Sidewalk Roughness Standards Development

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Human Engineering Research Labs

Mission: To continuously improve the mobility and function of people with disabilities through advanced engineering in clinical research and medical rehabilitation.

Personnel: clinicians (md, ot, pt) & engineers (ME, EE, CS, BioE)

Facilities: 30,000 SqFt (office space, clinical space, fab facility)

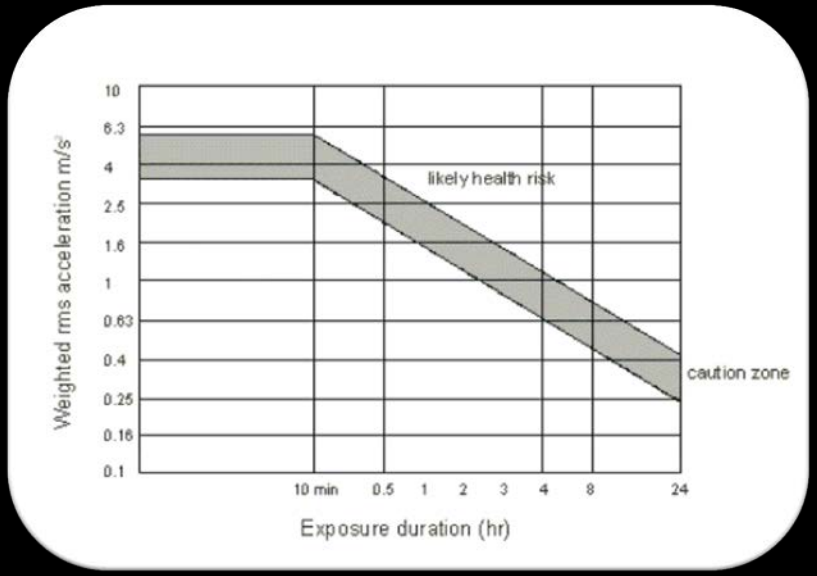
Funding: VA Center of Excellence, NSF, NIH, Dept of Ed., etc.

Major Activities: Clinical & technological interventions to improve the lives of PWD.

Motivation

Health Motivation (’90s)

- WC users are twice as likely to experience back and neck pain compared to the ambulatory population.
  - 60% of WC users report neck pain & discomfort
  - Postural issues are common among WC users
- Vibration Exposure Standards (ISO 10326 & 2631)
  - Provide Measurement techniques
  - Provide Exposure Thresholds



Related Research

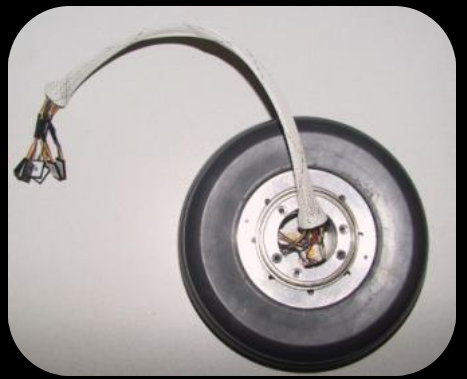
- **Roadloads (Van sickle ‘94,’96, ‘97, ’00,’04)**
  - Developed instrumentation to measure reaction force at caster and propulsion wheels of MWC & recorded data in-lab and in-home & during wheelchair testing.
- **Seating System Influence (DiGiovine 2000 & 2003)**
  - Influence of seating system on comfort and vibration exposure in-lab human trials
- **ICPI/BIA (Wolf, Cooper, Pearlman 2004 & 2007)**
  - Influence of surface features on vibration exposure
- **Suspension (MWC: Kwarciak; PWC: Wolf, 2008)**
  - Influence of suspension system on vibration exposure
- **Influence of Cushion (Pearlman, Garcia & Cooper, 2011)**
  - Characterization of the WC cushion transmissibility
- **Community Vibrations (Pearlman, Garcia & Cooper, 2012)**
  - Evaluation of MWC vibration exposure in the community

Roadloads

Research Question: What levels of vibration occur during WC use?

Methods

- Protocol: subject propel through obstacle course & in the community
- Dependent variables: reaction force at wheels and accelerations entering the body.
- Subjects: 16 MWC users over obstacle course & community, test-dummy during WC testing.



Roadloads (2)

Results

- **Mobility Course Data**: Accelerations at head & WC frame exceeded fatigue-decreased proficiency boundary.
- **Community Data**: Accelerations at WC frame greatly exceeded fatigue-decreased proficiency boundary

Conclusion: <u>Vibration levels are above safe and comfortable levels and may contribute to injury</u>.

ICPI/BIA

Research Question: How do surface characteristics of outdoor pathways influence vibration exposure?

