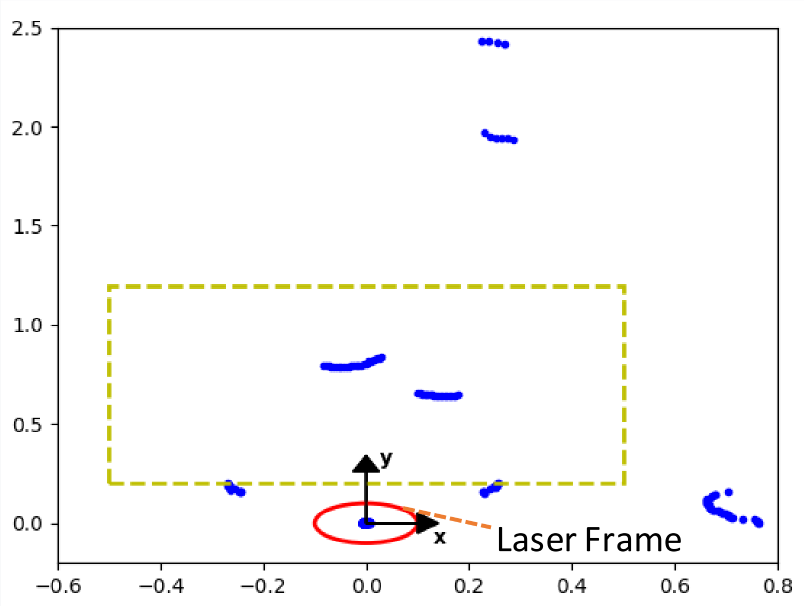
LTGADnet

Deep Leg Tracking by Detection and Gait Analysis in 2D Range Data for Intelligent Robotic Assistants



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LTGADnet Motivation

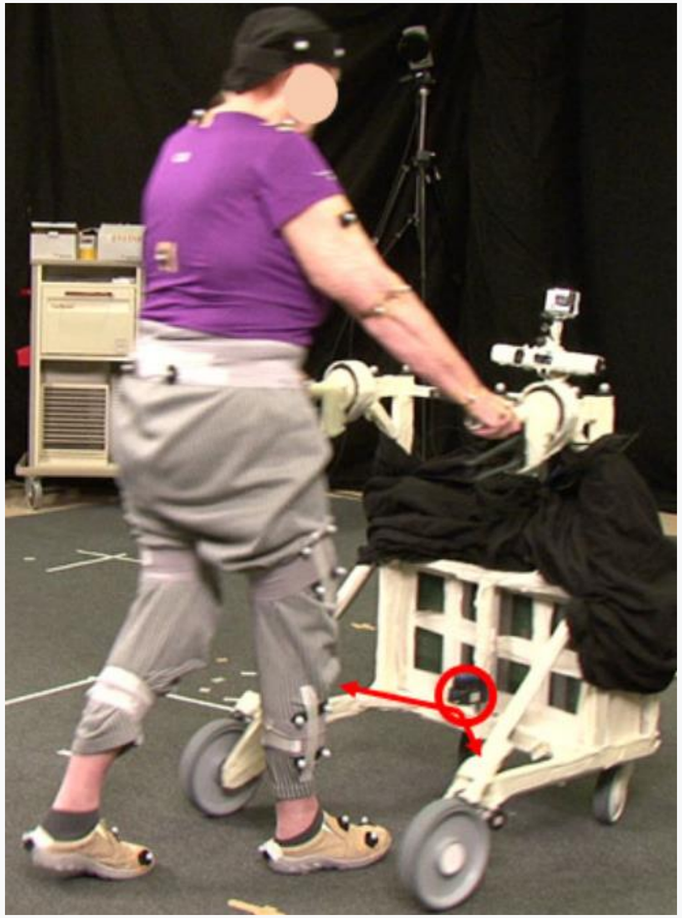
General Idea:

- Intelligent robotic rollators
- Adaptive to the patient’s needs
- Fall prevention, rehabilitation, etc.

Such robotic assistant could use:

- Algorithm for Leg Tracking and Gait Analysis
- Input data from simple 2D LiDAR due to fast scanning at low cost

