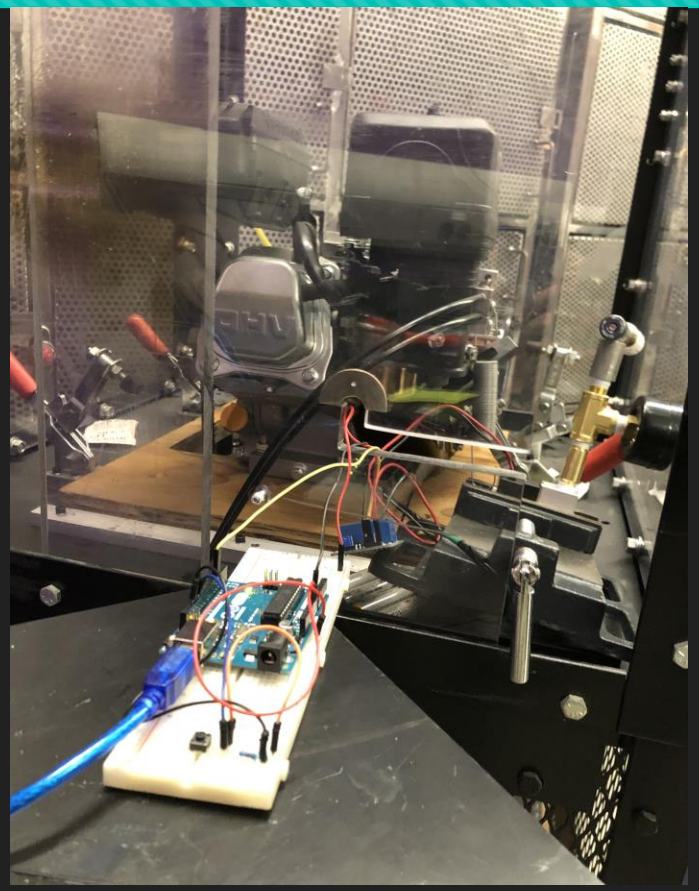
Airbag Design
- Size
- Shape

Conducted experiments

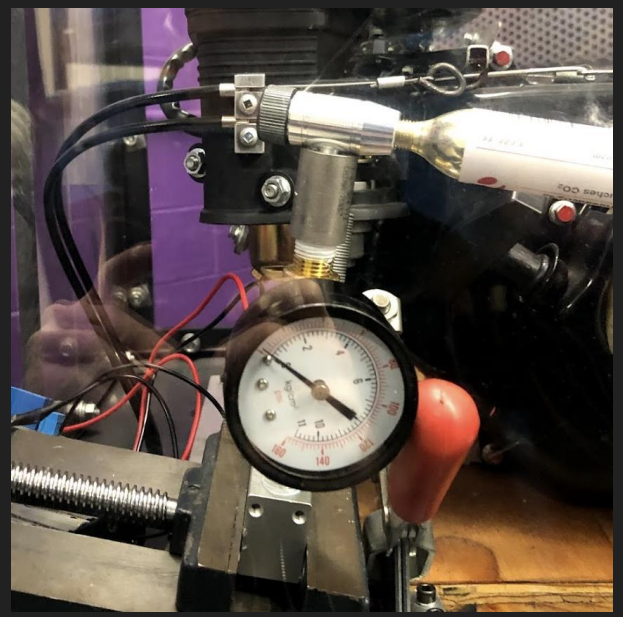
Pressure varying trials
- 20-100psi (10psi intervals)

Data Collection
- Problems -> Modify -> Redo

Actuation | Solenoid Controlled Test



Enclosed test setup



- Setting pressure – chokes flow
- Airbag pulsates!

Need consistent air flow!

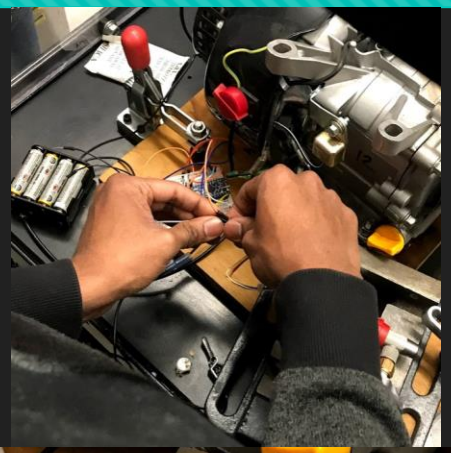
Actuation | Solenoid Controlled Test

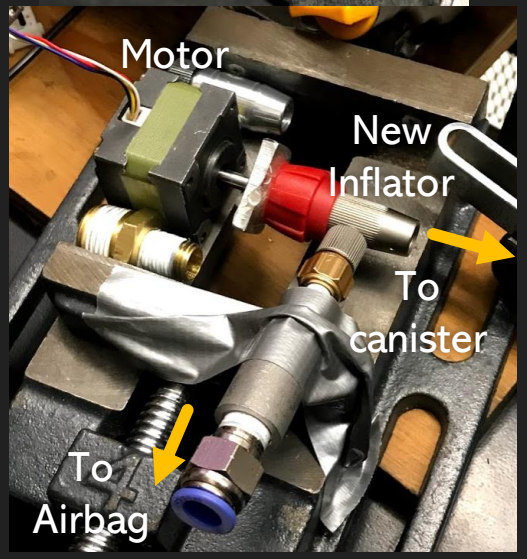
- Limiting factor – flow rate
- For a consistent flow – **Canister** swapped for **compressed air line**

Advantage	Drawback
Safer for symposium presentation	Tethered System
Convenient since canisters don't need to be replaced	