Methods

- Protocol: traverse over sidewalk surfaces at 1m/s & 2m/s (PWCs only)
- Independent Variables: surfaces (poured concrete + 8 BIA/ICPI surfaces) & device (PWC & MWC)
- Dependent Variables: Acceleration & Dose Value
- Subjects: 10 able-bodied

ICPI/BIA Support

ICPI/BIA (2)

Results

ICPI/BIA surfaces can result in lower exposure than poured concrete

- Large bevel → increased accelerations
- 90deg herringbone better than 45 deg herringbone pattern

Conclusion: <u>Surface design important, influential and have measurable effect on vibration exposure to WC riders.</u>

45 deg

90 deg

	Manual Wheelchair	Power Wheelchair (1 m/s)	Power Wheelchair (2 m/s)
Surface 1	0.47±.07	0.37±.09	1.17±.21
Surface 2	0.32±.06 *	0.28±.06 *	0.60±.12 *
Surface 3	0.39±.07 *	0.33±.08	0.67±.12 *
Surface 4	0.76±.16 #	0.85±.19 #	0.89±.14 *
Surface 5	0.46±.09	0.33±.10	0.75±.15 *
Surface 6	0.47±.08	0.37±.09	0.90±.14 *
Surface 7	0.59±.09 #	0.59±.08 #	0.76±.10 *
Surface 8	0.78±.09 #	0.38±.05	0.89±.15 *
Surface 9	0.48±.06	0.40±.05	0.66±.08 *

Vibrations in the Community

Research Question: what are the levels of community exposure over long periods of time?

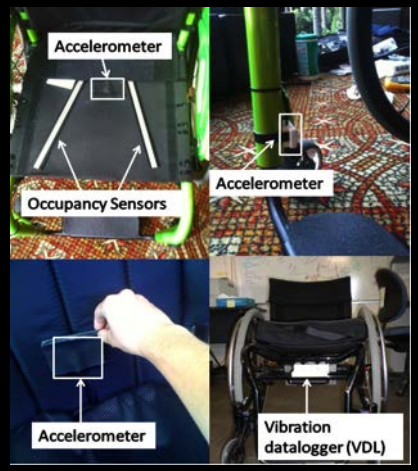
Methods:

Protocol: instrument and collect exposure data for ≥ 2 weeks.

Independent Variable: WC type (rigid, folding, suspension)

Dependent Variables: acceleration, dose, distance traveled

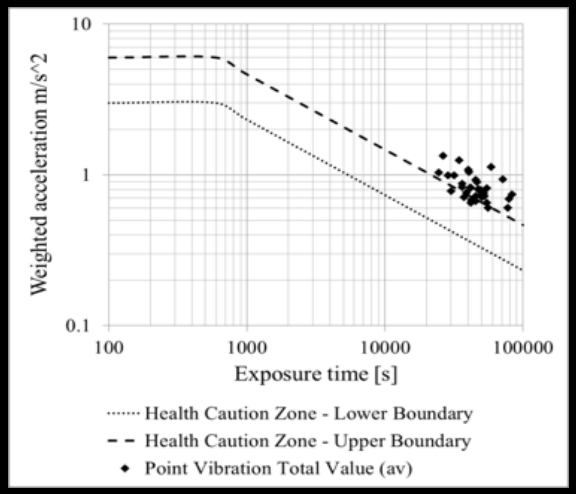
Subjects: 37 full-time MWC users



Vibration in the Community (2)

- Results
  - Exposure is mostly within or above caution zone
  - Results insensitive to WC type
- Conclusion: <u>WC riders nearly always exposed to risky levels of vibration</u>

	Health Caution Zone		
Site	% Below	% Within	% Above
Seat	0	30	70
Back	3	80	17

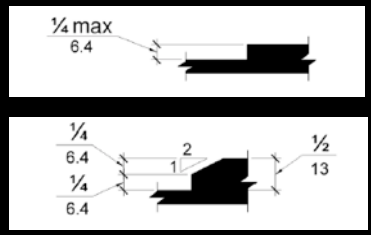


Regulations: ADA/ABA

- ADA/ABA
  - "physical or mental disabilities in no way diminish a person's right to fully participate in all aspects of society…"
  - "to provide a clear and comprehensive national mandate for the elimination of discrimination against individuals with disabilities and to provide clear, strong, consistent, enforceable standards addressing discrimination against individuals with disabilities."

