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Zero Velocity Detection in Foot-mounted Inertial Sensors: Novel method for generating zero velocity labels and a comparative analysis of data driven methods

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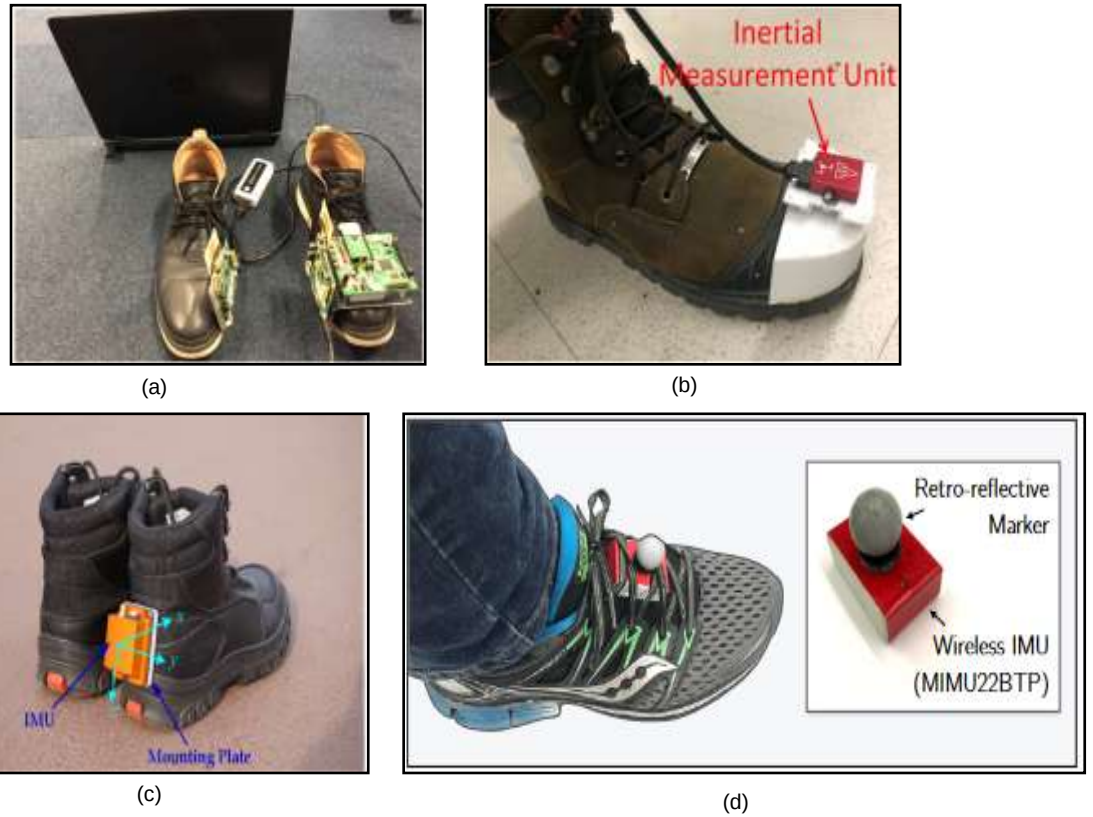
Foot mounted Systems: Positioning in Indoor Environment

- Applications:
  - Indoor navigation
  - Indoor Mapping
  - First responder positioning etc.
- Sensors are mounted on user's foot in foot mounted systems.
- Most used sensor : Inertial Measurement Unit (IMU).
  - But its observations consists of noise and bias.
  - Measure used to remove these effects:
    - Zero velocity update



(a) (b) (c) (d)

Figure 1: Foot mounted Systems used in various works (a) Zeng et al., 2017, (b) Wang et al., 2017, (c) Tian et al., 2016, (d) Wagstaff et al., 2017

Zero Velocity Update (ZUPT)

- It applies a constraint on IMU observation.
- Reduces error in position from cubic to linear.