- For Product | **Need a new mechanism to actuate the canister**

Actuation | Motor Controlled Test



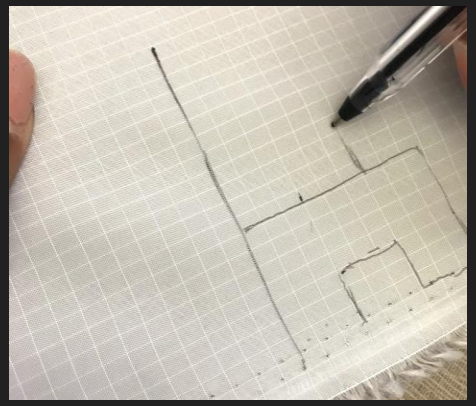


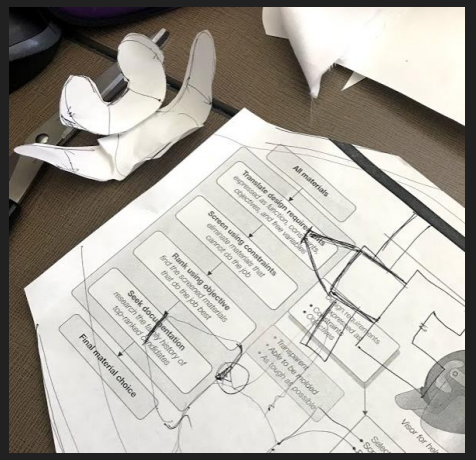
Similar enclosed test setup

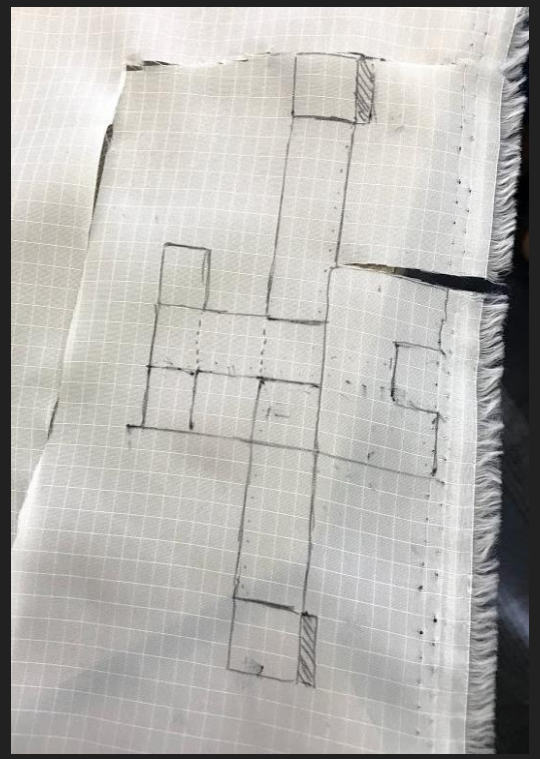
Actuation | Airbag Designs

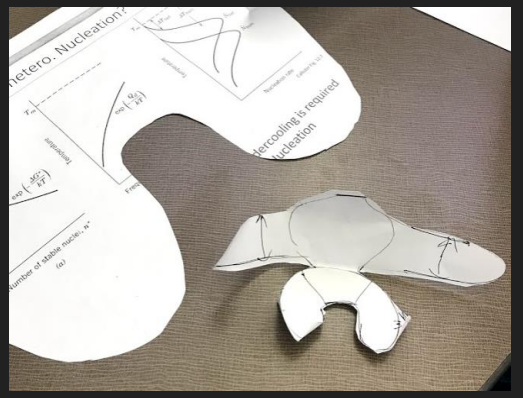
Single layered Material - PVC

Double-layered Material - PVC

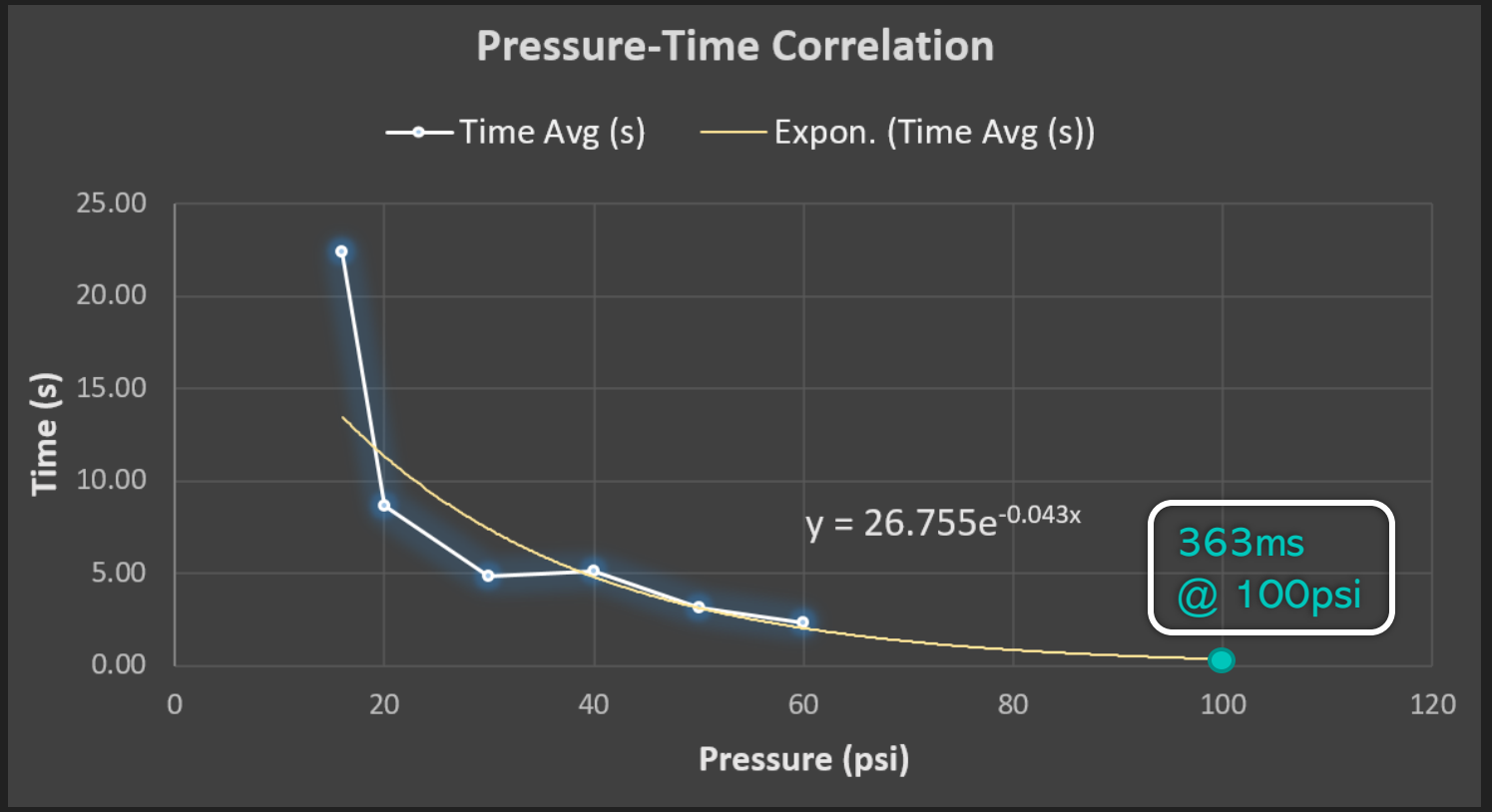








Actuation | Airbag Fill Time Extrapolation



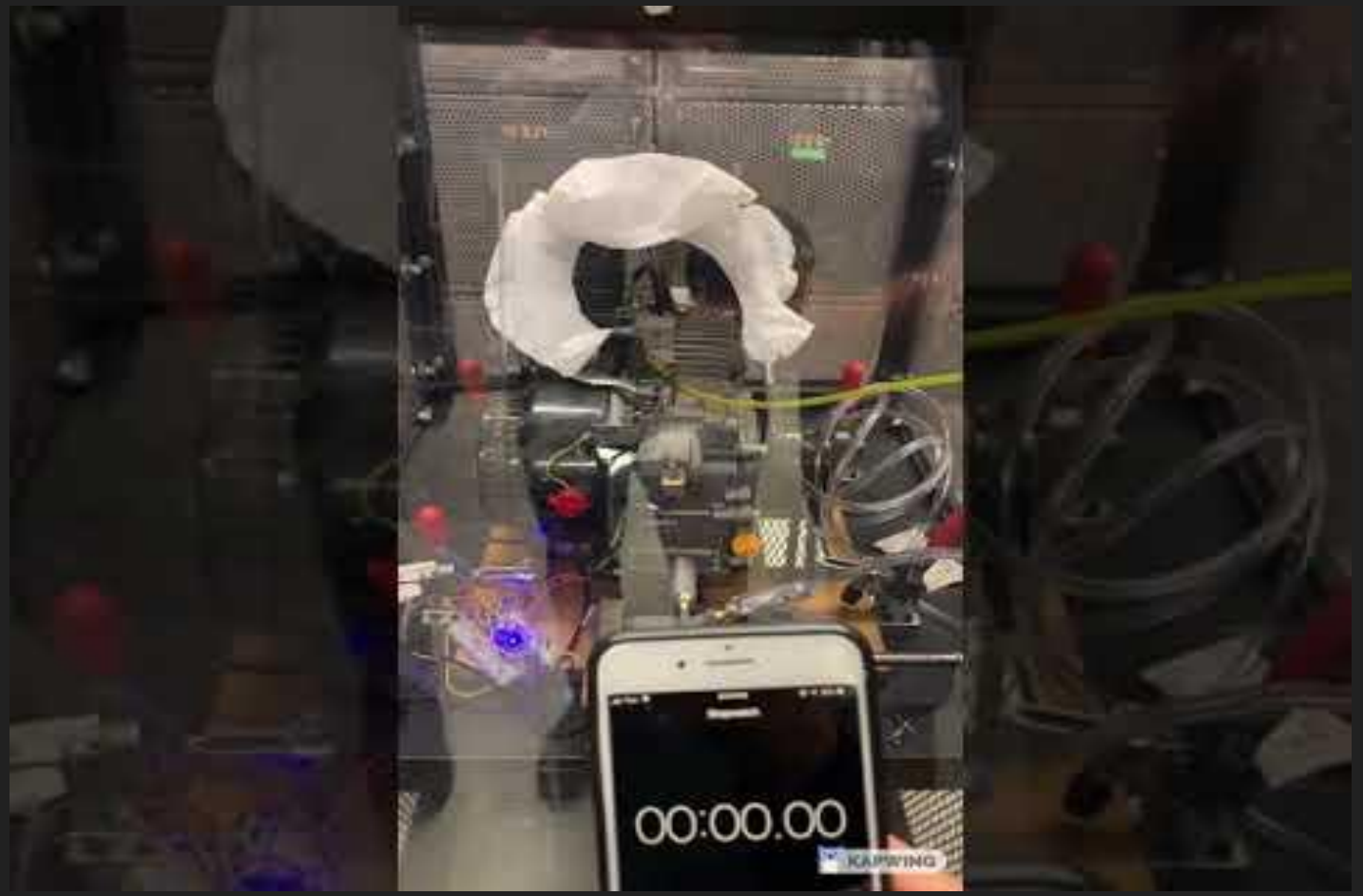
Actuation | Refined Designs

Flap panel neck column
Material - PEVA

Flat neck column
Material - PEVA

Larger Volume collar + grommet
Material – Lightweight PEVA

Actuation | After many airbag trials...



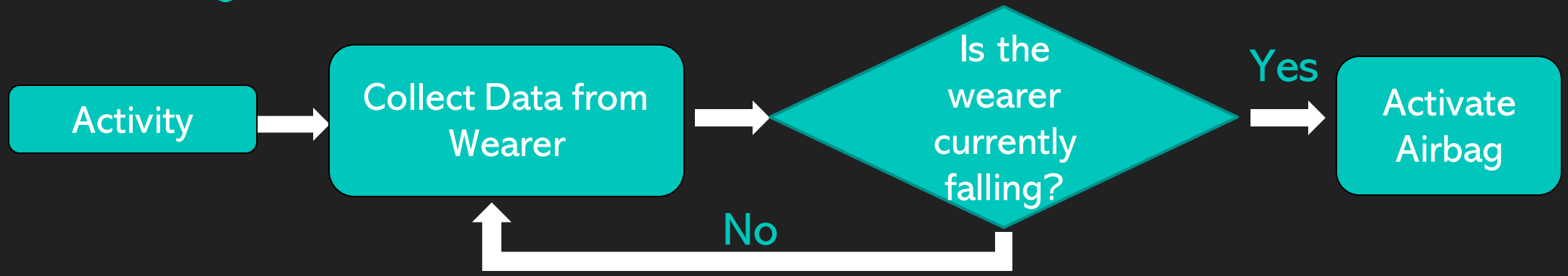
Actuation | Current Status

- Produced a motorized inflator sub-system
- Miniaturized the actuation system since the MDR
- Redesigned and iterated airbag designs (material, stitch types)
- Tube embedded in airbag for easy inflation

3.2. Sensing


Made in Indonesia Fabriqué en Indonésie
Hecho en Indonesia 印度尼西亚制造
No mercury
Sin mercurio
GB/T8897.2-2013
AA ALKALINE
AA/LR6/AM3/単3形/5号 1.5V
ARDUINO
NANO
V3.1
GRAUITECH.US
USA

Sensing | Data-Driven Design



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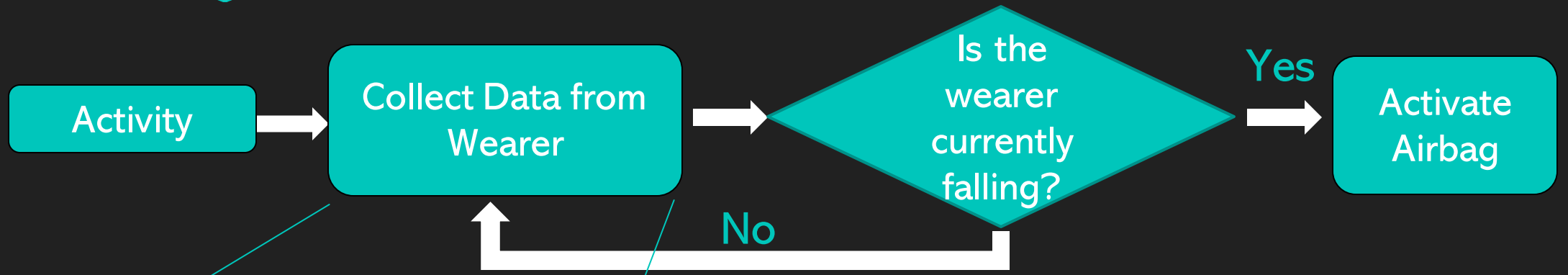
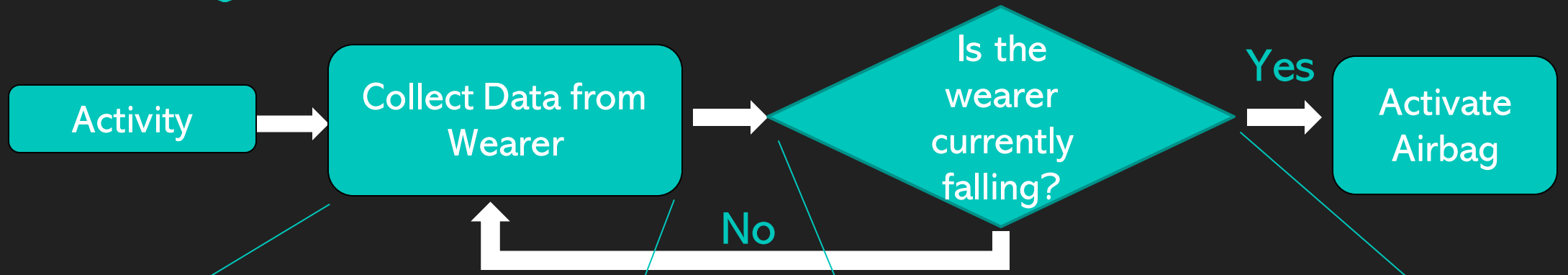


- What data should we collect?
- How do we collect this data?
- How quickly can we collect data?

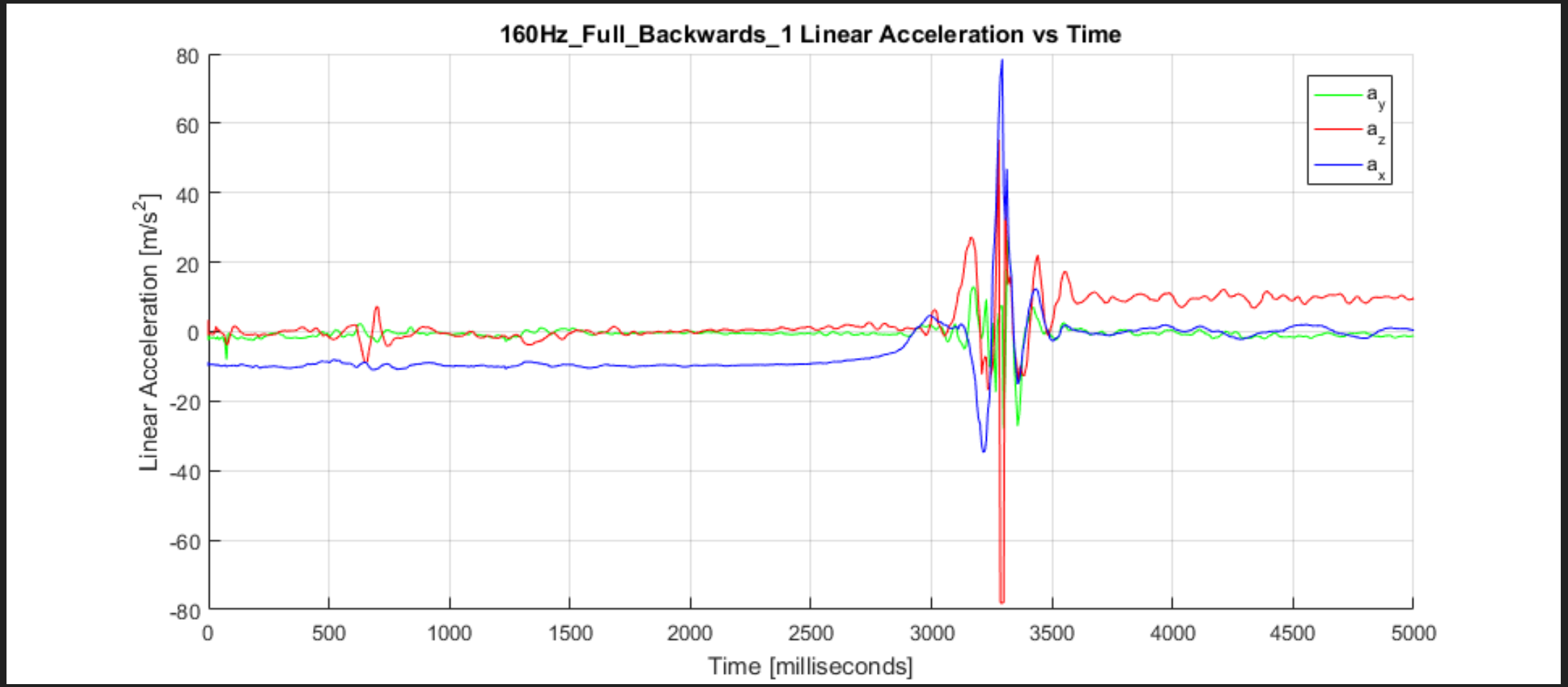
Sensing | Data-Driven Design



- What data should we collect?
- How do we collect this data?
- How quickly can we collect data?

- How do we process this data to detect a fall?
- Can we differentiate between fall and non-fall events?