LTGADnet Motivation

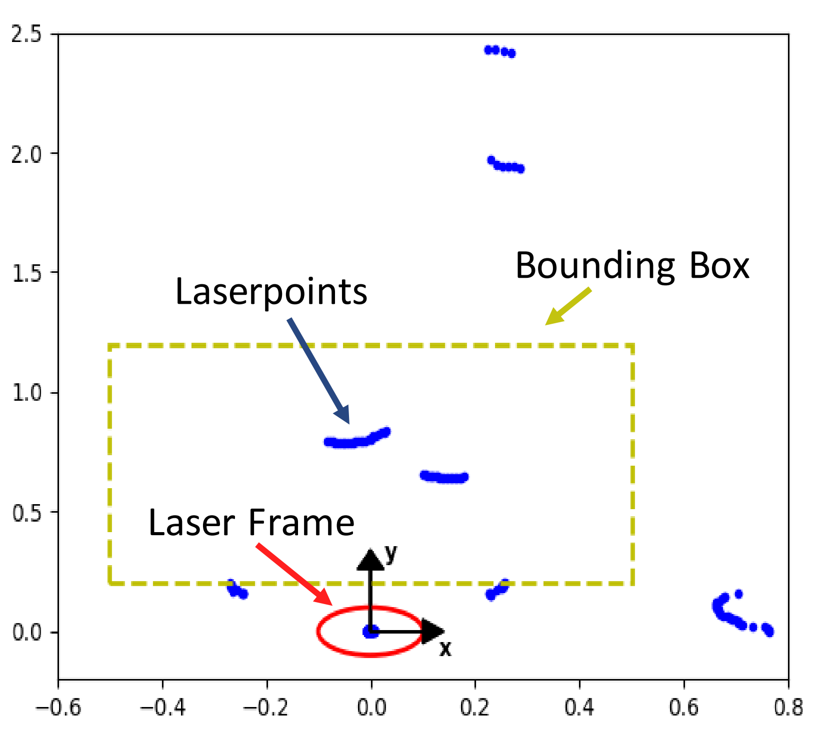


MOBOT - IRAL

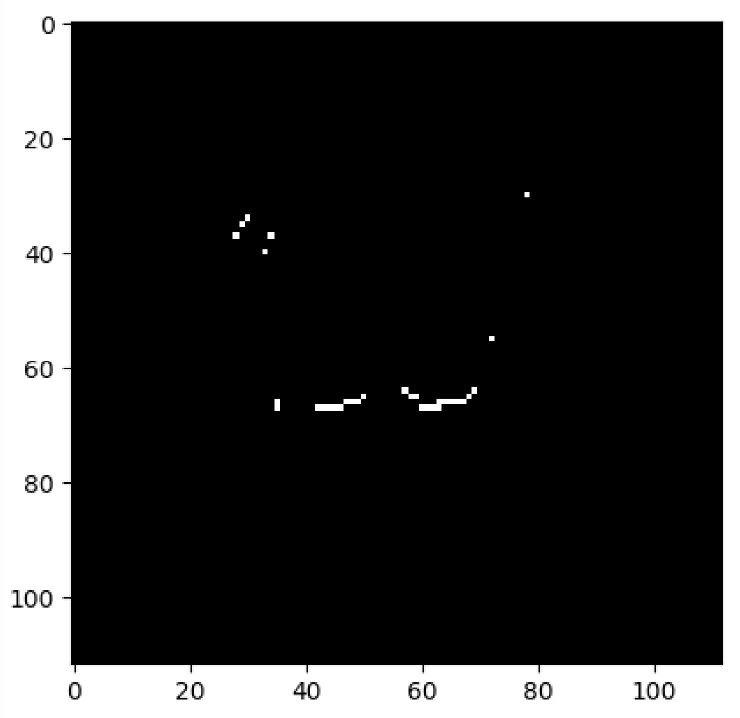
i-Walk - IRAL

- Existing algorithm: Interactive Multiple Model and Particle Filters
- Laser position at ~35cm above ground, scanning patient's tibia
- Slow due to the use of Particle Filters
- Need for faster algorithm, able to follow the laser's FPS
- Solution: Neural Networks

LTGADnet Dataset



Laser output as (x, y) points



Occupancy grid

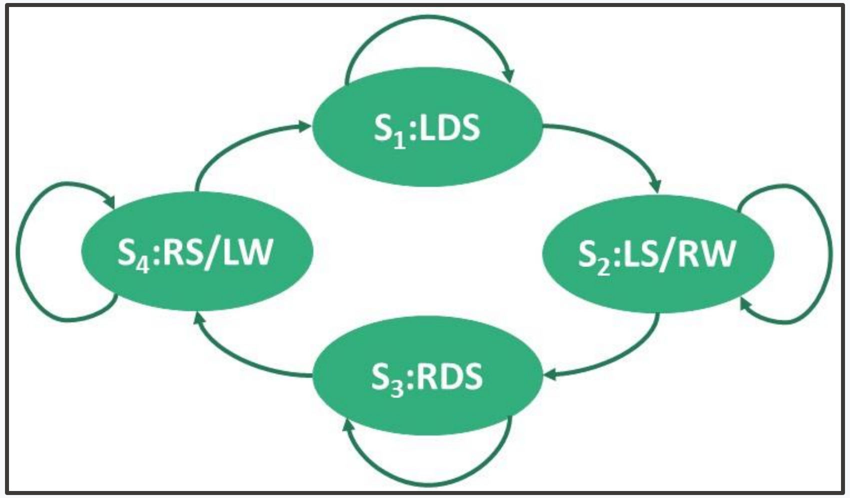
- Laser output mapped to (x, y) points
- Only points lying in bounding box (-0.5m, 0.5m) are kept, to exclude all objects except patient's legs
- Remaining points are transformed into an 112x112 occupancy grid, which will be the network's input

LTGADnet Dataset

Gait States

State Code	Code Name	Definition
s_1	LDS	Left Double Support
s_2	LS/RW	Left Swing/Right Stance
s_3	RDS	Right Double Support
s_4	RS/LW	Right Swing/Left Stance

State Markov Chain

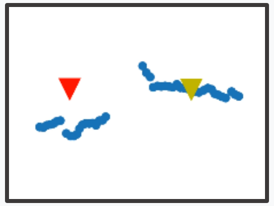


Problems:

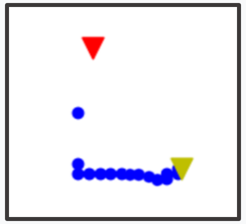
- Untrustworthy annotations
- Not enough frames of leg occlusions
- Small number of frame sequences for gait analysis

Solution:

1. Data augmentation (mirroring and shifting)
2. Computer Generated Data

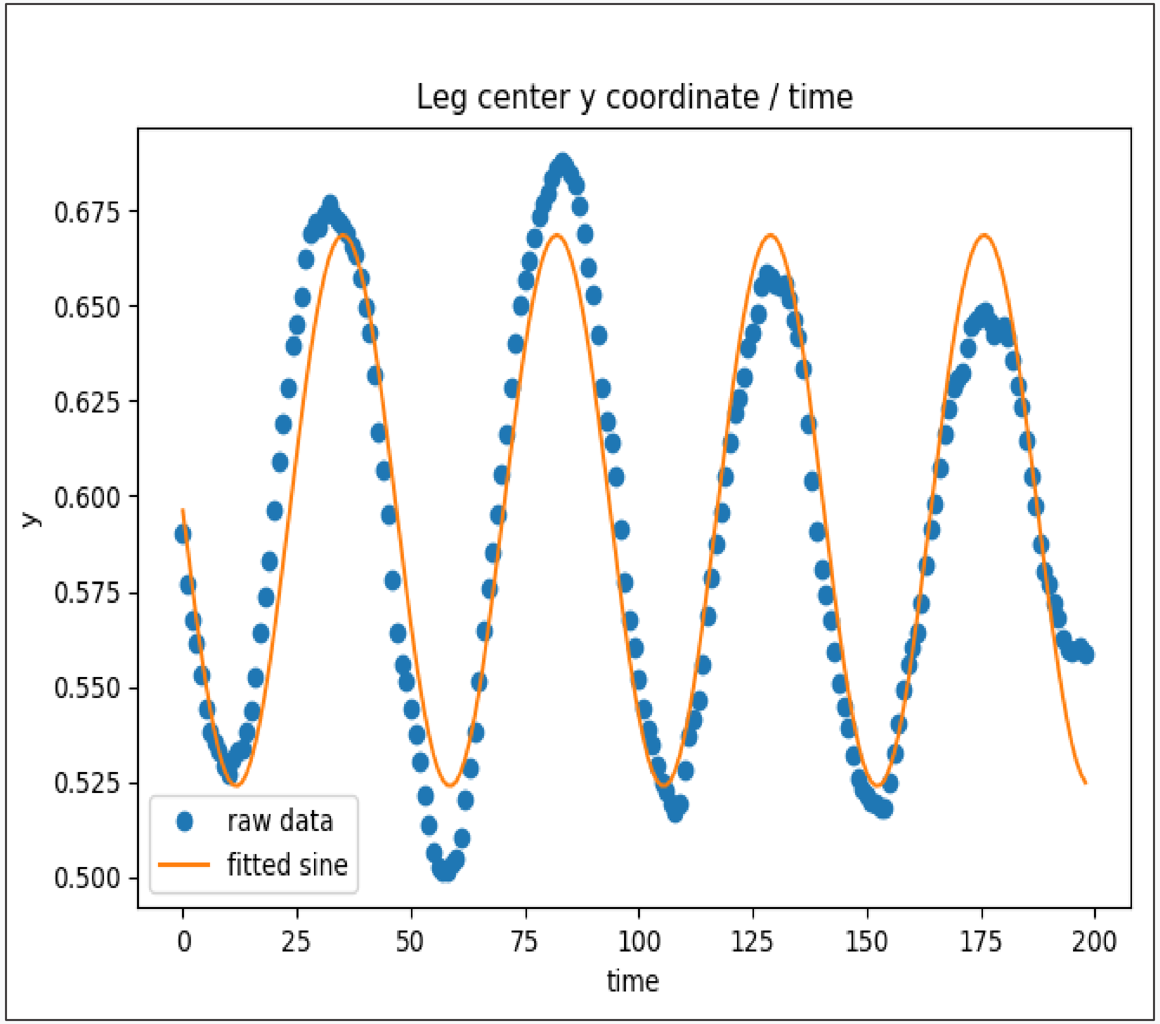


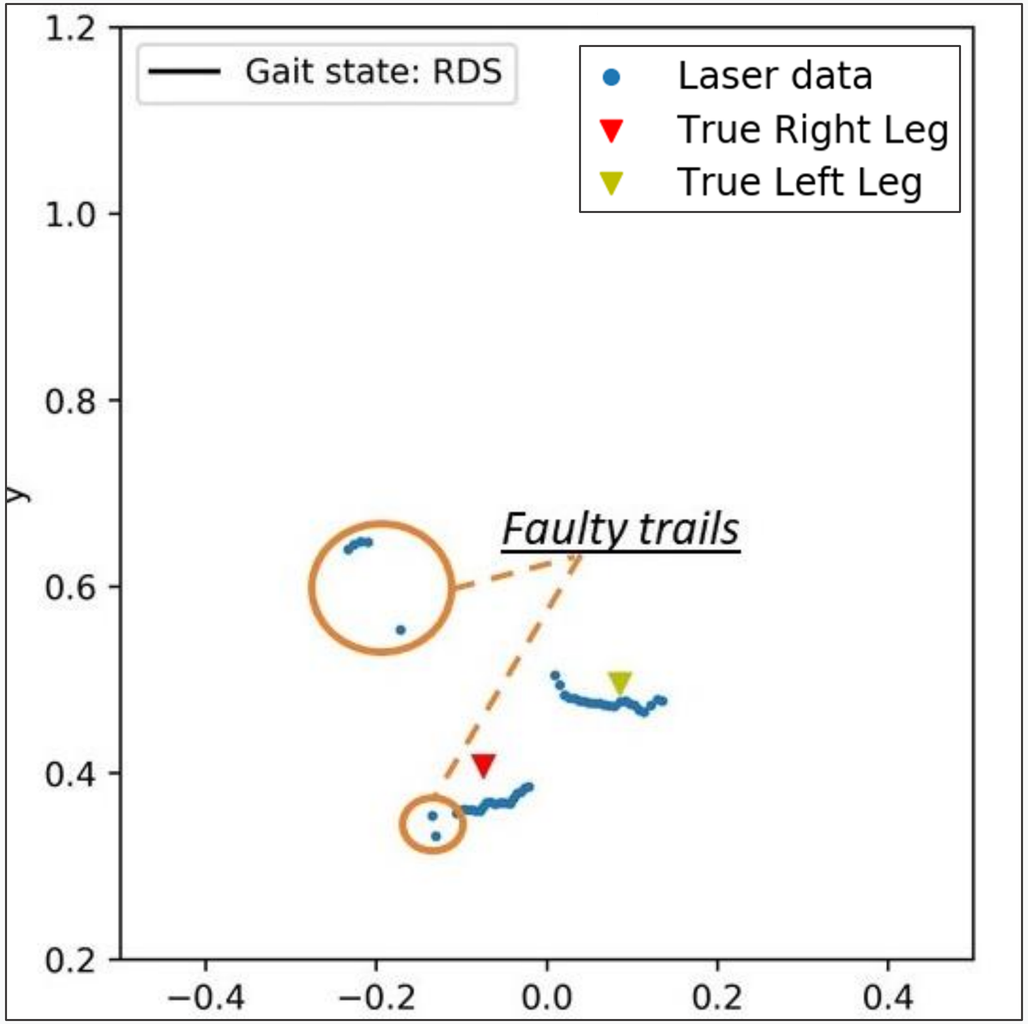