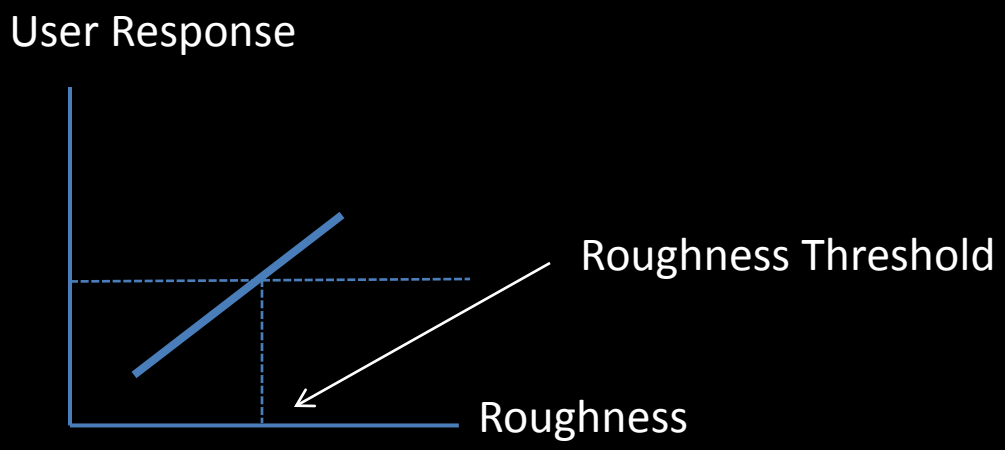
ADAAG

1. Surfaces should be stable, firm & slip-resistant
2. Running slope: 1:20
3. Cross-slope: 1:48
4. Level changes: ¼”or ½” with bevel
5. Surface Roughness



Goals of A/B Project

1. Characterize relationship between surface roughness and user-response
2. Develop ‘threshold’ roughness which is both comfortable and safe for users
3. Promote threshold and relevant measurement techniques through publications and standards: A/B Website, ASTM Standards, etc.



Timeline

Y1: Oct ‘10 – Sept ‘11

- Literature Review
- Study design

Y2: Oct ‘11 – Sept ‘12

- Data collection (2/3 complete)

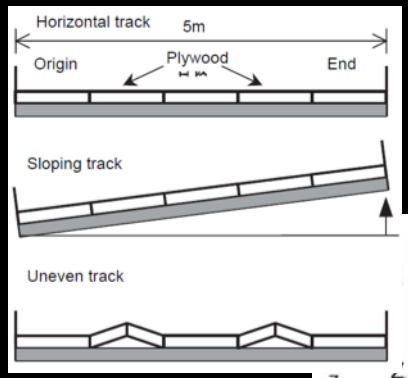
Y3: Oct ‘12 – Sept ‘13

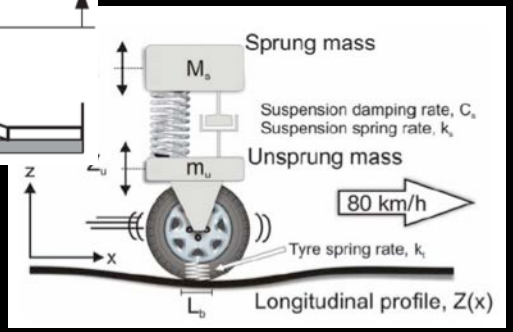
- Data collection complete
- Standard Development

Literature Review

Background Information Gathered

1. Consequences of vibration exposure
2. Roadway roughness measurement & analysis techniques
3. ADAAG topics relevant to sidewalk roughness
4. Wheelchair-related work within above topics





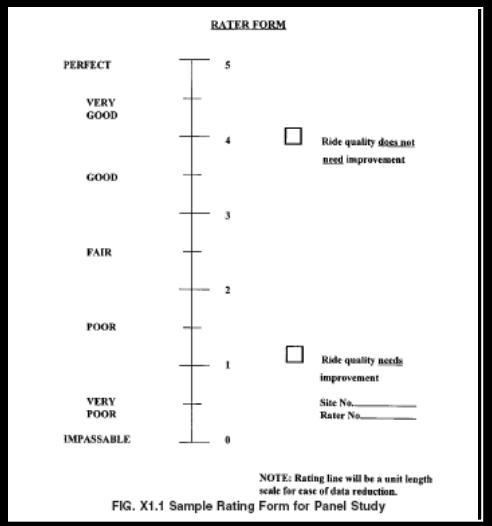
Analysis Techniques	Advantage	Disadvantage
International Roughness Index (IRI)	Internationally recognized, stable, portable, linear	Long measures don't allow localized detail
Power Spectral Density (PSD)	Describes types of roughness by using wavelengths and amplitudes	Long measures don't allow localized detail
Present Serviceability Index (PSI)	High level of precision and attention to detail	Subjective Measurements, Requires many man-hours to complete