Sensing | Anatomy of a Fall



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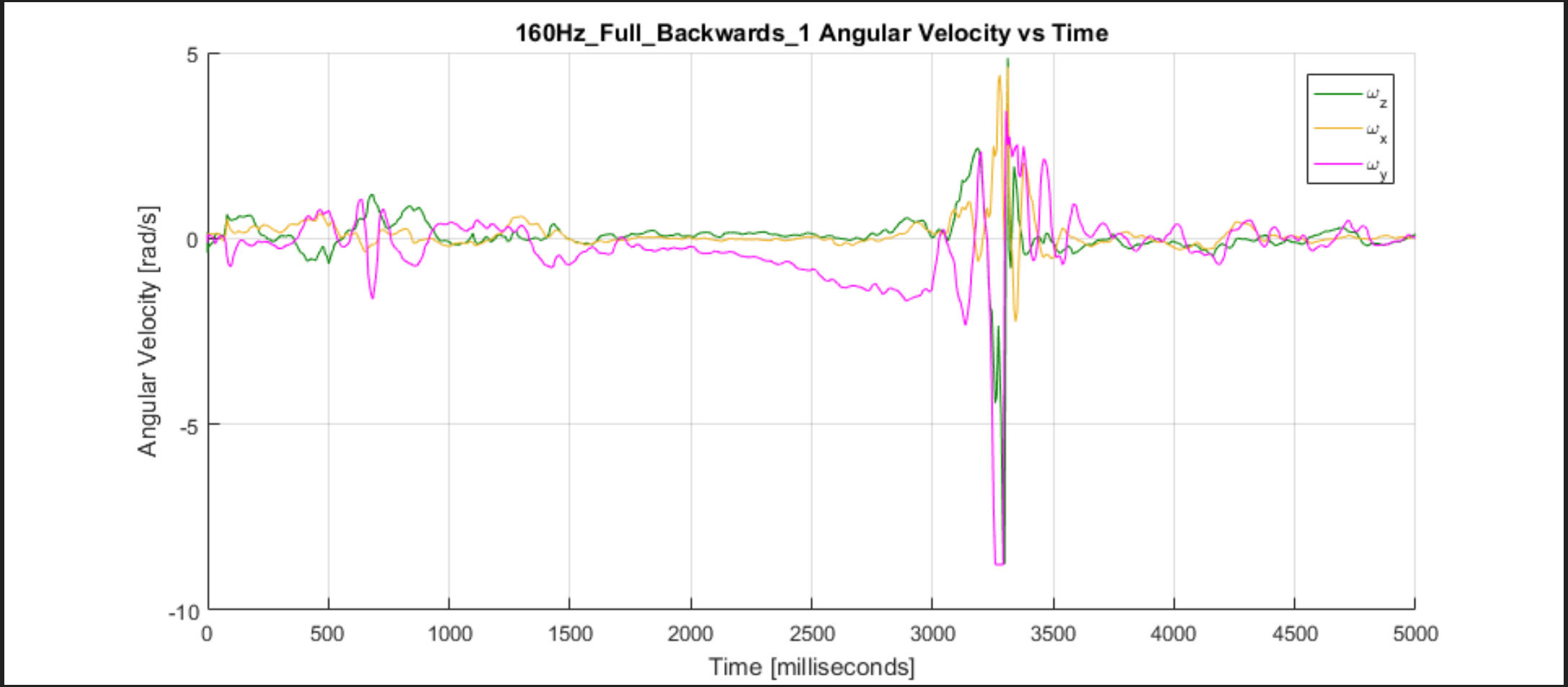

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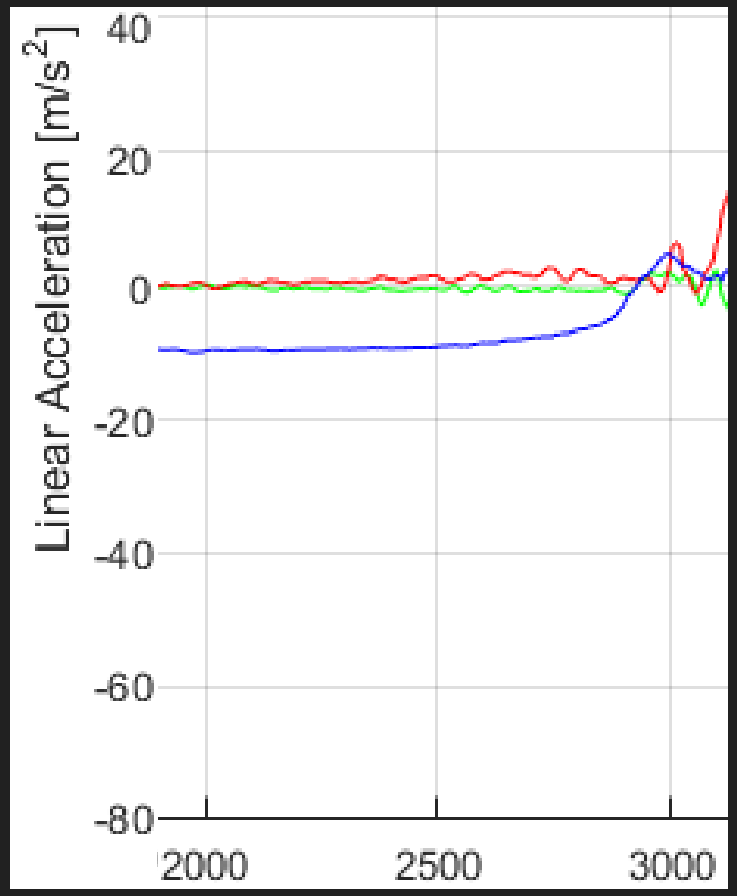
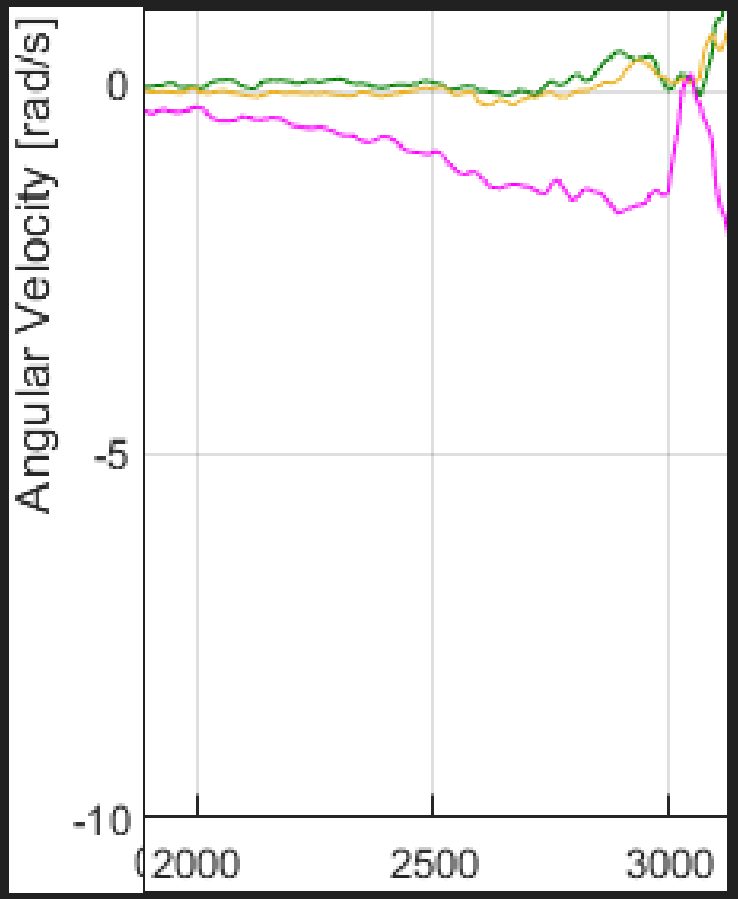
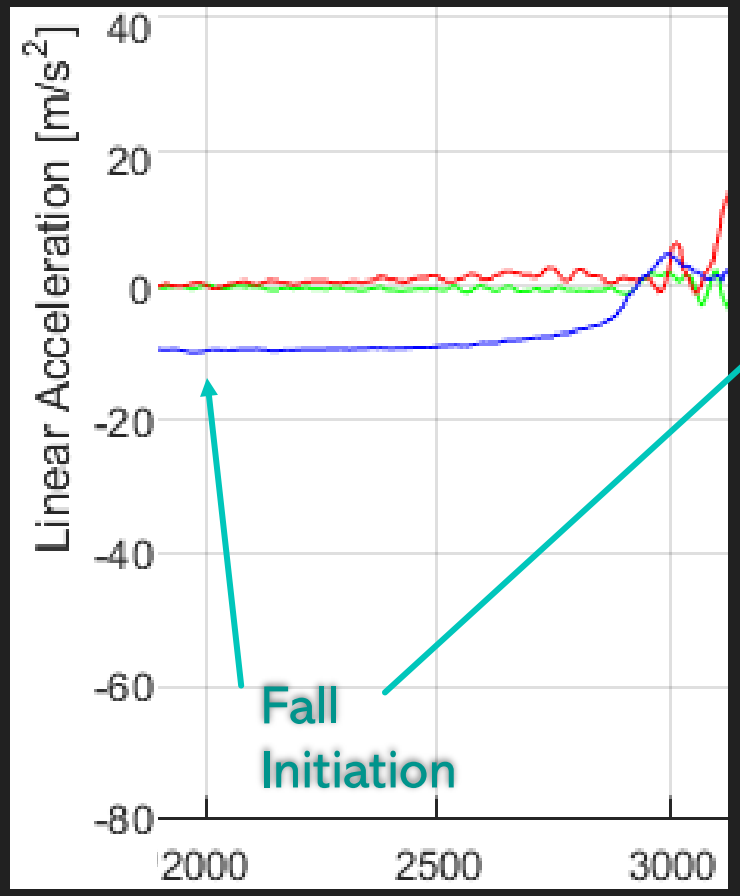
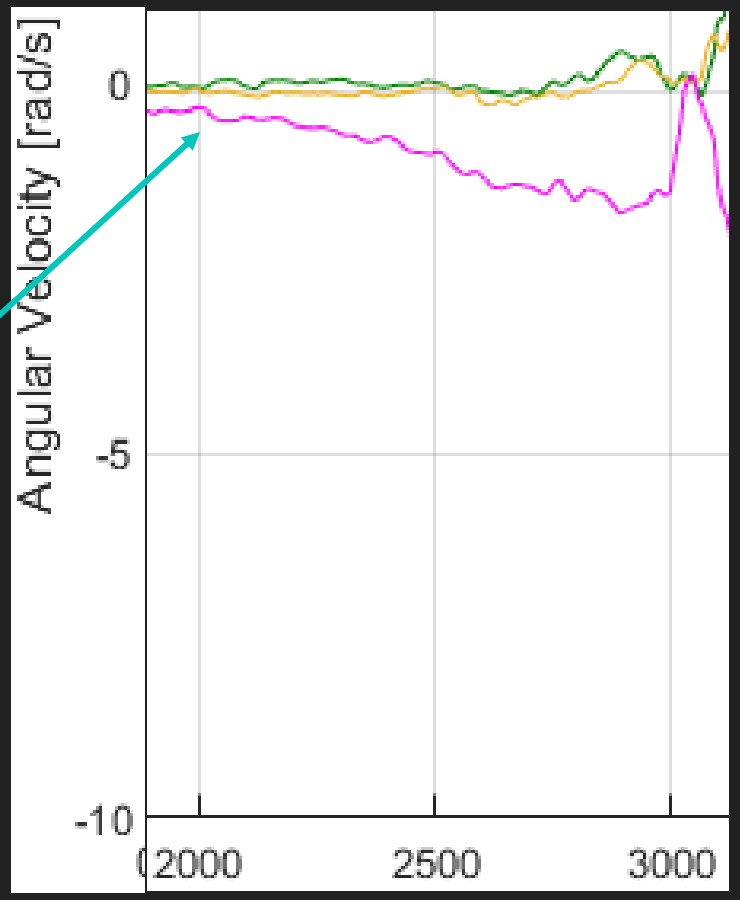




- X-axis acceleration (blue) and Y-axis angular velocity (magenta) are key indicators of fall

Sensing | Anatomy of a Fall





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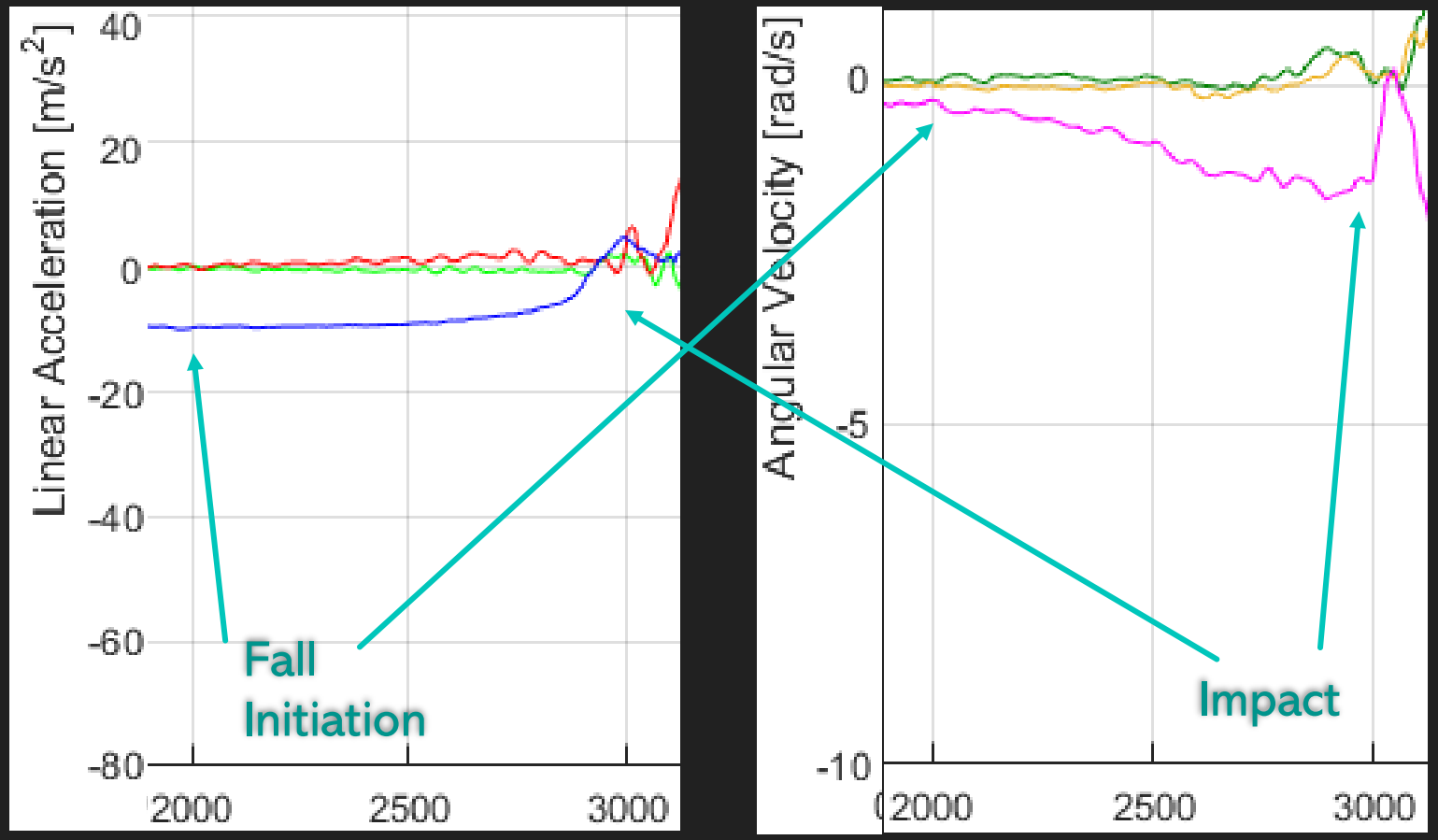