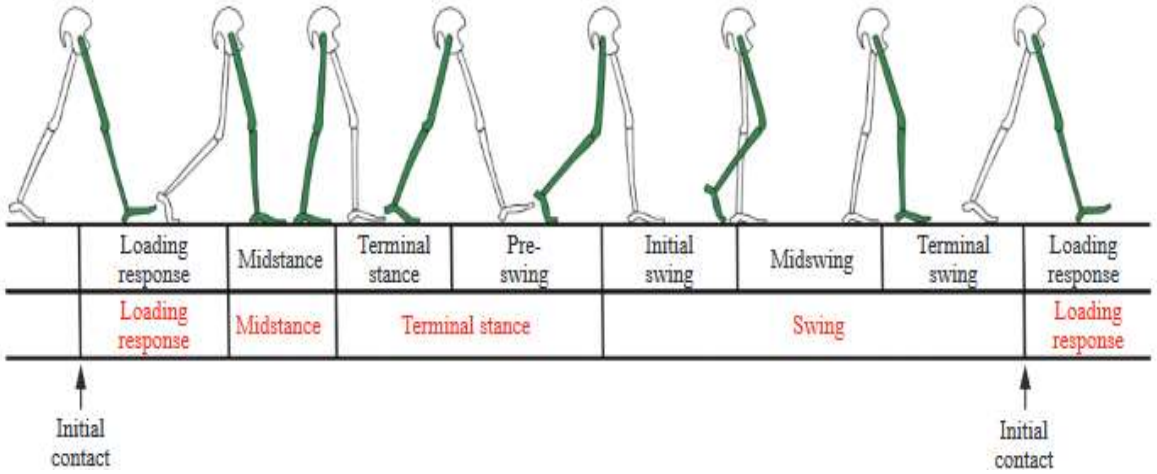


Figure 2: Eight Phases of gait cycle (Wahlstrom and skog et al., 2020)