Study Design

Intervention: subjects propel over surfaces

Outcomes: subjective feedback (ASTM 1927), acceleration, roughness index

Analysis: correlations between outcome variables


RATER FORM

PERFECT 5

VERY GOOD 4

GOOD

FAIR 3

POOR 2

VERY POOR 1

IMPASSABLE 0

Ride quality does not need improvement

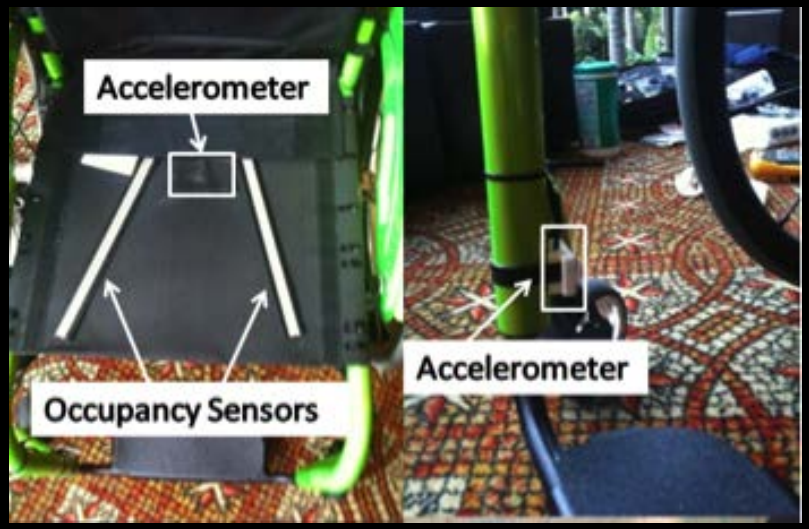
Ride quality needs improvement

Site No._____

Rater No._____

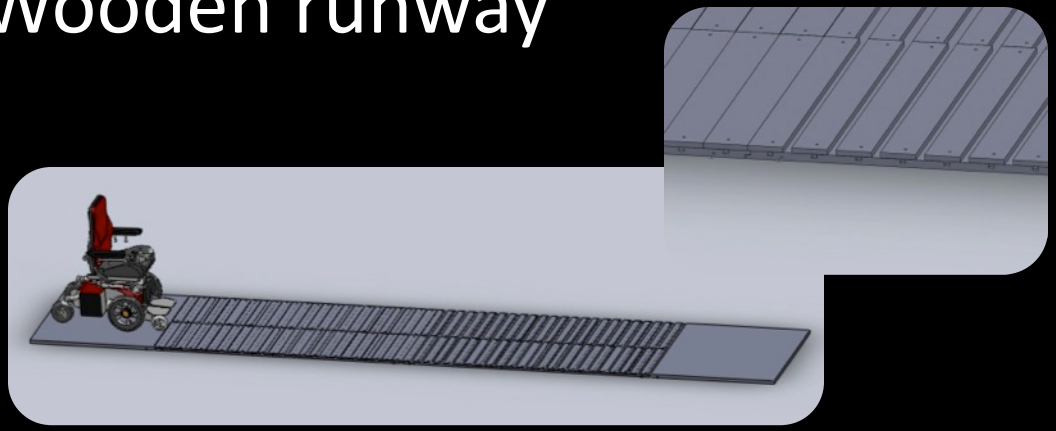
NOTE: Rating line will be a unit length scale for ease of data reduction.

FIG. X1.1 Sample Rating Form for Panel Study



Simulated Surfaces

Wooden runway



Surface	Roughness Index (in/ft)⁺:	Crack Frequency (in)⁺:	Crack Width (in)⁺:
1	0.20	No cracks	0
2	0.29	12	0.80
3	0.36	8	0.80
4	0.53	12	1.25
5	0.53	4	0.80
6	0.66	8	1.25
7	0.84	8	1.55
8	1.01	4	1.25
9	1.36	8	2.00