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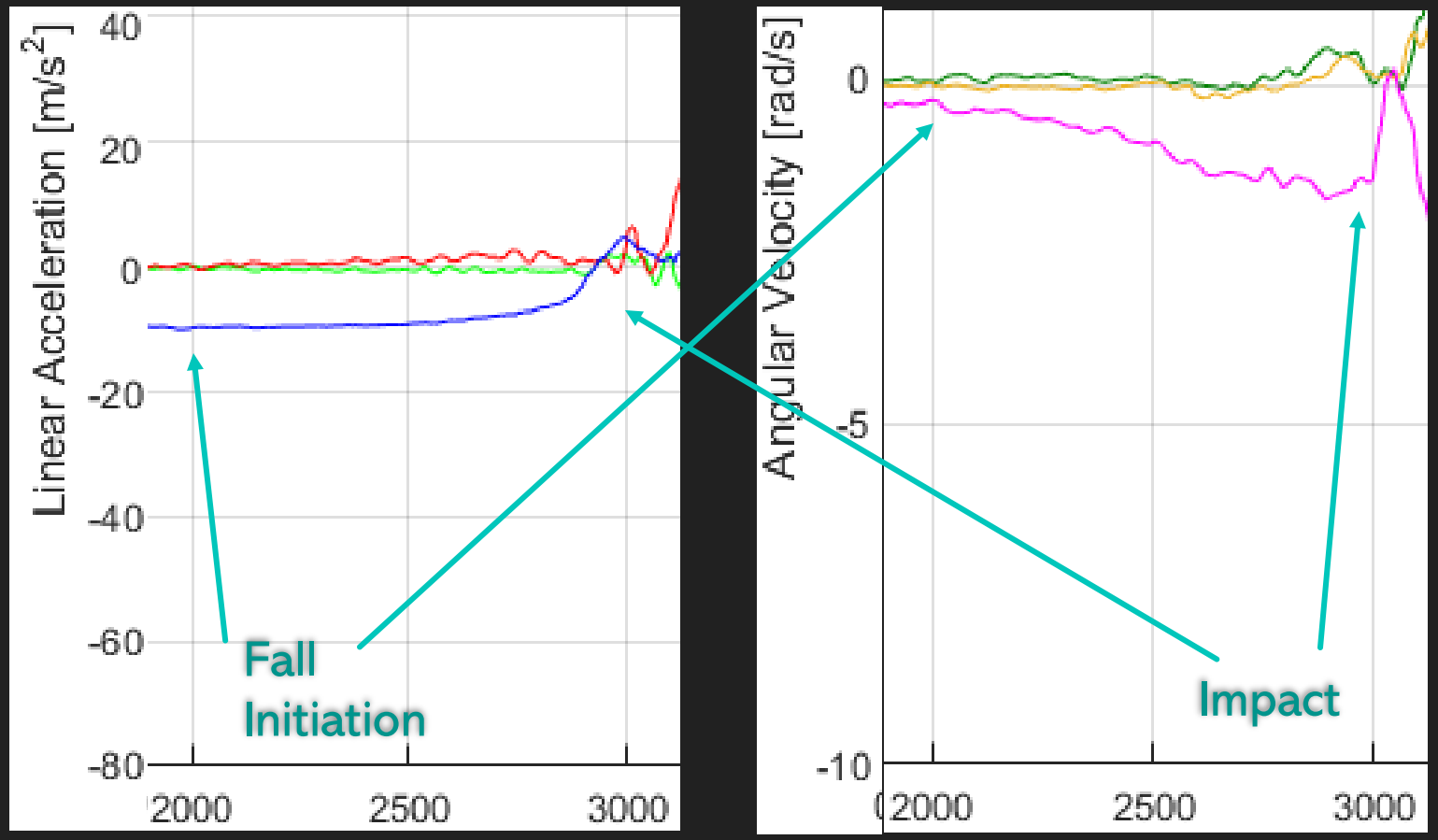
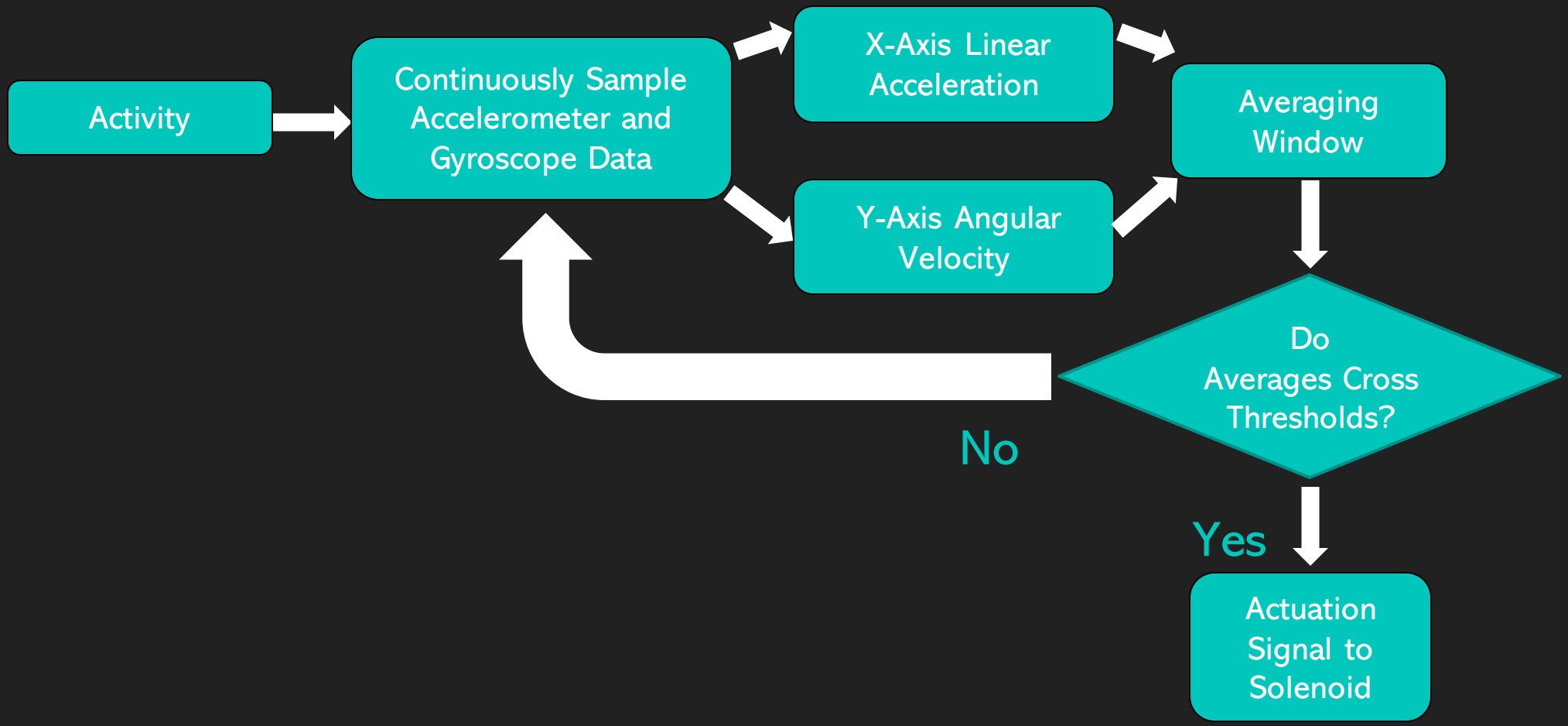
Sensing | Anatomy of a Fall

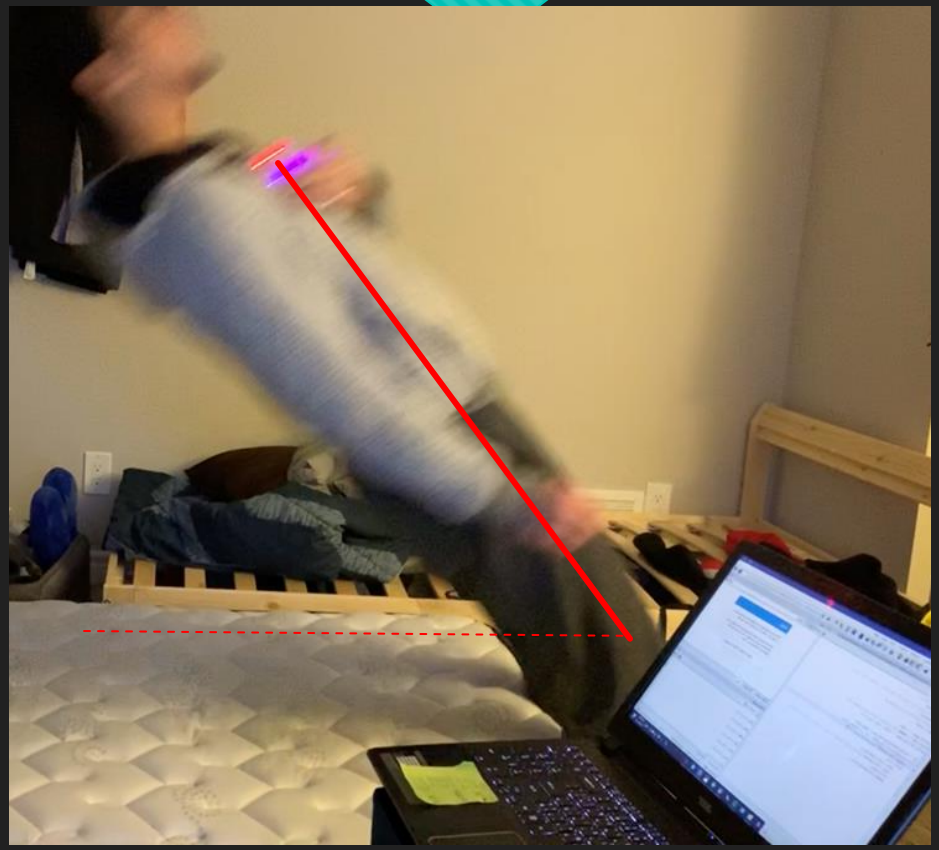


- Linear Acceleration: Rapid spike
  - Threshold > -0.5 m/s²
- Angular Velocity: Linear decrease
  - Threshold < -2 deg/s
- Combination of linear accel. and angular vel. thresholding to identify backwards falls