False annotation



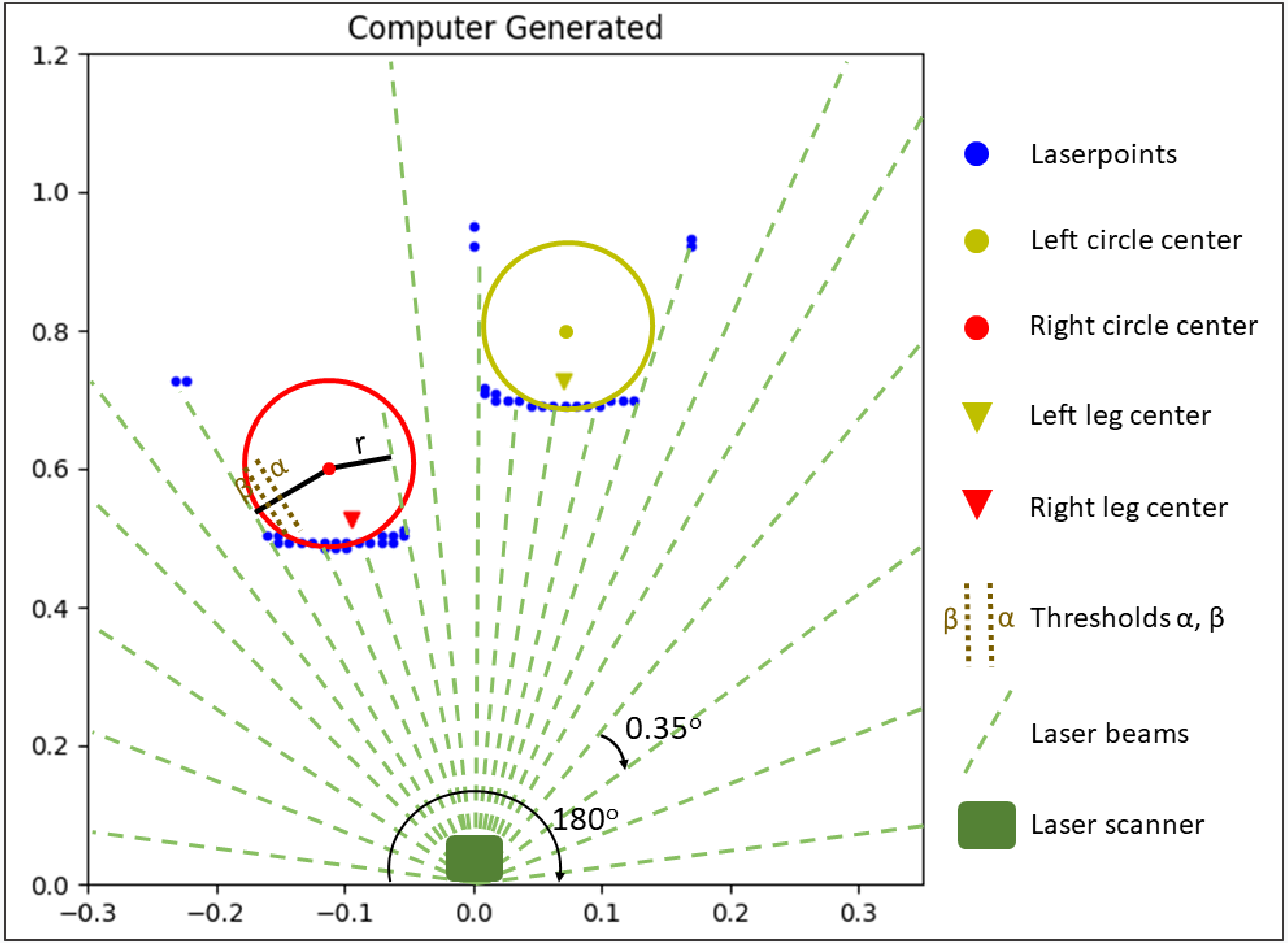
Leg occlusion

LTGADnet Dataset





LTGADnet Dataset



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