Community Surfaces

Research Protocol

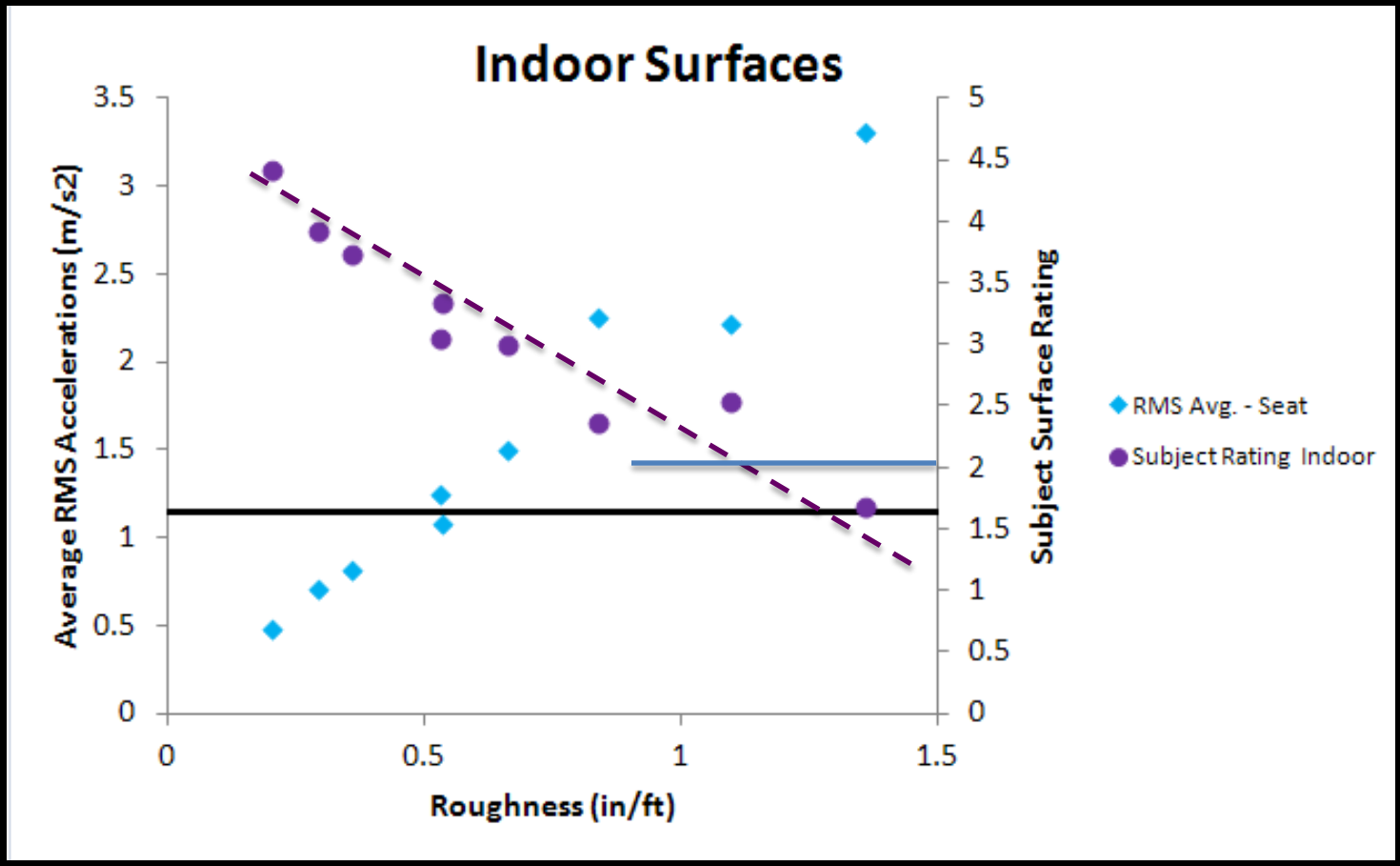
1. Informed Consent (20 min)
2. Demographics Questionnaire (30 min)
3. Simulated Surfaces (9) Driving (60 min)
4. Outdoor Surfaces (6) Driving (60 min)

- Driving Protocol:
  - Drive over each surface 3 times
  - Answer Subjective Questionnaire