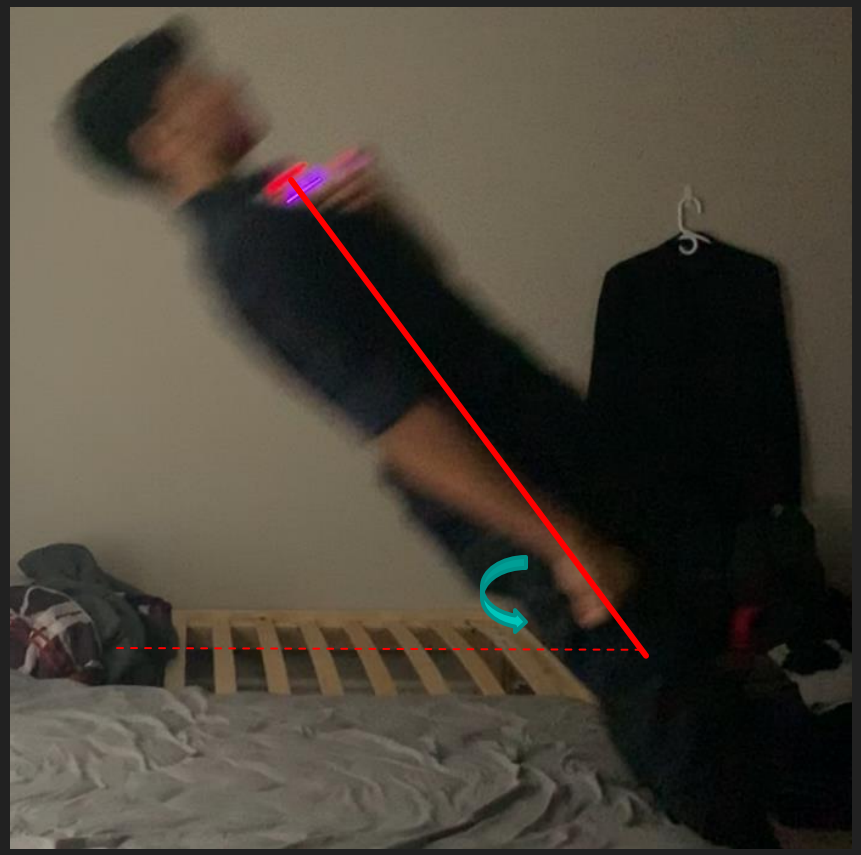
Sensing | Algorithm



Sensing | Implementation and Testing



Average Detection Angle: 54°

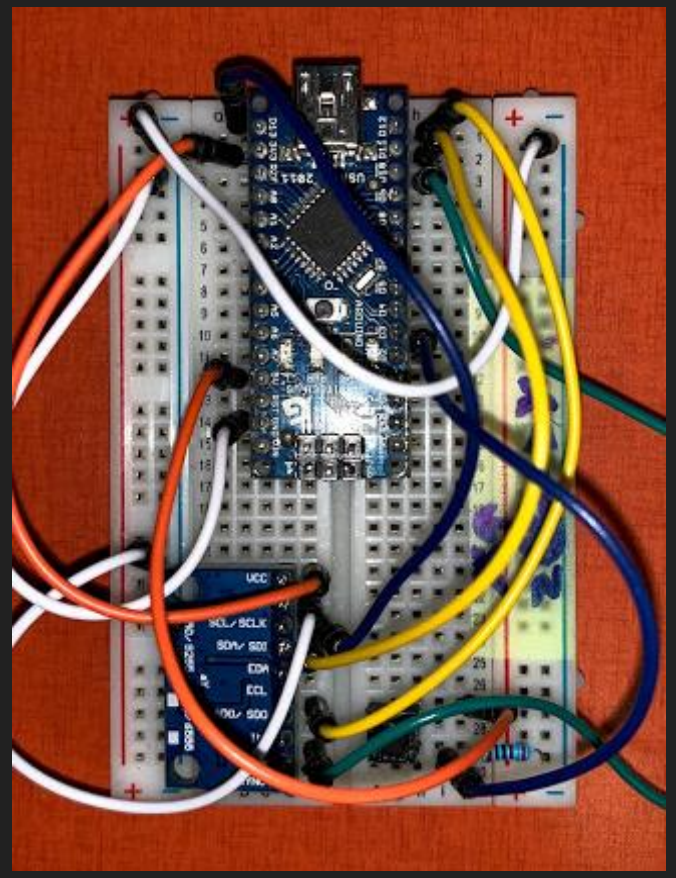


Average Detection Angle: 55°

Average Detection Angle: 51°

Sensing | Implementation and Testing

Sensing | Design Improvements: Hardware



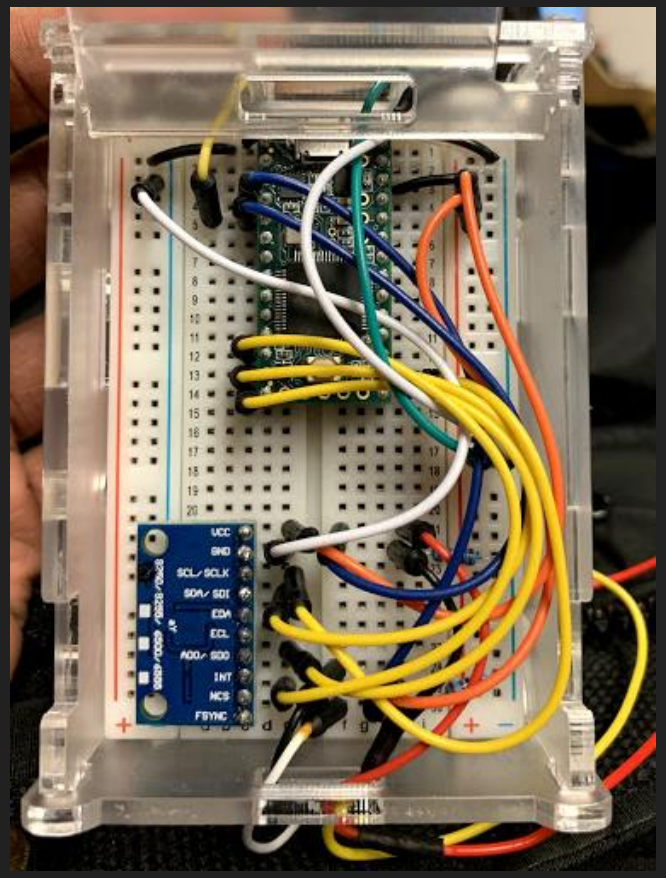
Arduino Nano + 9DoF IMU

Sampling Rate

250 Hz → 1000 Hz

SRAM

2 kB → 16 kB



Teensy 3.2 + 9DoF IMU

Sensing | Design Improvements: Algorithm

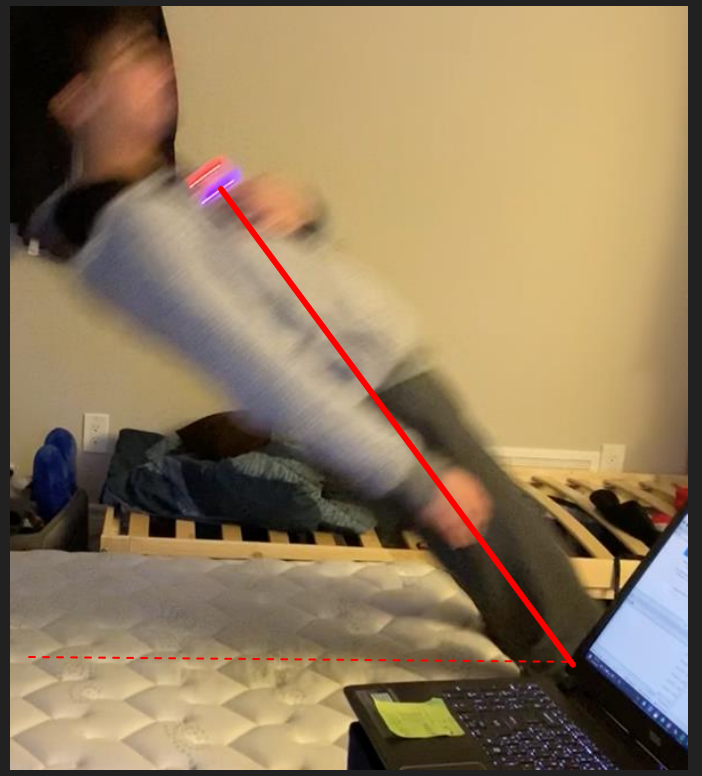
Average Detection Angle: 46°

Lin. Acceleration Threshold

> -0.5 m/s^2 → > -4 m/s^2

Ang. Velocity Threshold

< -2 rad/s → < -1 deg/s



Average Detection Angle: 54°

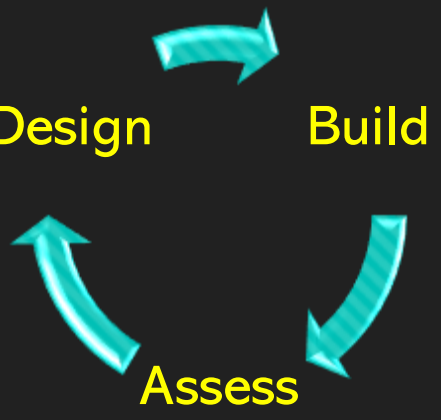
Sensing | Current Status

- Sensing system to detect simple backwards falls developed
- Repeatable (> 40 individual falls recorded, robust to height variation)
- Fall versus Non-Fall differentiation requires additional analysis of acceleration and velocity components

3.3. Packaging

Packaging | Iterative Design

Enclosure Designs
Vest Design
Jacket Selection/Design



Goal / Vision

Enclose all subcomponents for
1. Safety
2. User Comfort

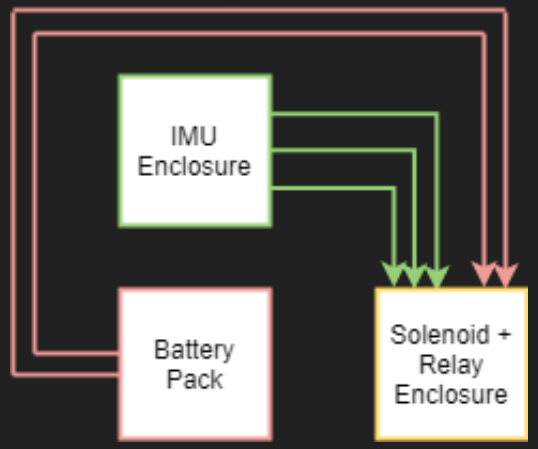
Functional Subsystem

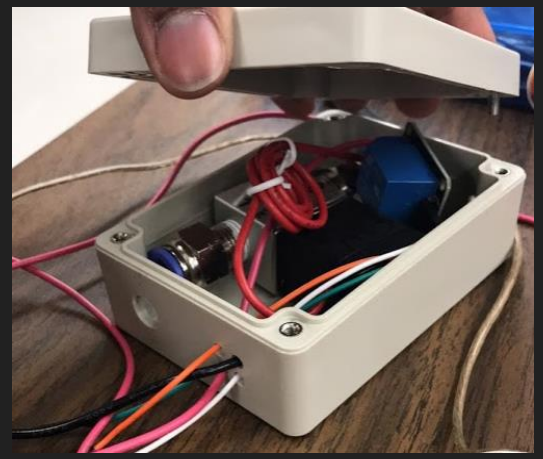
Subsystem Enclosures
Concealed Wires
Prototype Jacket