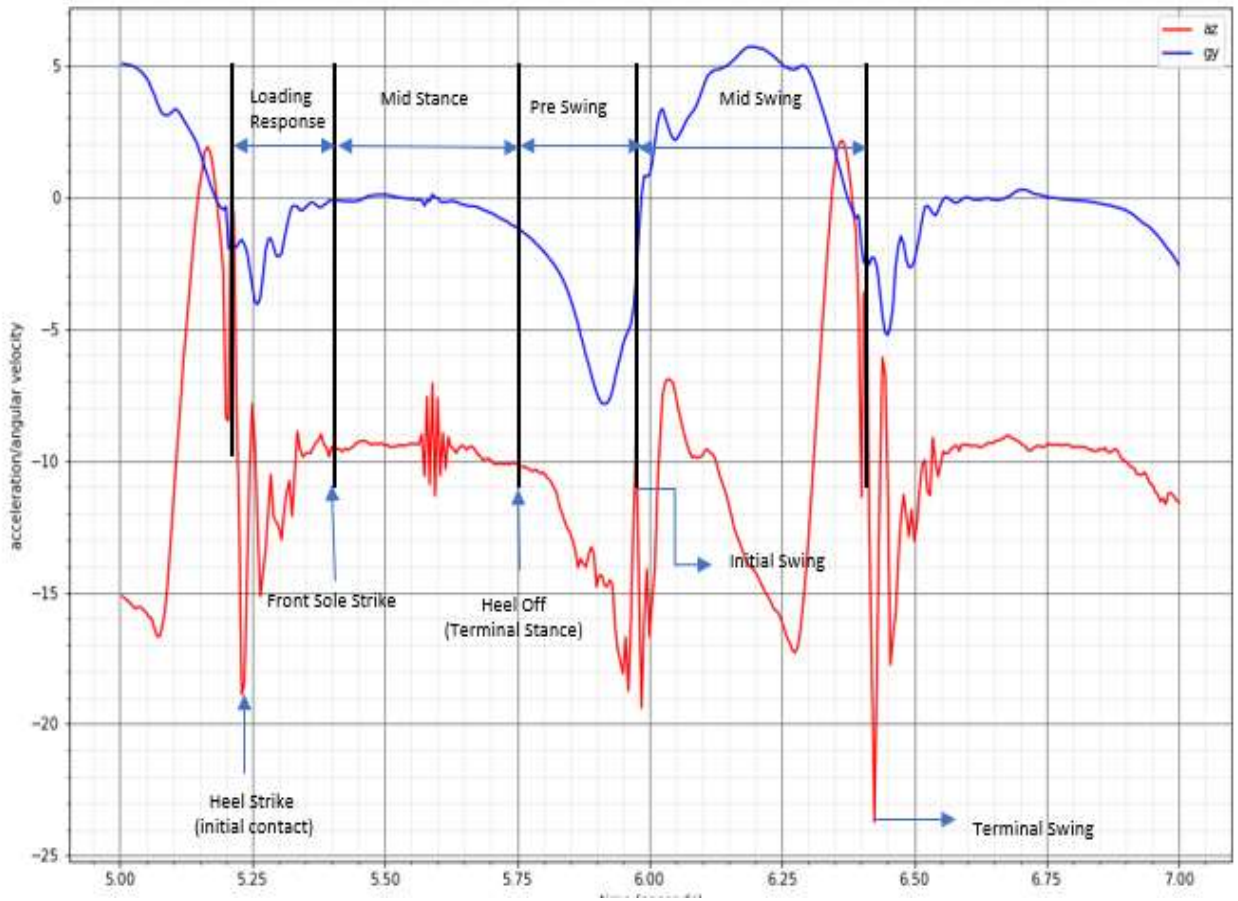


Figure 3: Eight Phases of gait cycle in IMU signal

Methods to perform Zero velocity Detection

- Threshold based approaches: (AMVD,ARED,AMD,SHOE)
  - Works very well in case of single motion.
  - Fails in case of variable motion.
- Learning based approaches: (Machine learning and deep learning based methods)
  - Generates a more generalised model which can work in all scenarios.
  - Requires a large amount of dataset for training the model.

Current publicly available datasets

- PyShoe (Wagstaff et al., 2017): Foot mounted sensor based
  - Ground truth available.
  - Labelling strategy is a little flawed.
- RIDI (Yan et al., 2017): Smartphone based
- WISDM (Kwapisz et al., 2011): Smartphone based
- RuDaCoP (Bayev et al., 2019): Smartphone based
- Foot SLAM dataset (Whalstrom et al, 2020): Foot mounted sensor based
  - Ground truth not available