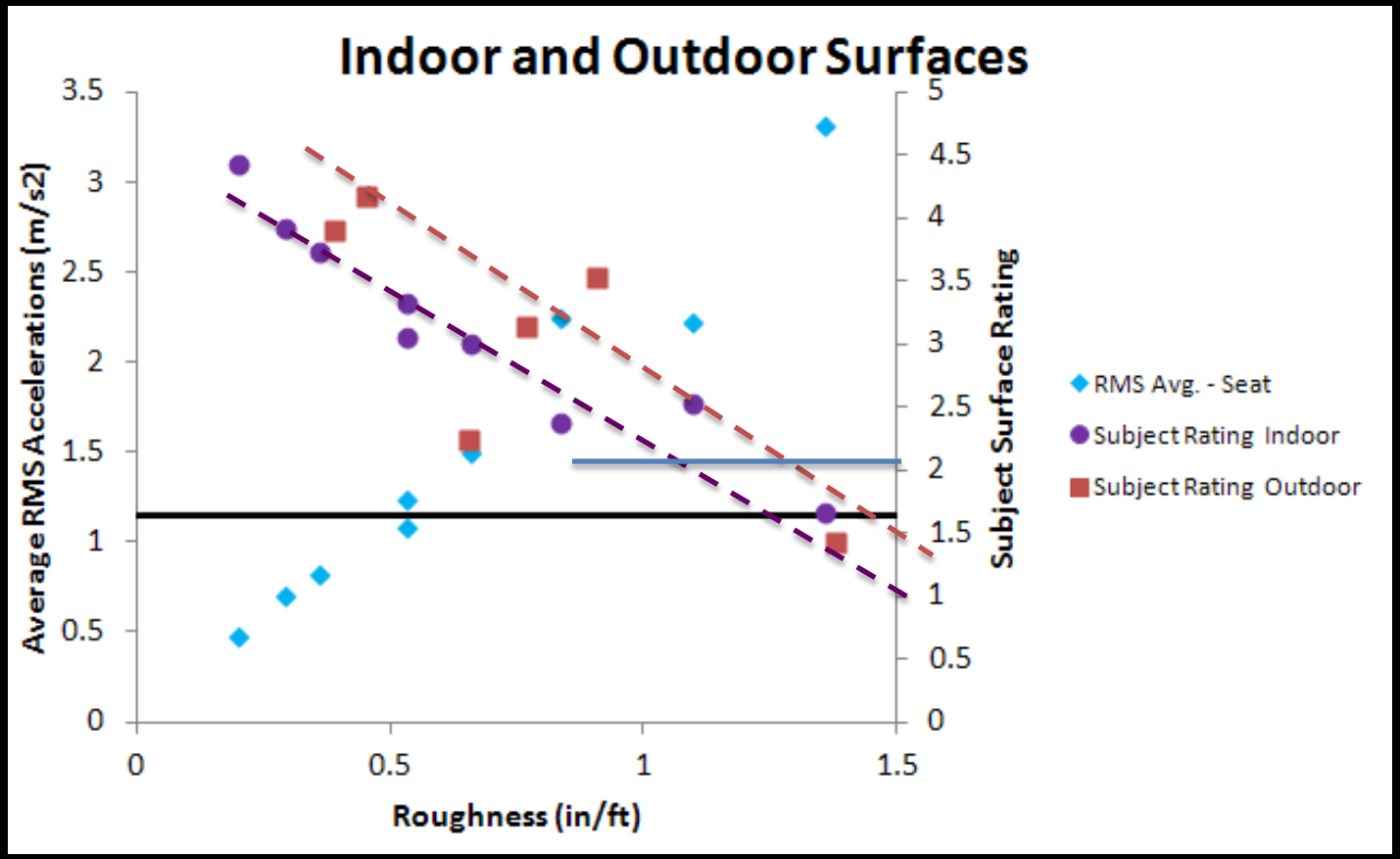
Research Progress

- 54 Subjects
  - 40 males; 14 females
  - 29 manual wheelchairs; 25 power wheelchairs
- 85% reported spending ≥6hrs/day in wheelchair
- 45% of subjects were unsatisfied with the pathways on which they typically travel
  - Damaged/Warped was the biggest complaint

Results


Indoor Surfaces
Average RMS Accelerations (m/s2)
Subject Surface Rating
Roughness (in/ft)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
RMS Avg. - Seat
Subject Rating Indoor

Results


Indoor and Outdoor Surfaces
Average RMS Accelerations (m/s2)
Subject Surface Rating
Roughness (in/ft)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
RMS Avg. - Seat
Subject Rating Indoor
Subject Rating Outdoor