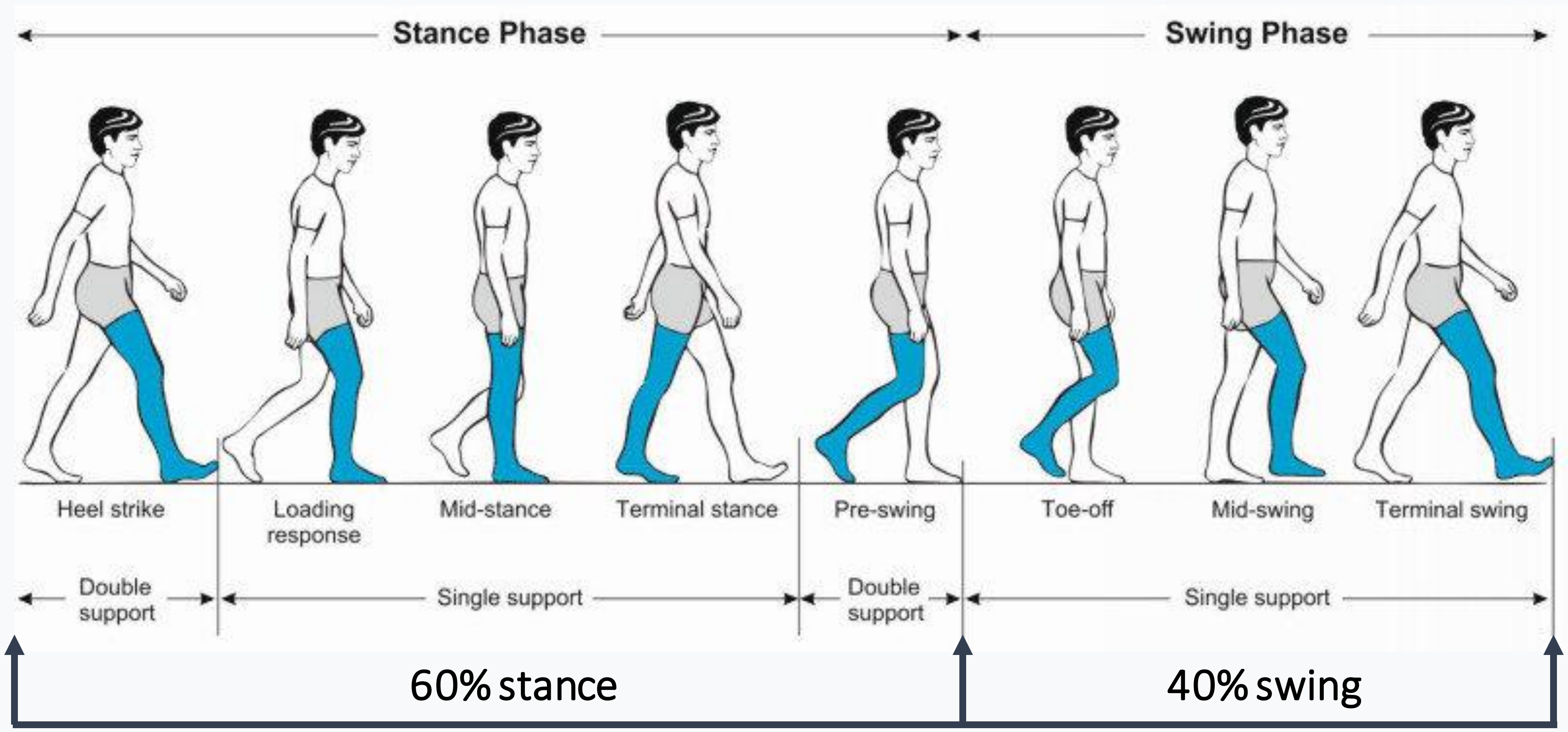
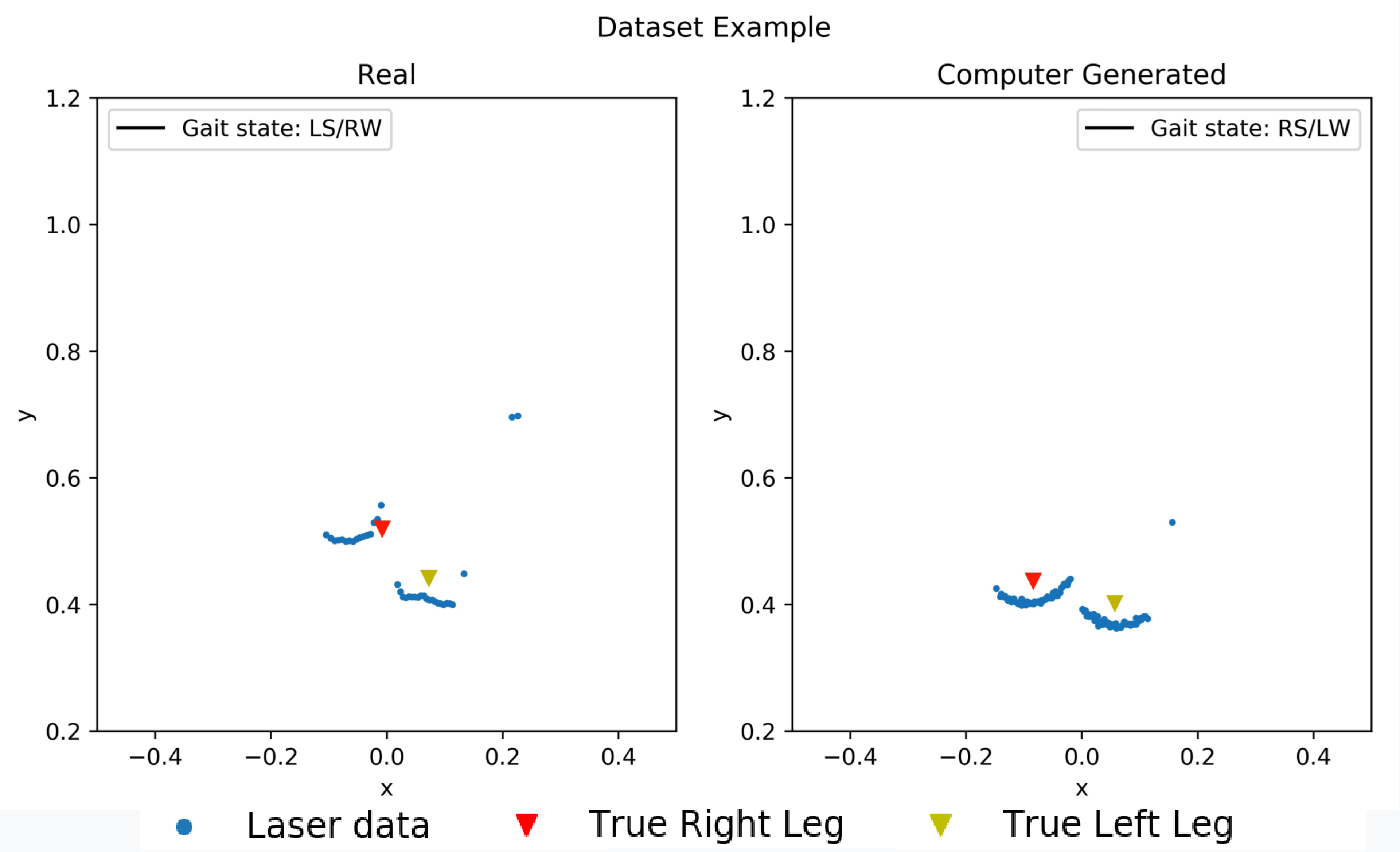
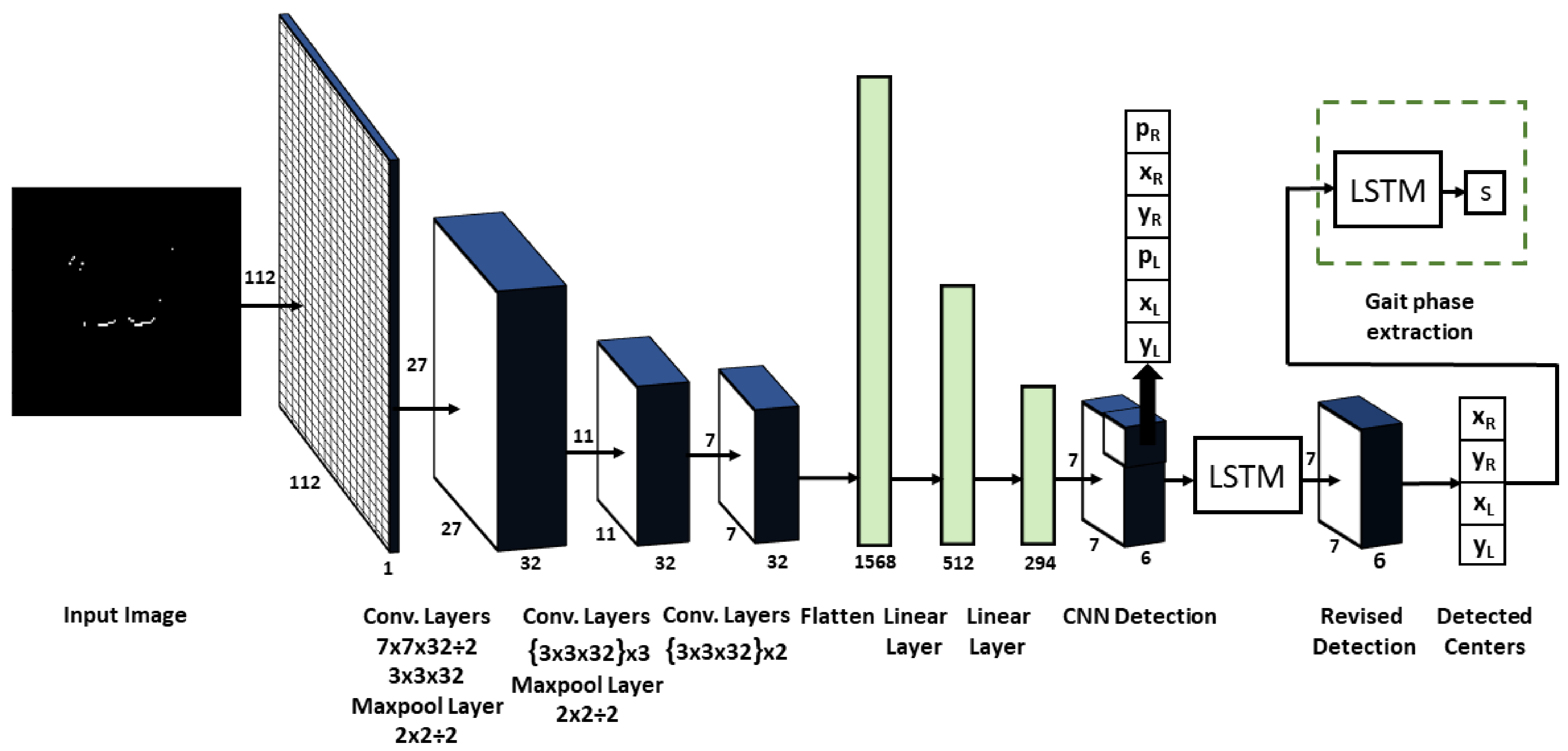