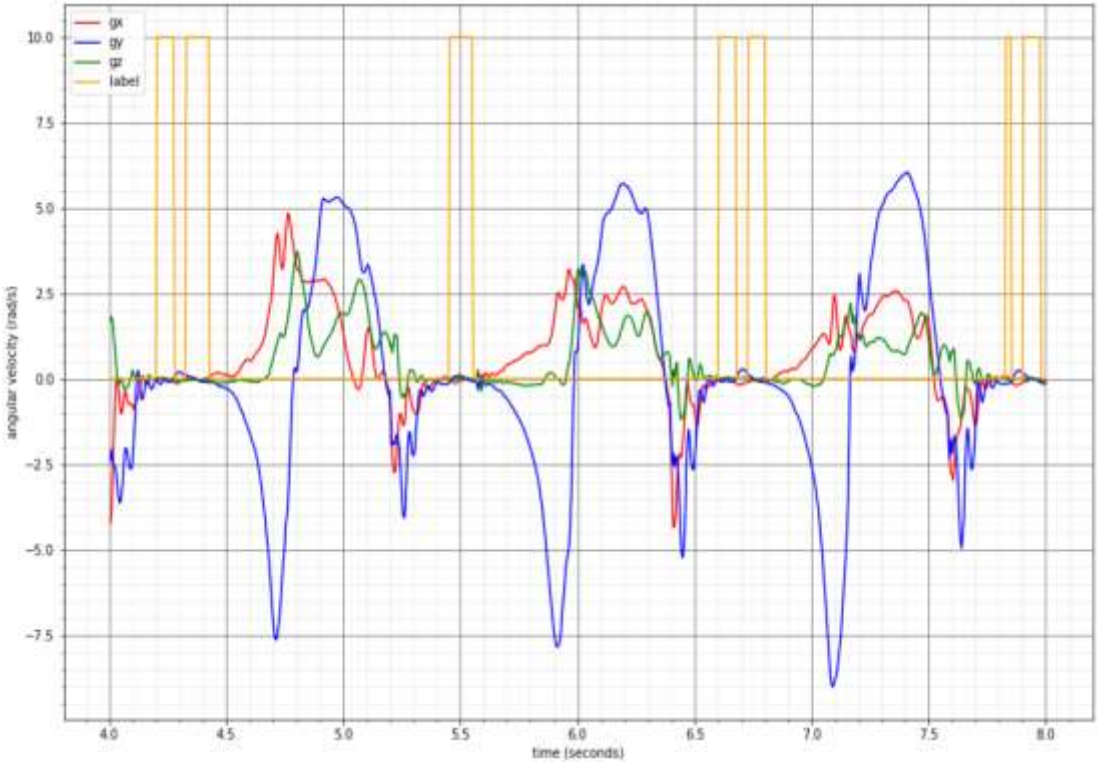


Figure 4: Labelled PyShoe dataset (Wagstaff et al., 2017)

Problems with current dataset and labelling strategy

- Current available dataset are not highly comprehensive (they do not contain variation of subjects and motion classes).
- Mostly available dataset are smartphone based.
- Foot mounted dataset are very less in number and not highly comprehensive.
- Labels are not available for some of the foot mounted datasets.
- Labelling strategy used in foot mounted dataset is not correct and usually highly expensive (computationally or economically).
- Additional sensors are also used but those datasets are not publicly available.

Our Contribution:

- A novel setup
- Proved hypothesis that the minimum distance between the foot lies in the midstance phase.
  - Two experiments were conducted with three subjects on different surfaces.

Subject	Sex	Height
1	Male	168 cm
2	Female	150 cm
3	Male	175 cm

Table 1: Demographics of the subjects

- Comparative analysis of data driven approaches on publicly available dataset.