Aesthetics
Subsystem Location
Measurement of Fit
User Comfort

Packaging | Overview

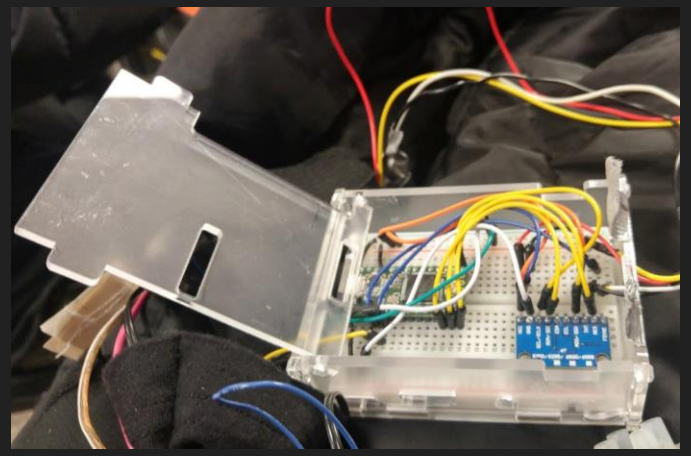
Routing schematic





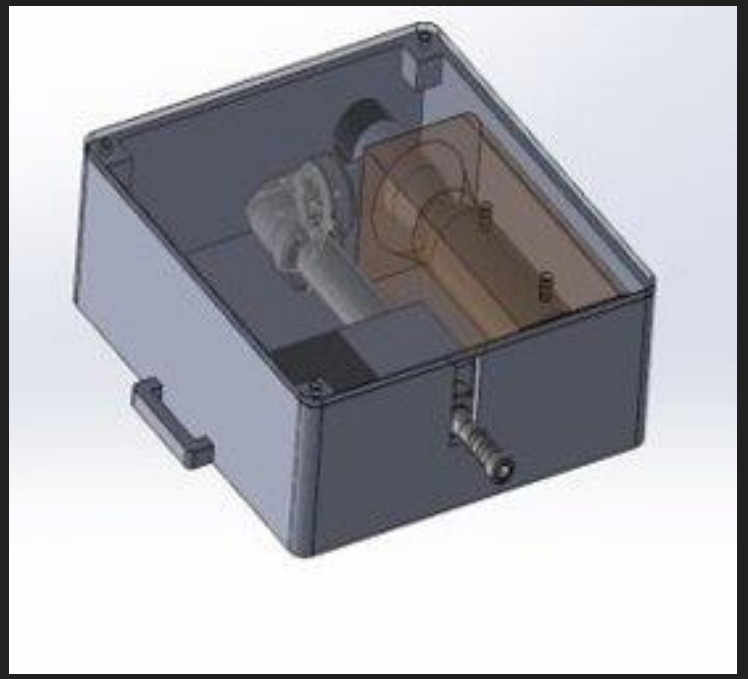
Solenoid + Relay Enclosure

Battery Enclosure



IMU Enclosure

Packaging | Pneumatic Enclosure

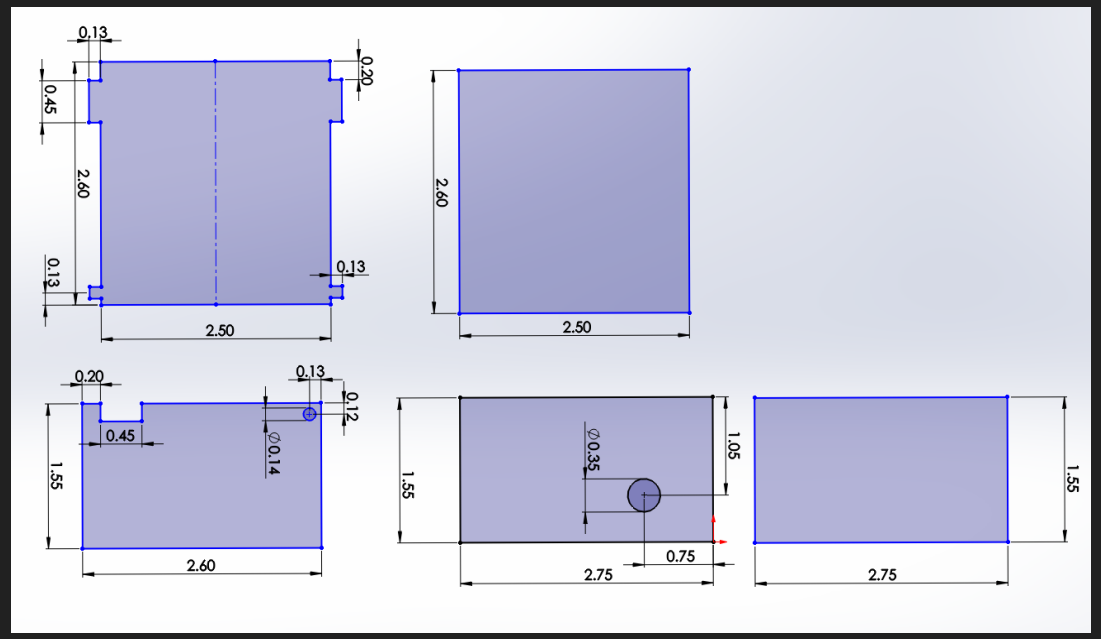


Canister Pneumatic Enclosure CAD

Canister Pneumatic Enclosure

Airline Pneumatic Enclosure

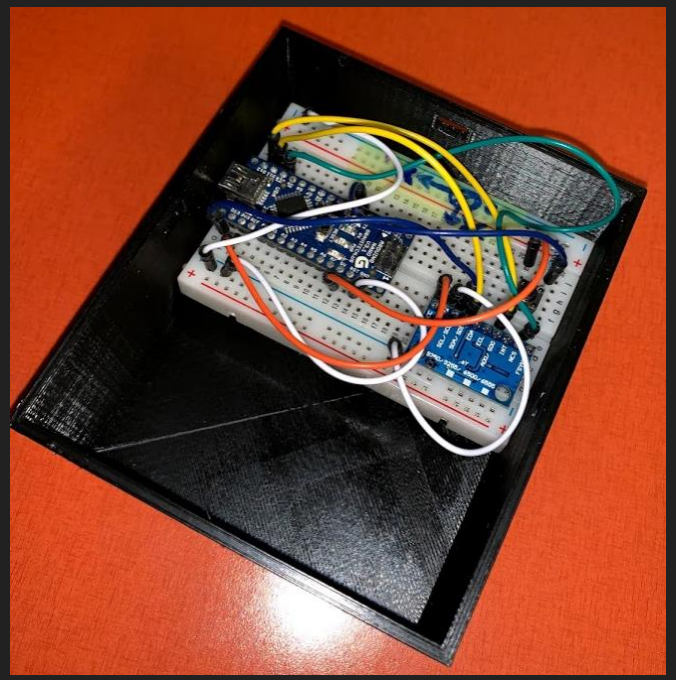
Packaging | Battery Enclosure



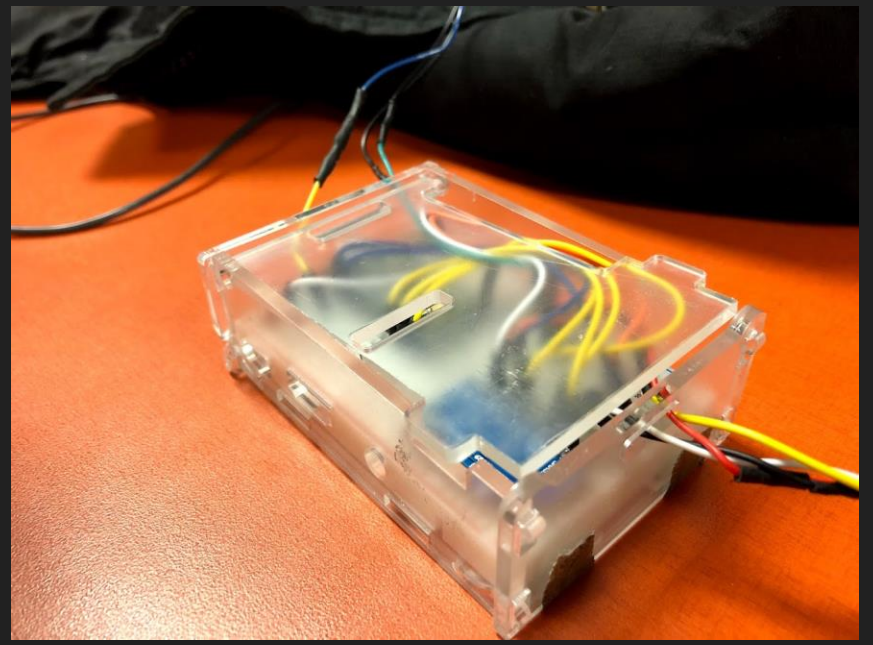
2D CAD

Final Design

Packaging | IMU Enclosure



Initial Design



Final Design

Packaging | Initial Strap-Based Design

Key usability issues:

- Difficulty in wearing/taking off
- Inadequate subsystem support/routing concealment
- Social cost to geriatric users

Packaging | Jacket Design

Mounting Points

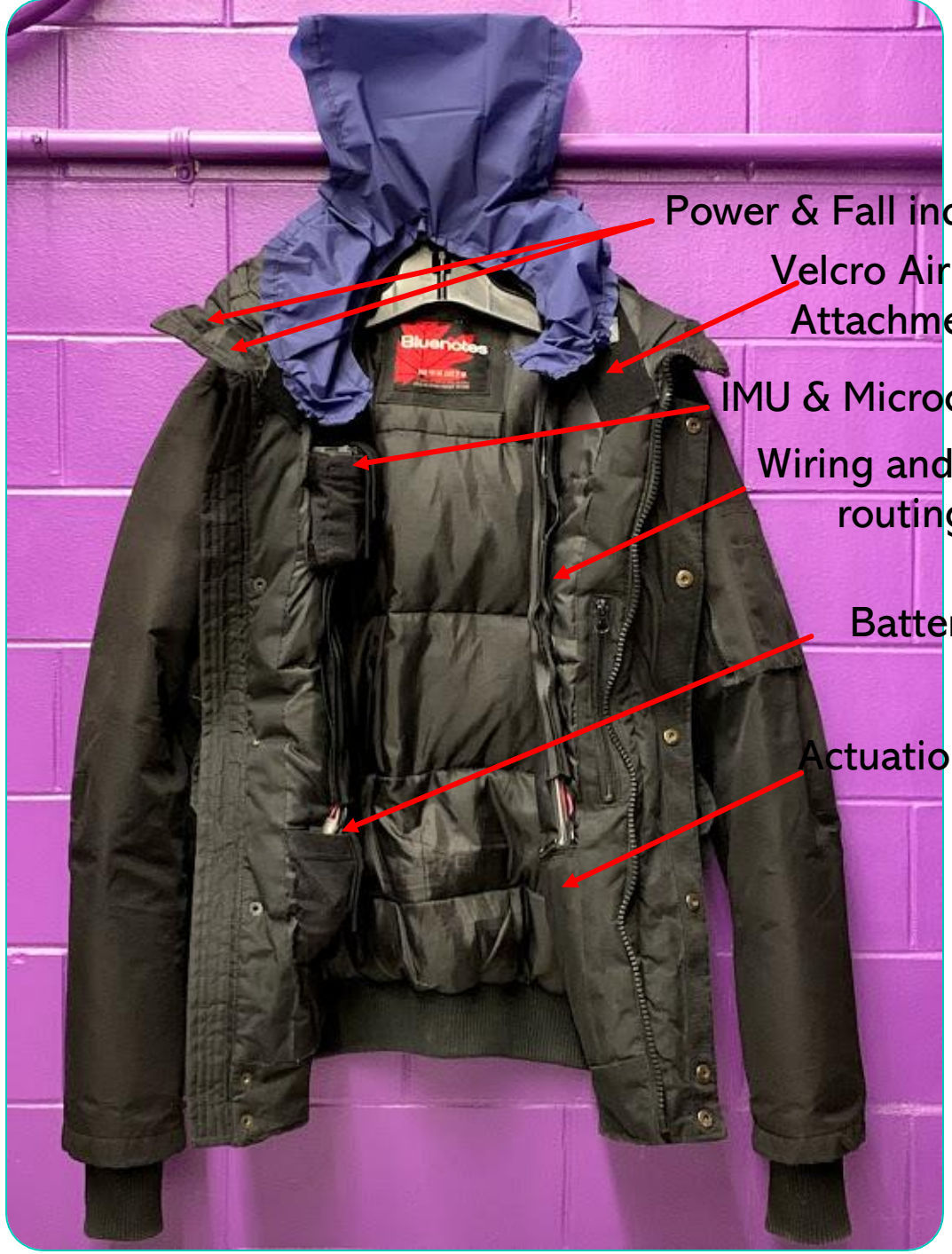
- Battery Pack
- IMU
- Solenoid + Relay

Velcro Airbag Attachment

Nylon routing

Velcro Strap

Stitched Pockets

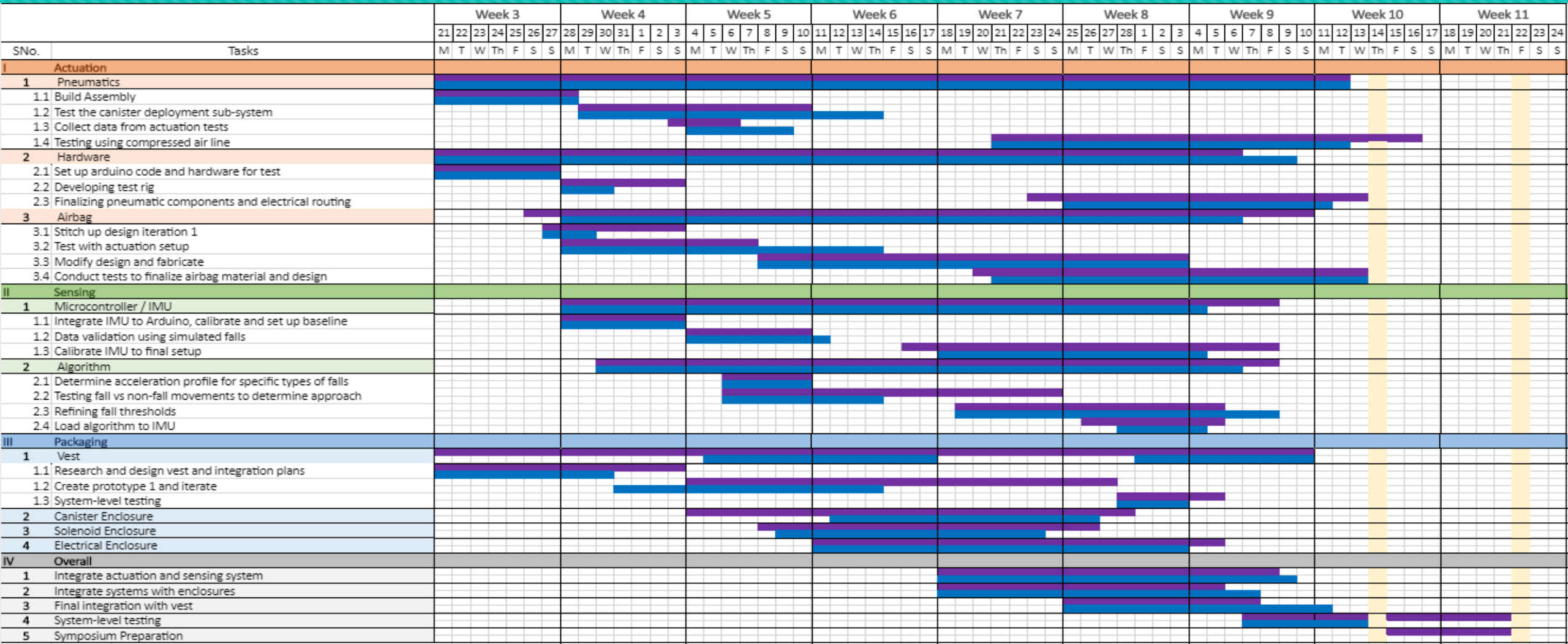

Power & Fall indicator
Velcro Airbag Attachment
IMU & Microcontroller
Wiring and tube routing
Battery Pack
Actuation system

Packaging | Current Status

- Accomplished enclosure fabrication for:
  - Solenoid + relay (Pneumatic)
  - IMU
  - Battery pack
- Completed bulk package integration
- Concealed wires by using Velcro straps