Picture from Walter Pirker and Regina Katzenschlager. "Gait disorders in adults and the elderly: A clinical guide". In: Wiener klinische Wochenschrift 129 (Oct. 2016), doi:10.1007/s00508-016-1096-4.

LTGADnet Dataset



LTGADnet Architecture



Neural Network Compartments

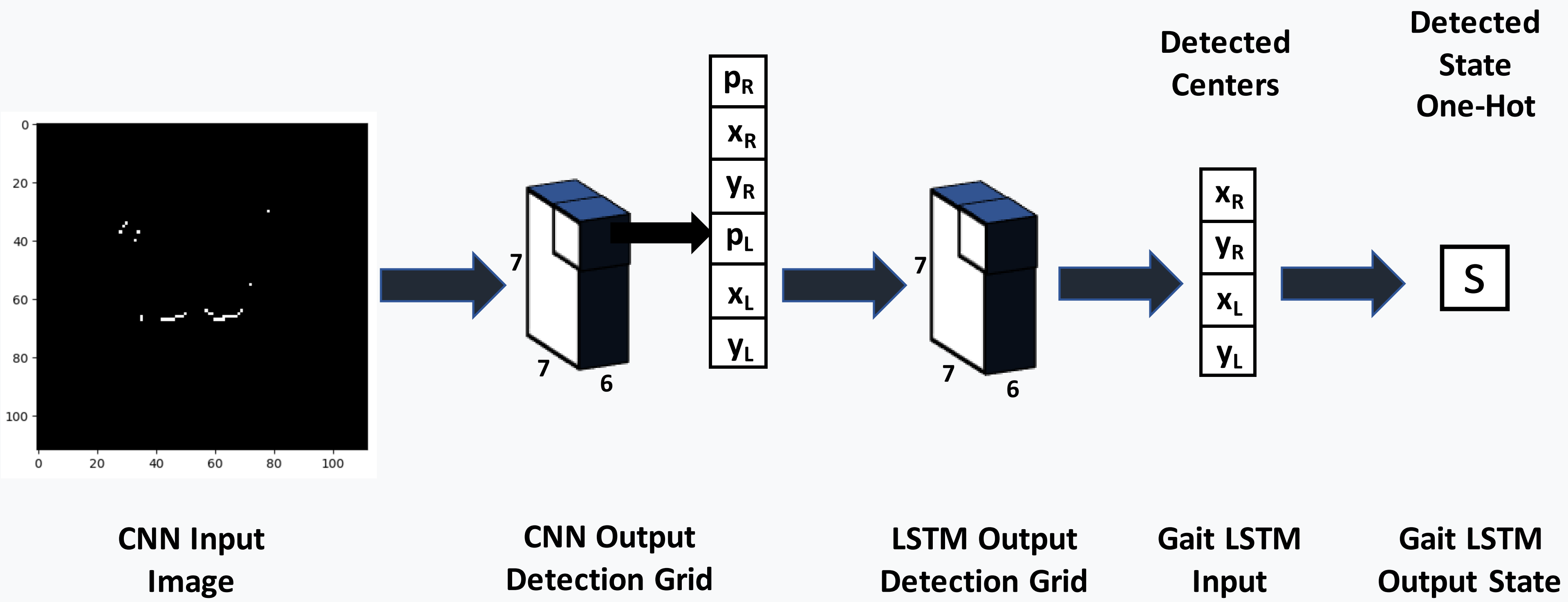
1. **CNN + Linears**: Detection
2. **LSTM**: Tracking
3. **LSTM**: Gait state estimation