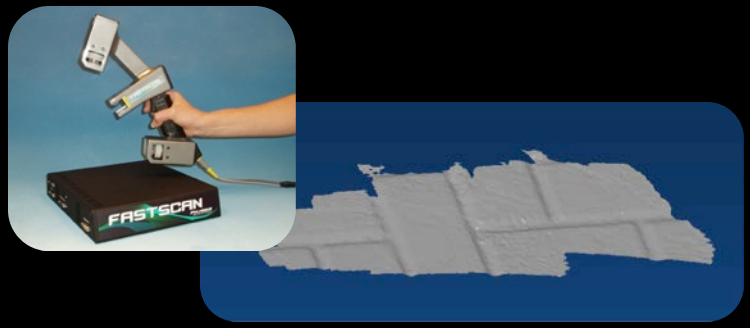
How We Characterize Surface Roughness

- Where the pathway measurement tool (PathMET) comes in

Prototype Instrumentation

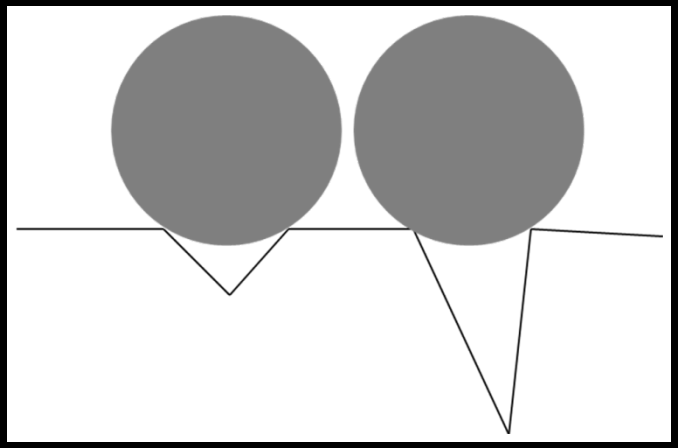
Instrumented Wheelchair

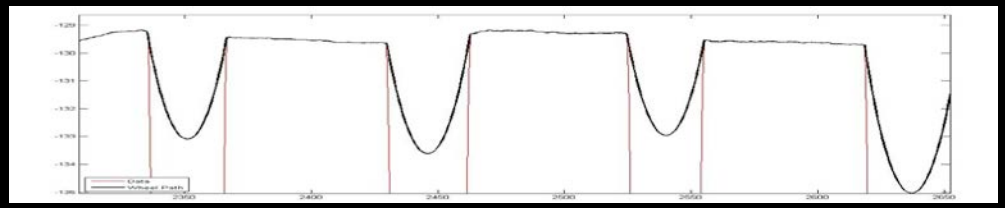
Laser Scanner



Algorithm Work

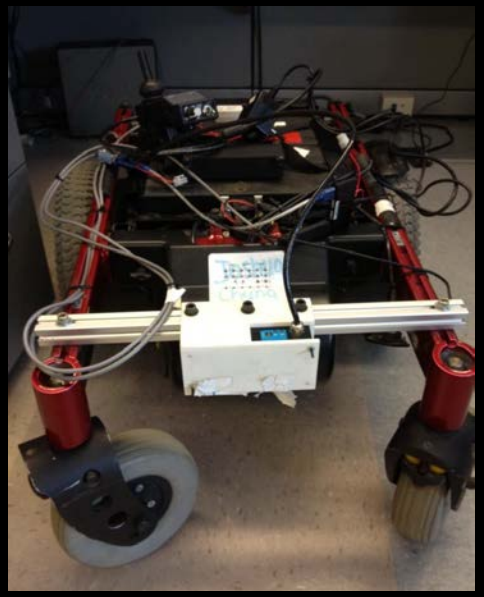
- Sidewalk Roughness Index (in/ft)
  - Summed vertical deviations for a given horizontal distance
- A wheel path algorithm developed to determine vertical motion of a wheel (x diameter) surface profile





PathMET (1.0)

- power-wheelchair base
  - Walk-behind
  - High-resolution laser (<1mm)
  - Encoder on wheels



- System is sufficient for A/B study, but may not easily be translatable industry use