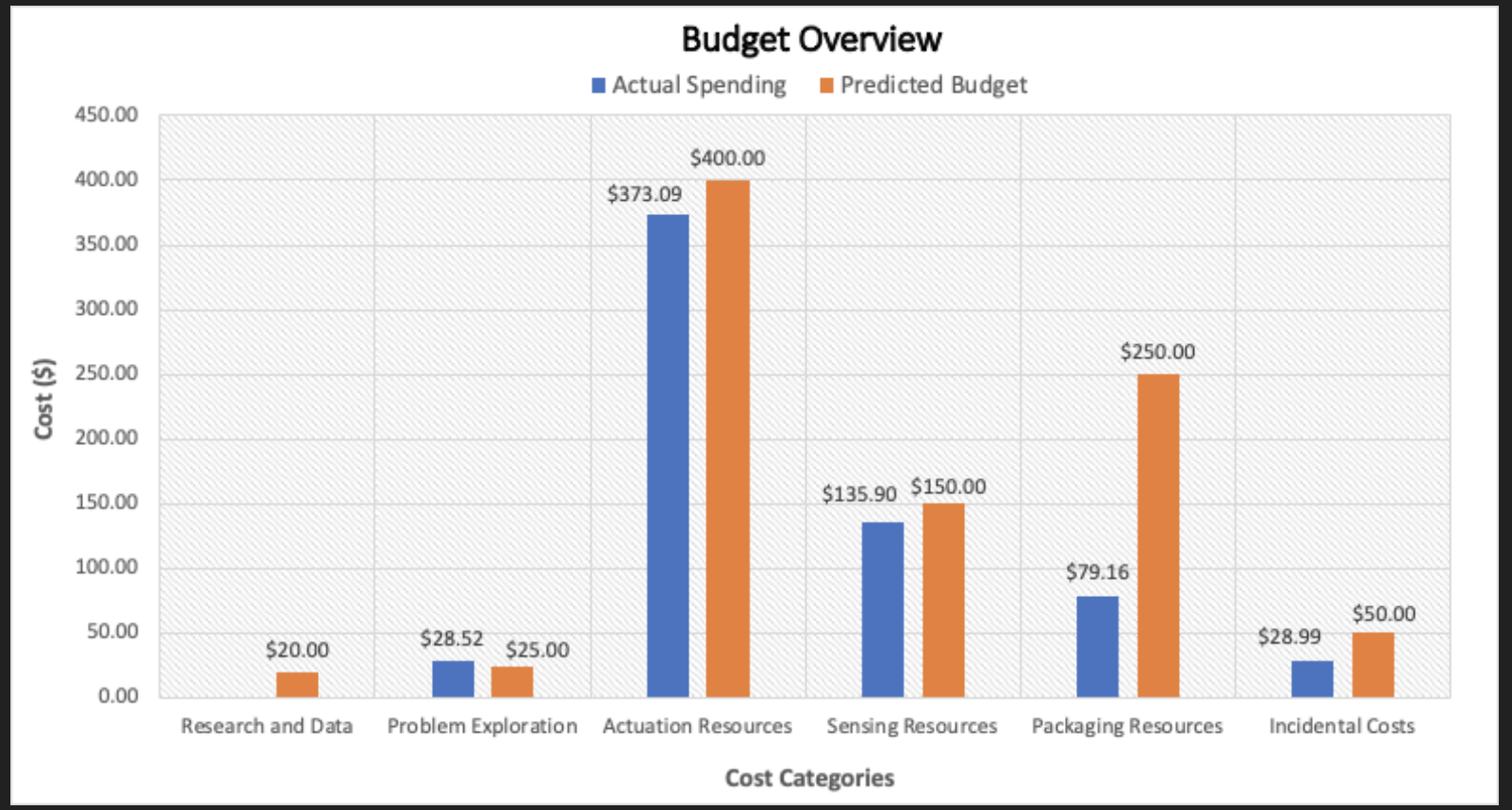
4. Project Management

Gantt Chart


Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
M T W Th F S S M T W Th F S S M T W Th F S S M T W Th F S S M T W Th F S S M T W Th F S S M T W Th F S S M T W Th F S S M T W Th F S S
SNo.
Tasks
I Actuation
1 Pneumatics
1.1 Build Assembly
1.2 Test the canister deployment sub-system
1.3 Collect data from actuation tests
1.4 Testing using compressed air line
2 Hardware
2.1 Set up arduino code and hardware for test
2.2 Developing test rig
2.3 Finalizing pneumatic components and electrical routing
3 Airbag
3.1 Stitch up design iteration 1
3.2 Test with actuation setup
3.3 Modify design and fabricate
3.4 Conduct tests to finalize airbag material and design
II Sensing
1 Microcontroller / IMU
1.1 Integrate IMU to Arduino, calibrate and set up baseline
1.2 Data validation using simulated falls
1.3 Calibrate IMU to final setup
2 Algorithm
2.1 Determine acceleration profile for specific types of falls
2.2 Testing fall vs non-fall movements to determine approach
2.3 Refining fall thresholds
2.4 Load algorithm to IMU
III Packaging
1 Vest
1.1 Research and design vest and integration plans
1.2 Create prototype 1 and iterate
1.3 System-level testing
2 Canister Enclosure
3 Solenoid Enclosure
4 Electrical Enclosure
IV Overall
1 Integrate actuation and sensing system
2 Integrate systems with enclosures
3 Final integration with vest
4 System-level testing
5 Symposium Preparation

Work Breakdown Structure

Finance / Budget Review

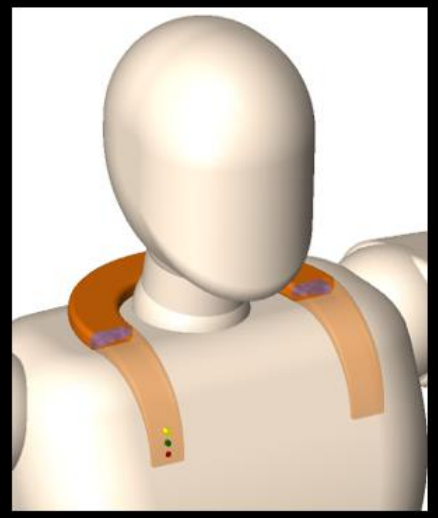


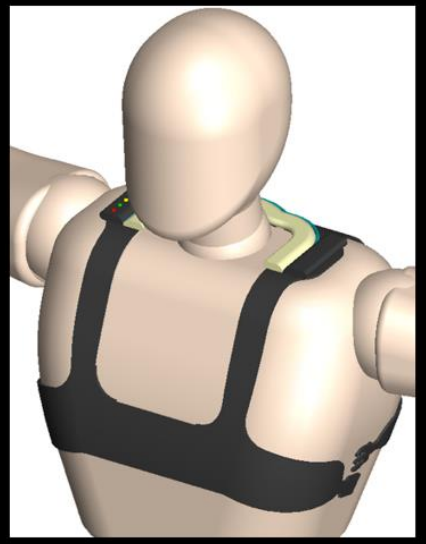
Total Project Expenditure: $644.11 / $900

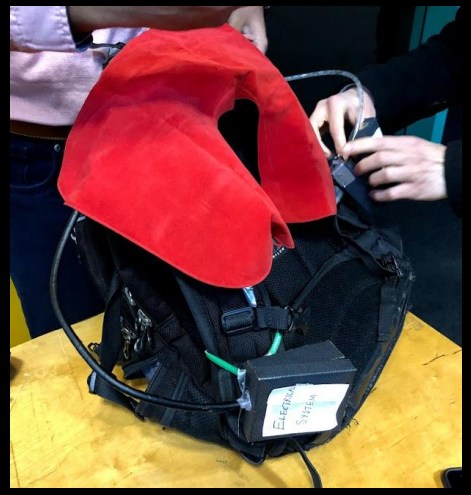
5. Symposium Showcase

Symposium Showcase Setup

1. Jacket to be placed on wooden model "person"
2. Connect to compressed air line for actuation
   - Air line to solenoid; Solenoid to airbag
   - Solenoid triggered by the sensing signal when model is dropped.
3. Video of working product with canister setup
   - Prototype of the actuation system with the motorized setup (w/out canister)







6. Conclusion

Conclusion

Functional Prototype has been built

- Successful testing of isolated sub-systems
- Successful integration of sub-systems
- Further work:
  - Complex fall cases
  - Differentiation between Falls and Non-Falls
  - Integration of motorized CO_2 actuation

Lessons Learned:

- Research-fueled ideation
- Iterative design process
- Significance of mindful project management at each project stage


Thank you

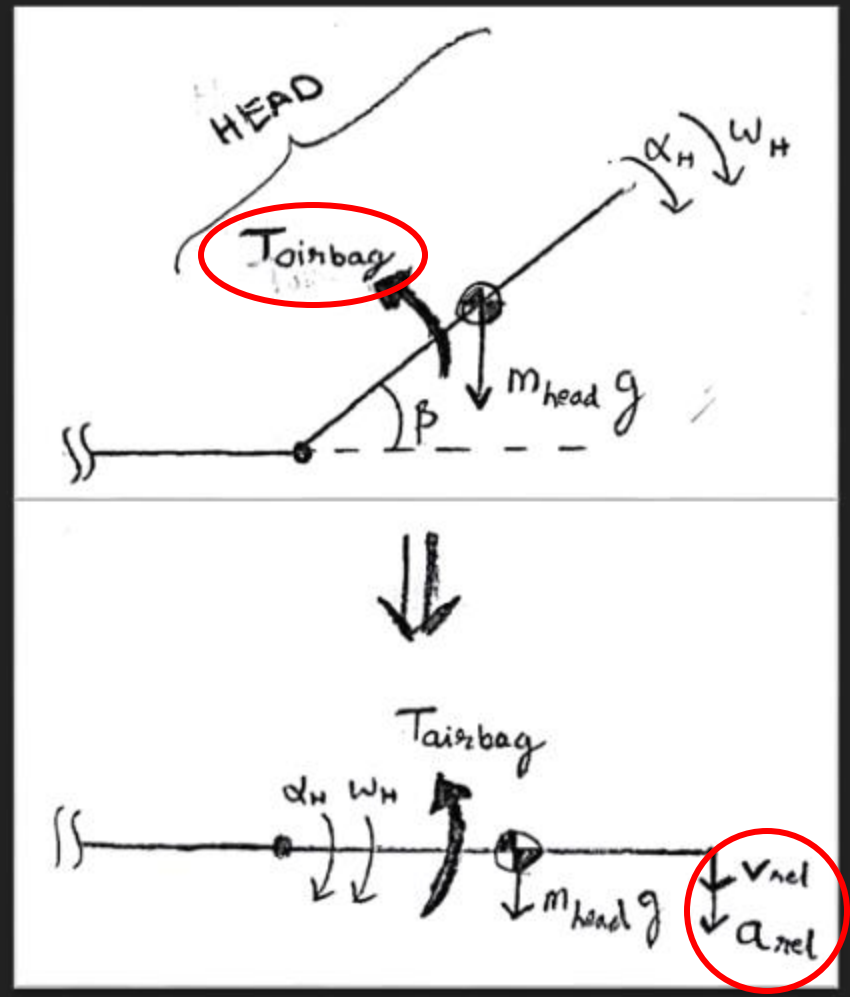
Appendix

NIC Spec -> Force on Neck

- According to ME 481 calculations, need to impart **218 N** shear force on neck to bring NIC down to 15m^2/s^2
- Value corroborated by crash test research: 245 – 400 N shear force https://books.google.ca/books?id=f-vML_ZQWsIC&pg=PA348&lpg=PA348&dq=human+neck+maximum+pounds+force&source=bl&ots=Gh4rUL51AR&sig=ACfU3U2dcUVqoPAhj32uiWd2sPKnTlOpuA&hl=en&sa=X&ved=2ahUKEwjM_pvM0PrgAhVMooMKHZr_DHcQ6AEwEXoECAwQAQ#v=onepage&q=human%20neck%20maximum%20pounds%20force&f=false
- Maximum neck forces during collision peak at approx 700 N for a 22g deceleration (much higher than what we anticipate – Fig 8 https://www.hindawi.com/journals/abb/2018/4542750/
- Therefore spec set to between **220-700 N** of force exerted on neck
- Pressure * Contact Area = Force

Specifications | Force Exerted

- Neck Injury Criterion (NIC) used as an indicator of whiplash likelihood
- NIC = $0.2a_{rel} + v_{rel}^2$ [m^2/s^2]
- NIC < 15 m^2/s^2 to avoid whiplash injury
- Fall modelling: **218 N** of force needed