LTGADnet Architecture

TABLE III: Ablation Study

Architectures	Mean distance (cm)	Max distance (cm)
CNN7	3.67	37.05
CNN9	4.27	32.03
LSTM1	**3.16**	**15.26**
LSTM2	3.15	19.21
TCN	3.47	40.10
LSTM1assoc	3.21	13.51
TCNassoc	3.87	48.80

LTGADnet Architecture



LTGADnet Training

Leg Tracking Loss

$$Confidence\ Loss = \sum_{i=1}^{7}\sum_{j=1}^{7}\sum_{k=1}^{2}(C_{ijk} - \hat{C}_{ijk})^2$$

$$Detection\ Loss = \sum_{i=1}^{2}(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2$$

$$Association\ Loss = \sum_{i=1}^{2}(\hat{x}_i^t - \hat{x}_i^{t-1})^2 + (\hat{y}_i^t - \hat{y}_i^{t-1})^2$$

$$Loss = Confidence\ Loss + 5 \cdot Detection\ Loss + Association\ Loss$$

Gait Analysis Loss

$$f_i(s) = \frac{e^{s_i}}{\sum_{j=1}^{4} e^{s_j}}$$

$$Loss = -\sum_{i=1}^{4} t_i \log\left(f_i(s)\right)$$

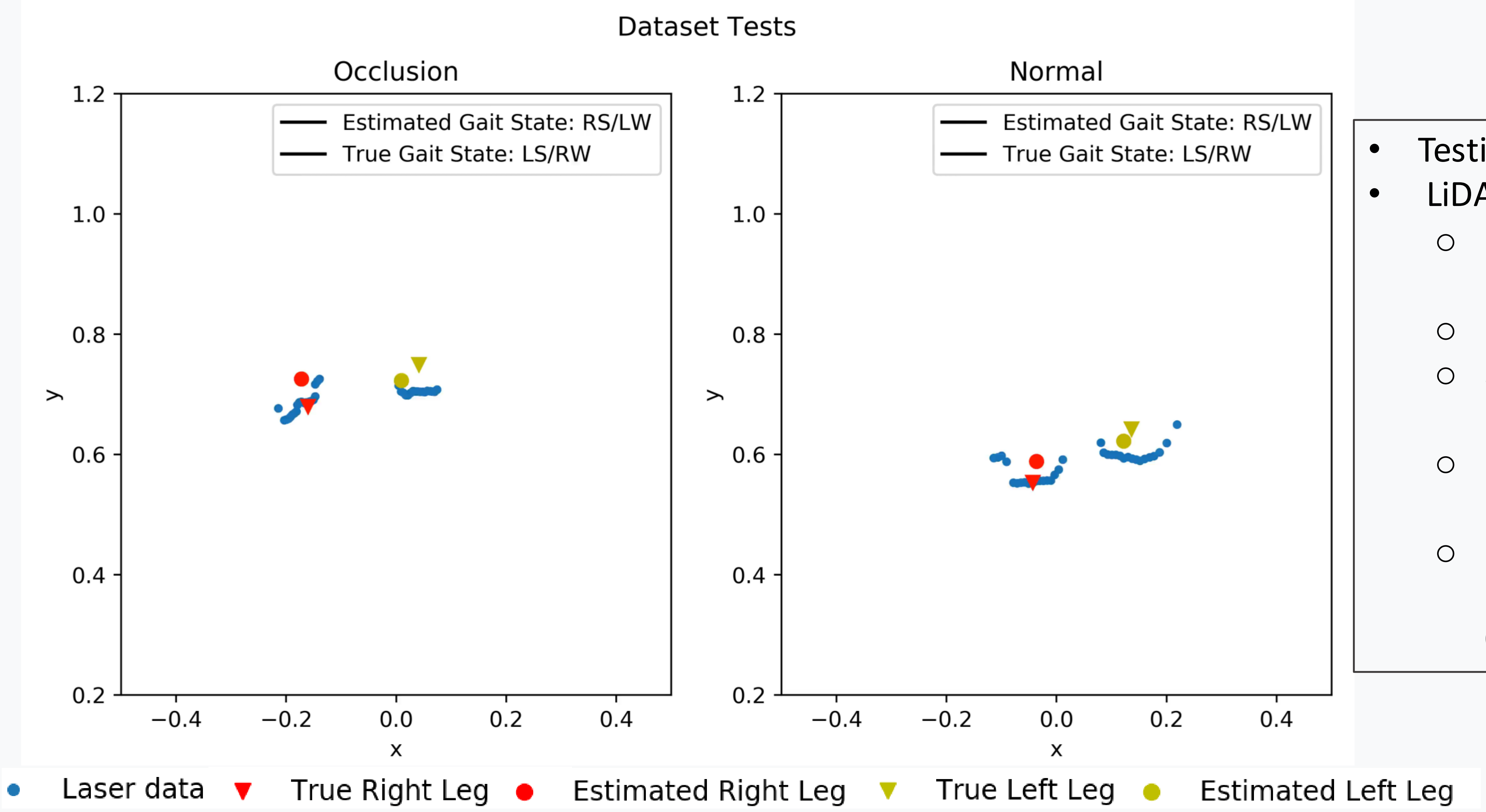
LTGADnet Performance

Leg Tracking centers **RMSE**: 3.23 cm
Gait Analysis **Accuracy**: 70.81%
Single-Frame Detection and Gait State Estimation **Time**: 0.002 sec