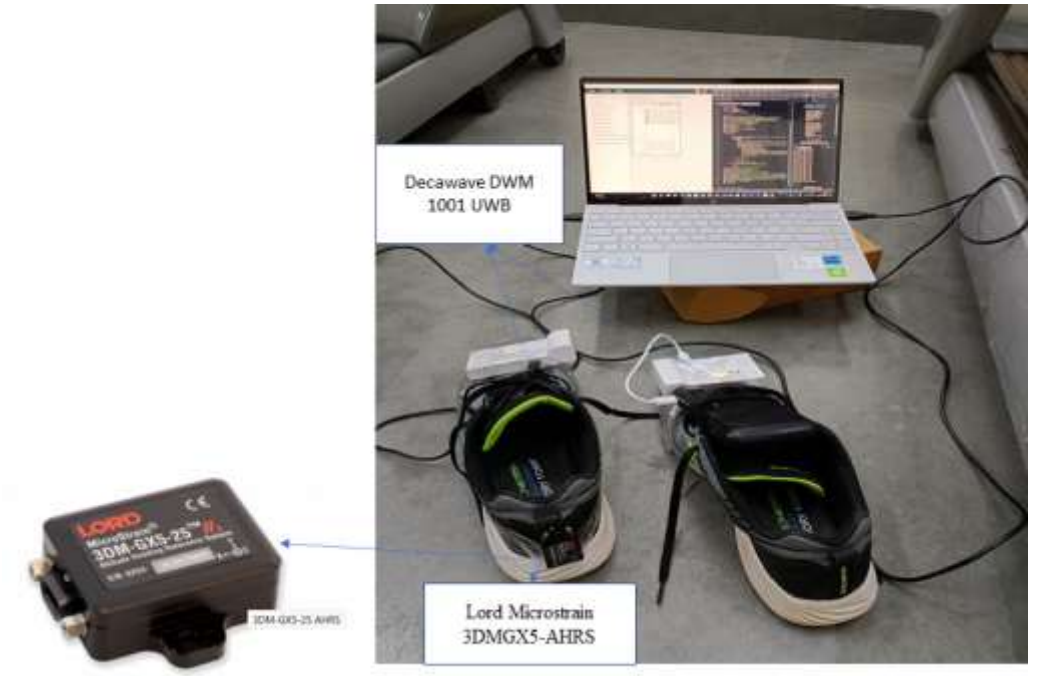


Figure 5: Our Setup (Consisting of one IMU and two UWB sensors)

Variation of distance between foot during walking motion

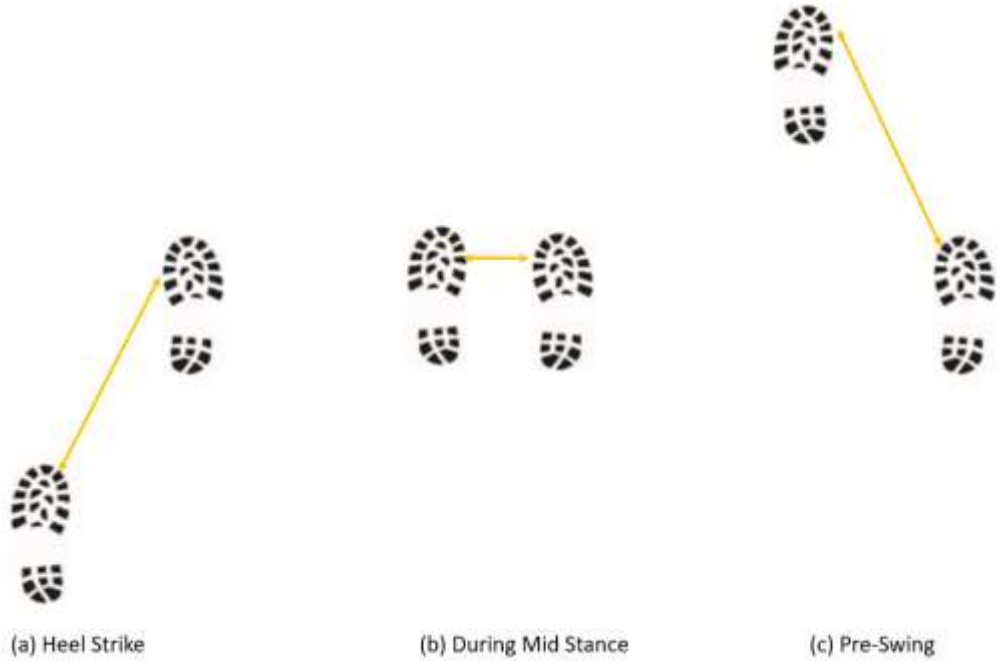


Figure 6: Variation of distance between feet during different events(Theoretically)