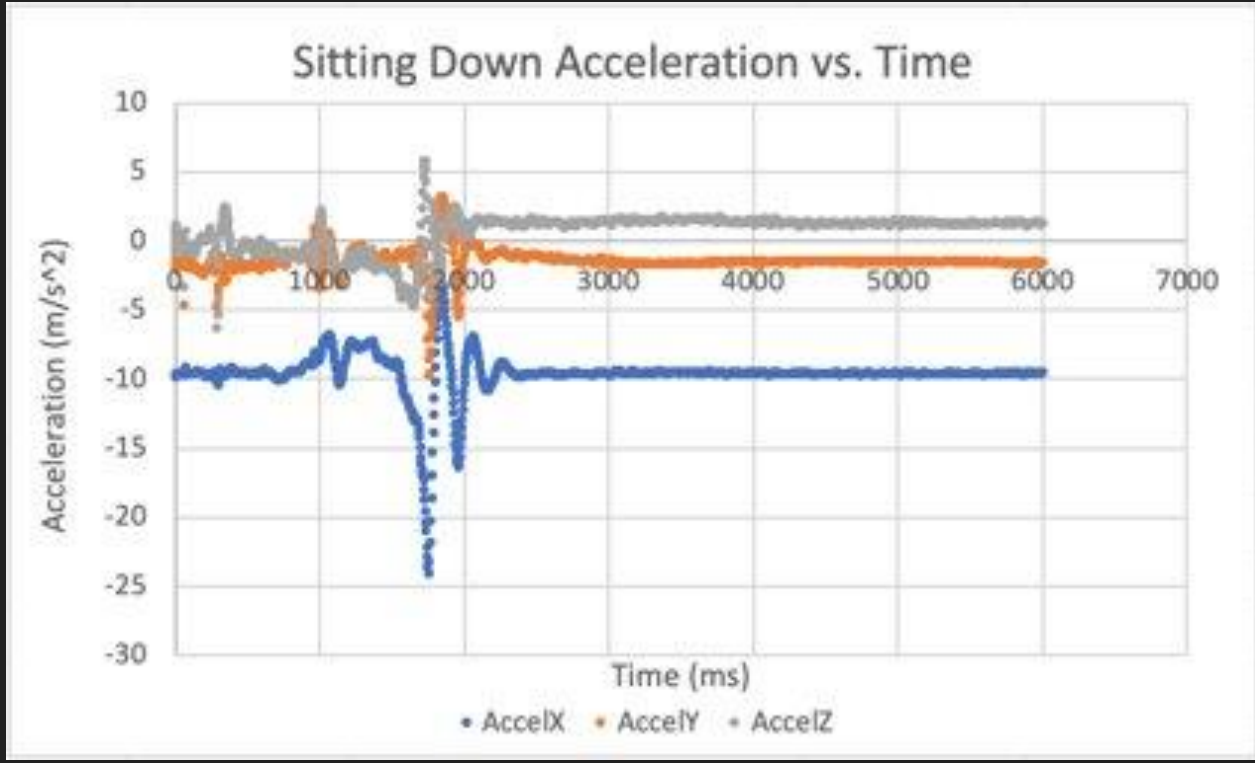


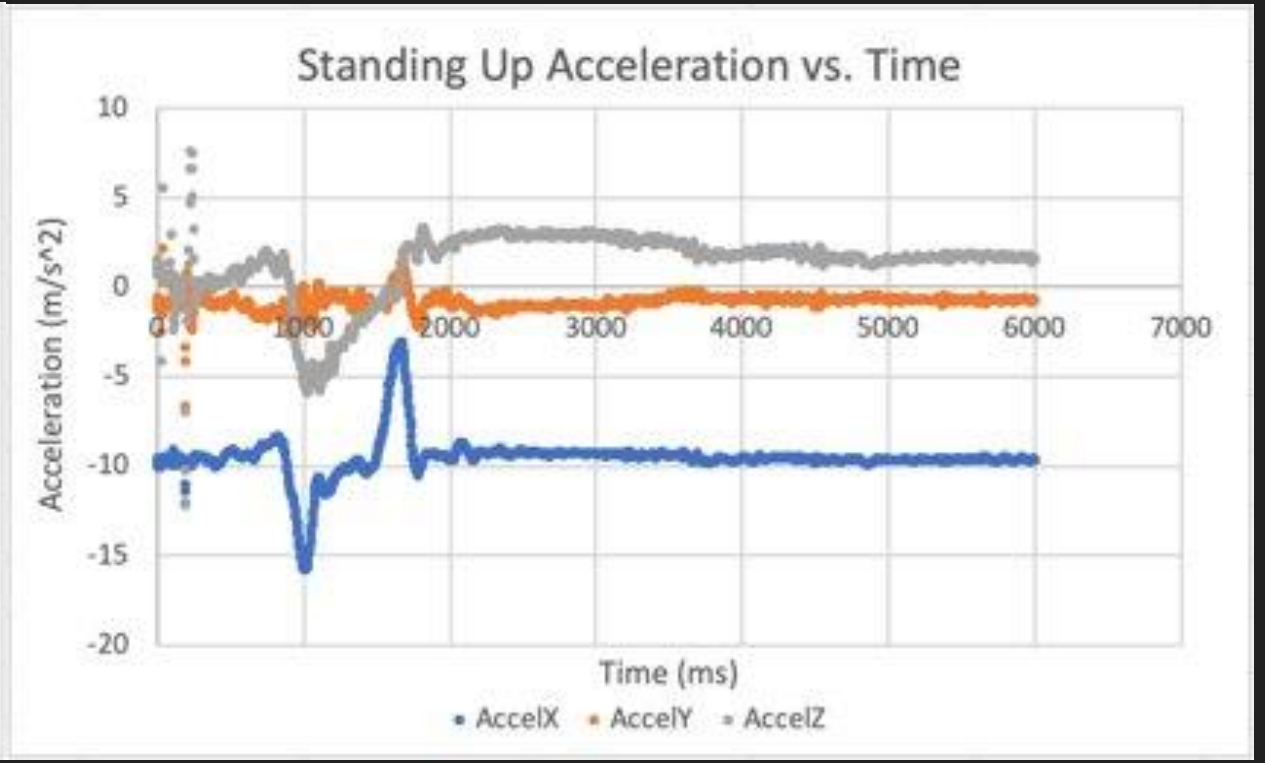
Specifications | Force Exerted

Current Options:

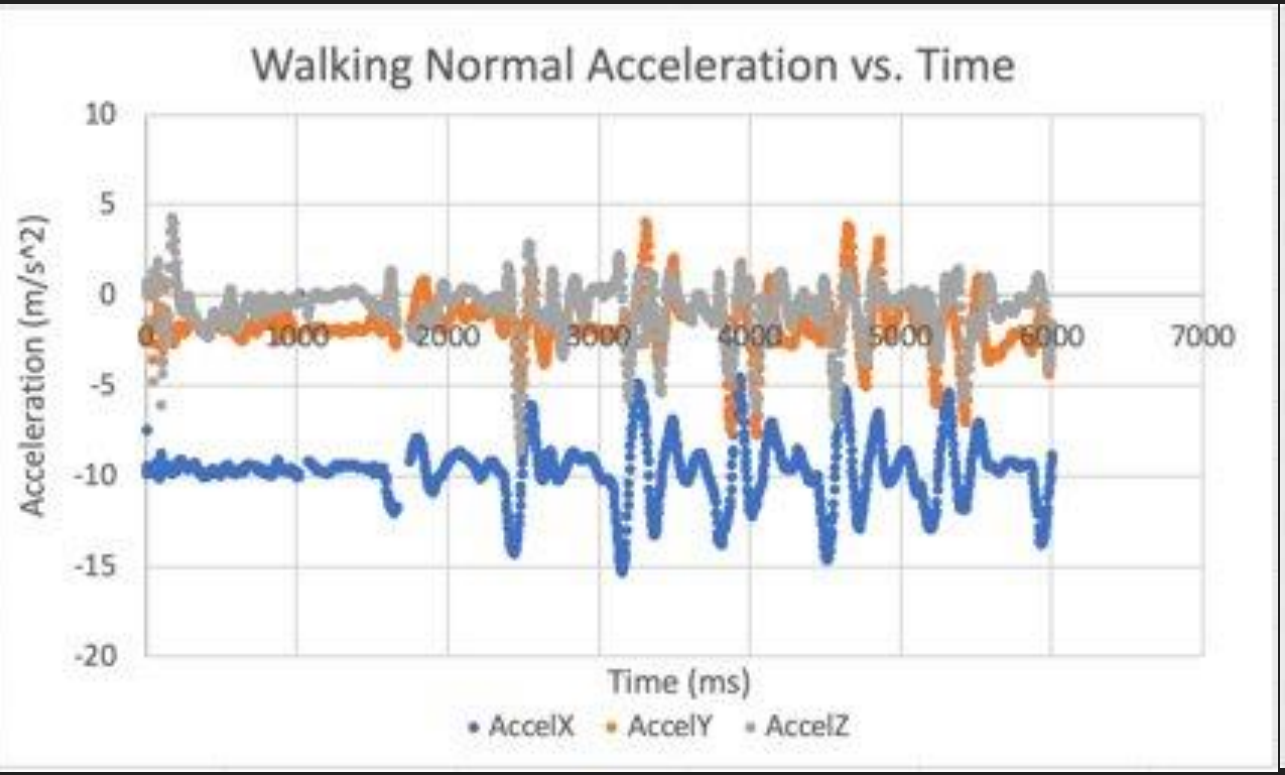
1. Potential to replicate NIC testing using multiple accelerometers + flexible neck
2. Measure airbag force using weighing scale (over time). Use impulse and momentum calculations

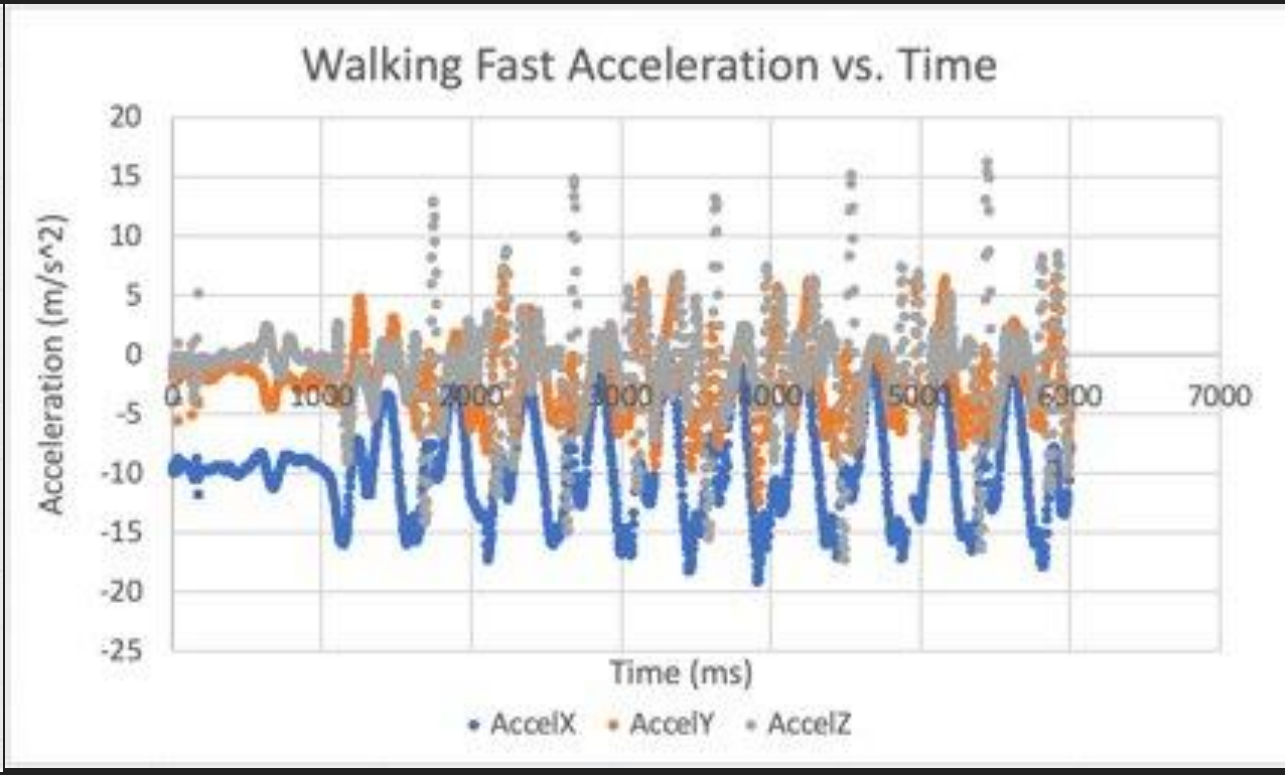
Sensing | Non-Fall Data



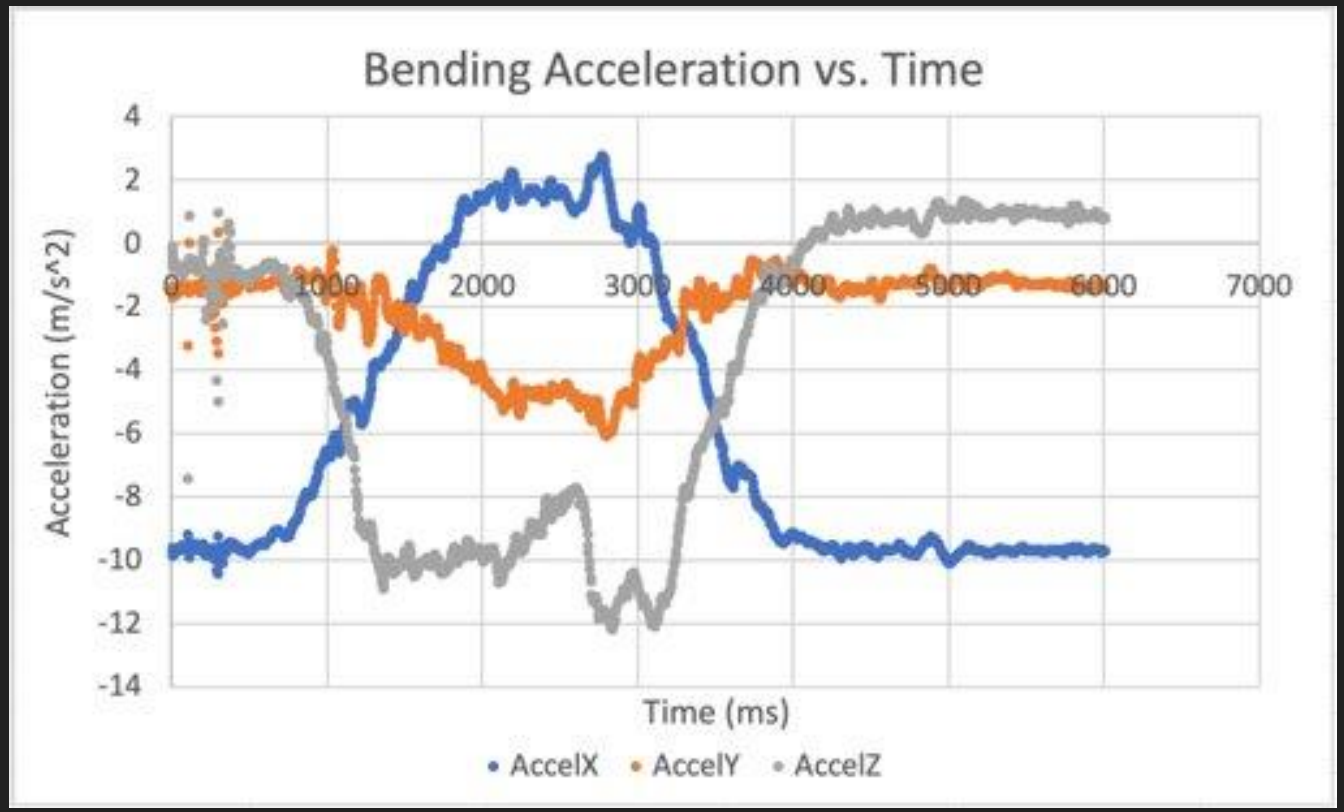


Sensing | Non-Fall Data





Sensing | Non-Fall Data



Sensing | Data Collection

- 9 DOF IMU measures:
  - Acceleration (m/s^2) along 3 principal axes
  - Angular velocity (deg/s) about 3 principal axes
  - Magnetic field (μT) along 3 principal axes

Product Specifications (MDR for reference)

Specification	Ideal Target	Minimum Target
Total Actuation Time	< 0.2 seconds	< 0.75 seconds
Coverage of Critical Zones	C1 – C7 Vertebrae	
Weight (NEW SPEC)	650g (based on Hovding)	
Neck Injury Criterion (NIC) Value	< 15 m^2/s^2	
CO_2 Cylinder Safely Constrained	WHMIS Gas Cylinder standards to be met	
Reusable / Rechargeable	Canister + Airbag	
Adjustable	95th percentile human	80th percentile human