Leg Tracking									
Experiment / Metric	1	2	3	4	5	6	7	8	mean
Mean (cm)	2.42	2.04	3.28	4.11	4.57	2.46	3.26	3.68	3.23
Max (cm)	9.63	9.87	22.16	58.32	14.59	7.79	30.31	42.95	24.45
Median (cm)	2.21	1.81	2.60	2.95	3.74	2.18	2.75	3.31	2.69

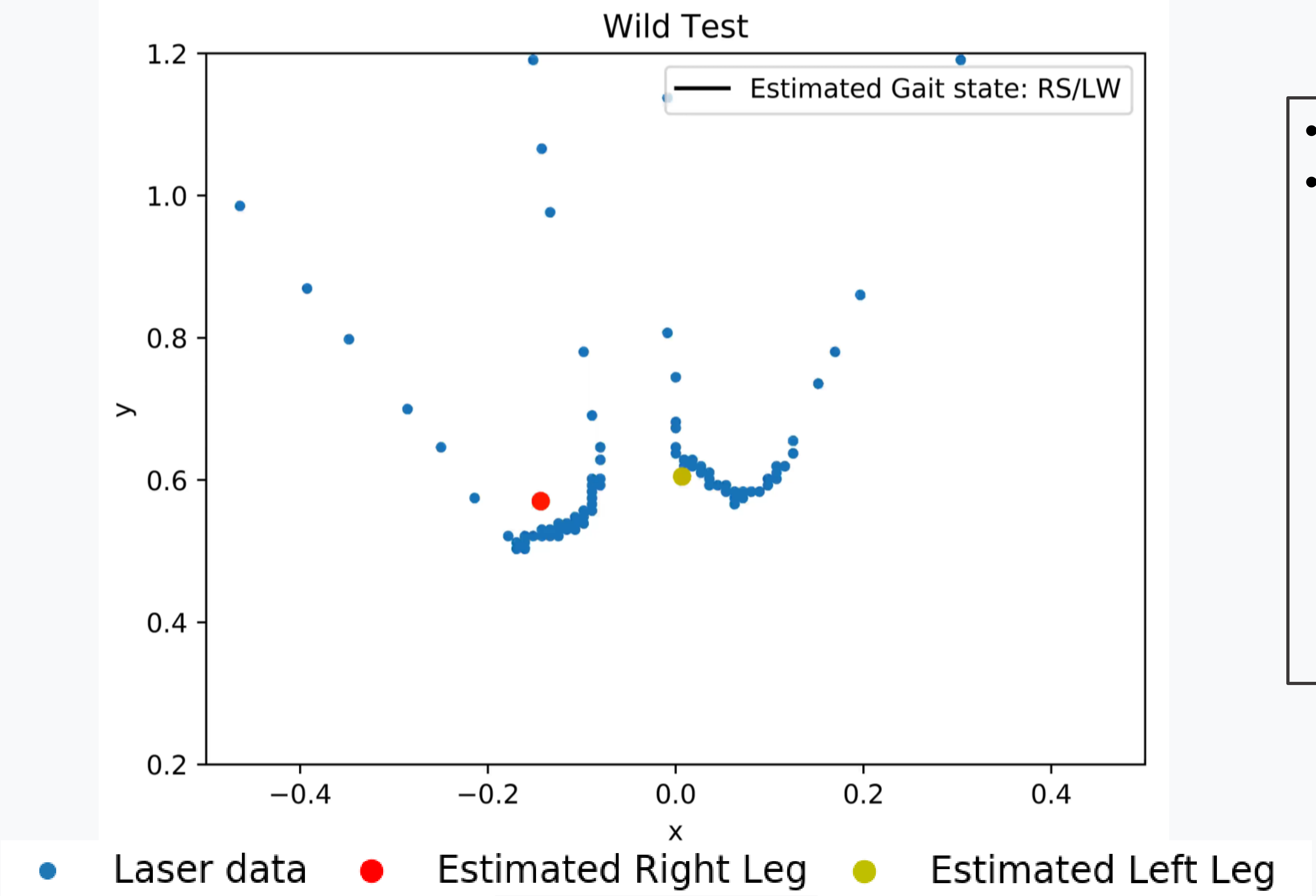
Gait Analysis									
Experiment / Metric	1	2	3	4	5	6	7	8	mean
Accuracy (%)	75.60	71.56	68.85	72.74	69.27	63.17	69.36	75.89	70.805
Precision (%)	78.88	71.36	68.87	74.80	70.76	67.85	69.38	77.50	72.425
Recall (%)	75.60	71.57	68.85	72.74	69.27	63.17	69.37	75.89	70.8075
F1 score (%)	76.57	71.28	67.62	72.10	68.68	61.94	69.21	76.24	70.455

LTGADnet Testing



- Testing on MOBOT
- LiDAR:
  - Hokuyo LiDAR UBG-04LX-F0
  - 28msec/scan
  - scanning range: 0.02 – 5.6m
  - angle range: -120º – 120º
  - angular resolution: 0.36º

LTGADnet Wild Testing



- Testing on i-Walk
- LiDAR:
  - Hokuyo LiDAR UST-10LX
  - 25msec/scan
  - scanning range: 0.06 – 10m
  - angle range: $-135^{o} – 135^{o}$
  - angular resolution: 0.25^{o}

LTGADnet Conclusions

- Novel, lightweight network for leg tracking and gait analysis
- Fast and accurate leg tracking
- Sufficient gait analysis, yet not optimal

- Computer generated data immensely improve leg tracking
- Not that efficient on gait analysis
- Difficult to imitate human walking

<u>Future Work:</u>
- Expansion of real dataset
- Different gait data augmentation
- Bi-directional LSTM for post-gait analysis
- Self-supervised learning methods

Thank you

Acknowledgements

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