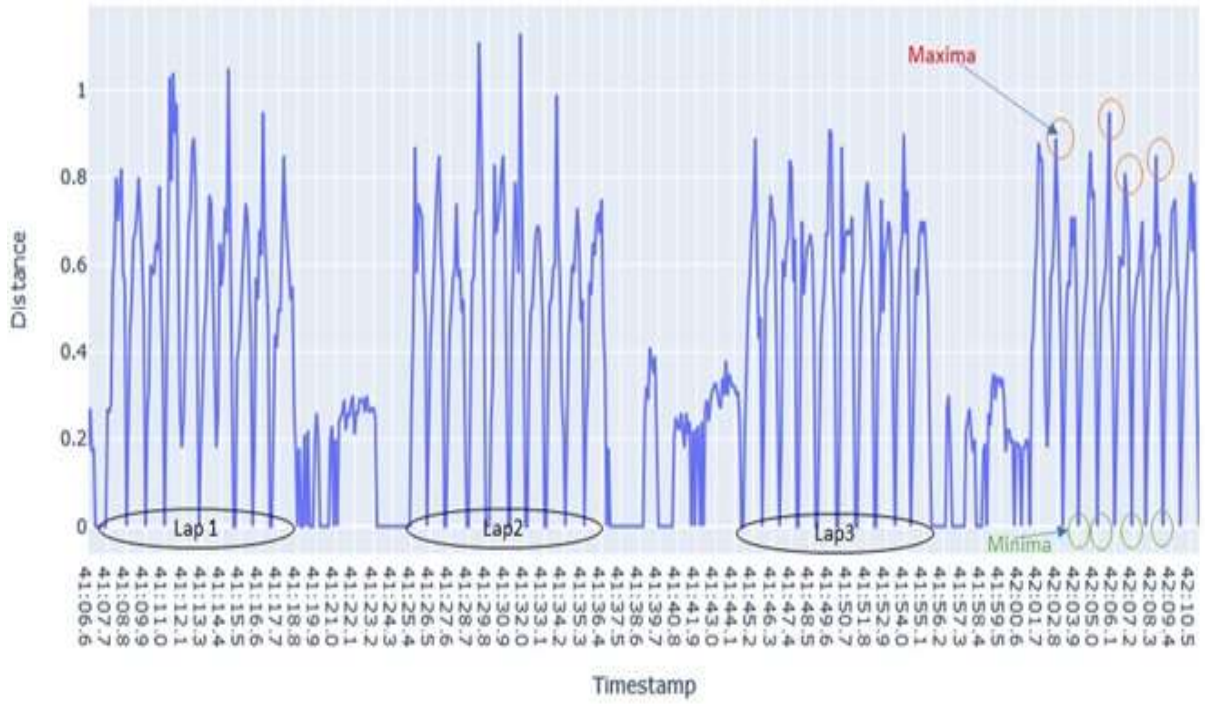


Figure 7: Variation of distance between the feet during motion (Experimentally)

Experiments

Experiment 1: On flat surface

Subject	Sex	Steps Taken	Step Length
1	Male	53	55 cm
2	Female	36	60 cm
3	Male	43	65 cm

Table 2: Experiment 1: Steps taken by each subject

Experiment 2: On Treadmill

Subject	Sex	Steps Taken	Avg. Step Length	Time taken
1	Male	107	60 cm	3 minutes
2	Female	170	40 cm	3 minutes
3	Male	97	45 cm	2 minutes

Table 3: Experiment 2: Steps taken by each subject

Results

Figure 8: Experiment 1 results

Figure 9: Experiment 2 results

Comparison of Data driven methods:

- 5 methods were applied to pyshoe dataset.
- Two types of motions (walking and running) are considered.
- For threshold method for mixed motion, threshold selected was taken from Wagstaff et al., 2017.
- Out of all models, hybrid model CNN-LSTM performed best.

Metrics (%)	LSTM	CNN	CNN-LSTM	SVM	SHOE
Accuracy	92.3%	93.08%	94.64%	89.89%	93.73%
Precision	93.04%	94.19%	94.99%	78.42%	99.27%
Recall	92.19%	92.43%	94.26%	90.83%	84.18%

Table 4: Comparison of data driven and fixed threshold-based method on PyShoe dataset

Conclusion

- Minimum distance between the feet occurs twice in a single gait cycle.
- It occurs alternatively during the midstance phase.
- It can be used as a basis to generate a labelling technique for zero velocity detection.
- Hybrid models perform better for zero velocity detection as compared to single and threshold based models.

Thank You

For your kind attention!