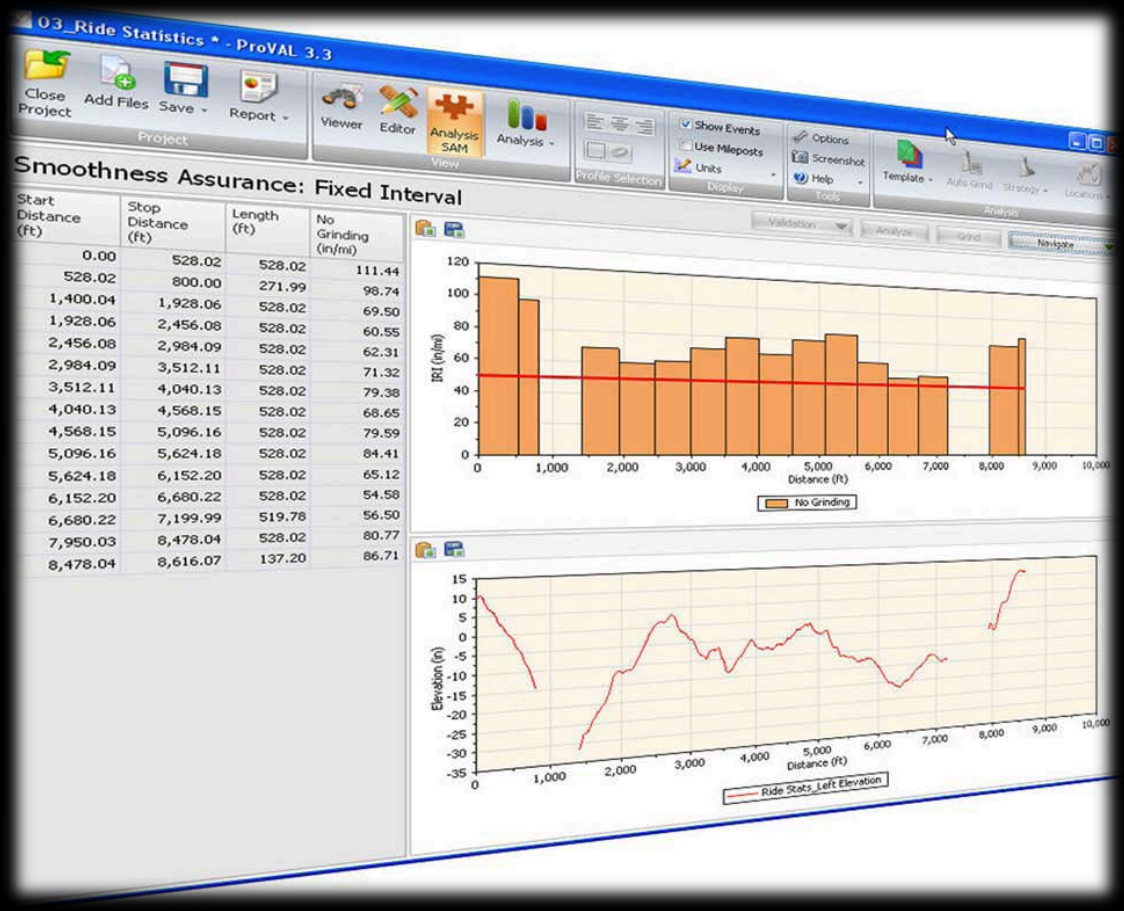
PathMET Data Collection

PathMET Work

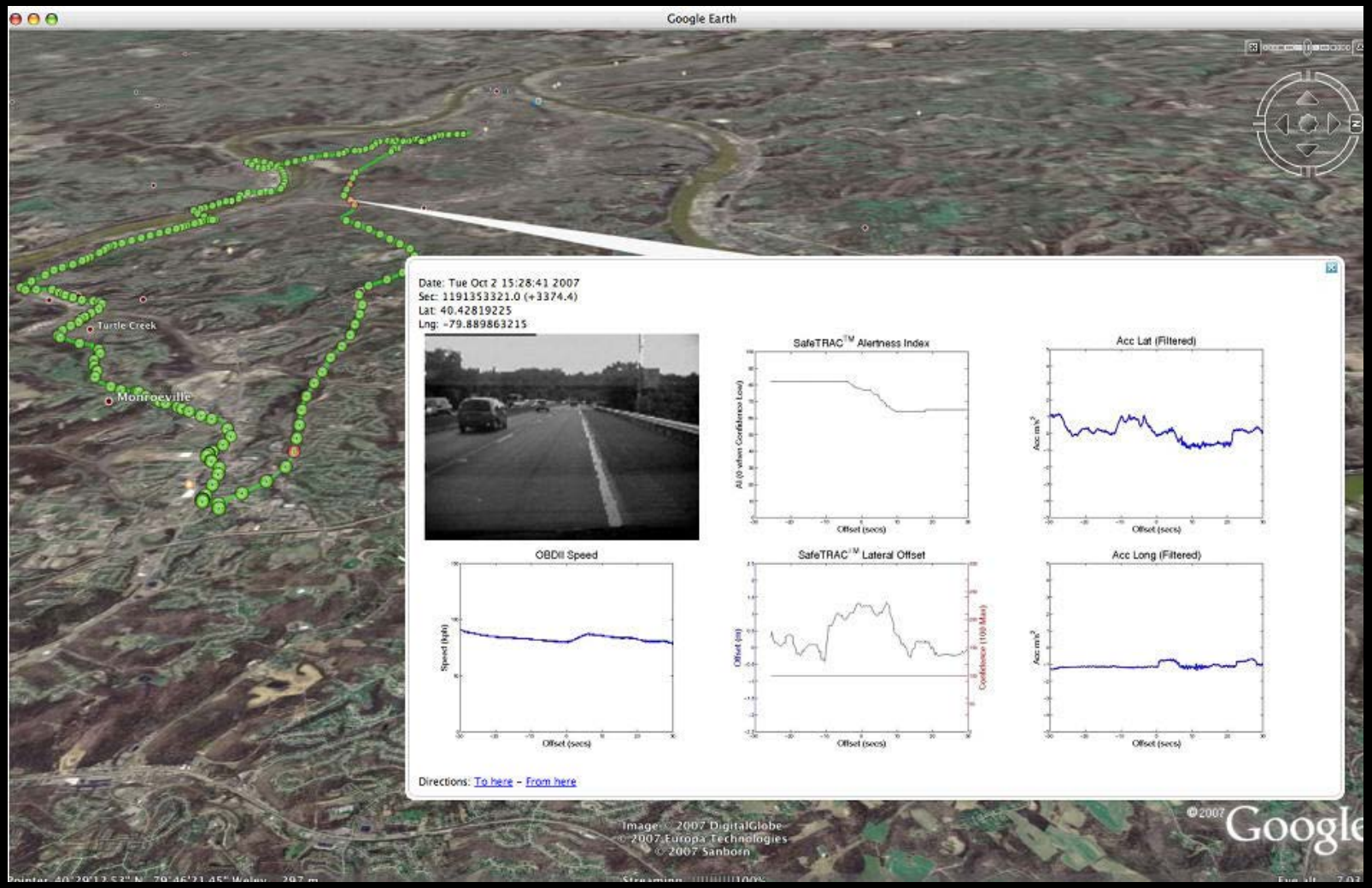
- Development of a Pathway Measurement Tool (PathMET), Funded by ICPI/BIA.
- Basic Timeline (12 Month)
  - Aug: Project Initiated
  - Now: ongoing design work
  - Dec: Hardware and Software Design Review
  - April: Fabrication and Basic Testing Complete
  - June: Final Validation Complete
  - August: Final report, Find Commercial Partner

Exploring Mechanical Design

Software Integration: ProVAL



Software Integration: Google Maps



My Questions…

- Potential commercial partners for PathMET?
- Can ProVAL be modified to analyze our data?
- Can we integrate sidewalk roughness into pavement management systems?

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Acknowledgements & Questions

- Funding: Access Board, Dept. of Ed, VA, & ICPI/BIA
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- Staff: Emily Teodorski, Josh Brown, Zack Mason, Mark McCartney

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