IMAC-XL

Synthesizing Dynamic Time-series Data for Structures Under Shock Using Generative Adversarial Networks

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Summary

- Validation of state observers for high-rate structural health monitoring requires the testing of state observers on a large library of pre-recorded signals, both uni- and multi-variate.
- However, experimental testing of high-value structures can be cost and time-prohibitive.
- Finite element modeling lacks the fidelity to reproduce the non-stationarities present in the signal, particularly at the higher end of the digitized signal's frequency band.
- In this preliminary work, generative adversarial networks (GANs) are investigated for the synthesis of uni- and multi-variate acceleration signals for an electronics package under shock.
- Results show that GANs are capable of producing material reminiscent of that obtained through experimental testing.

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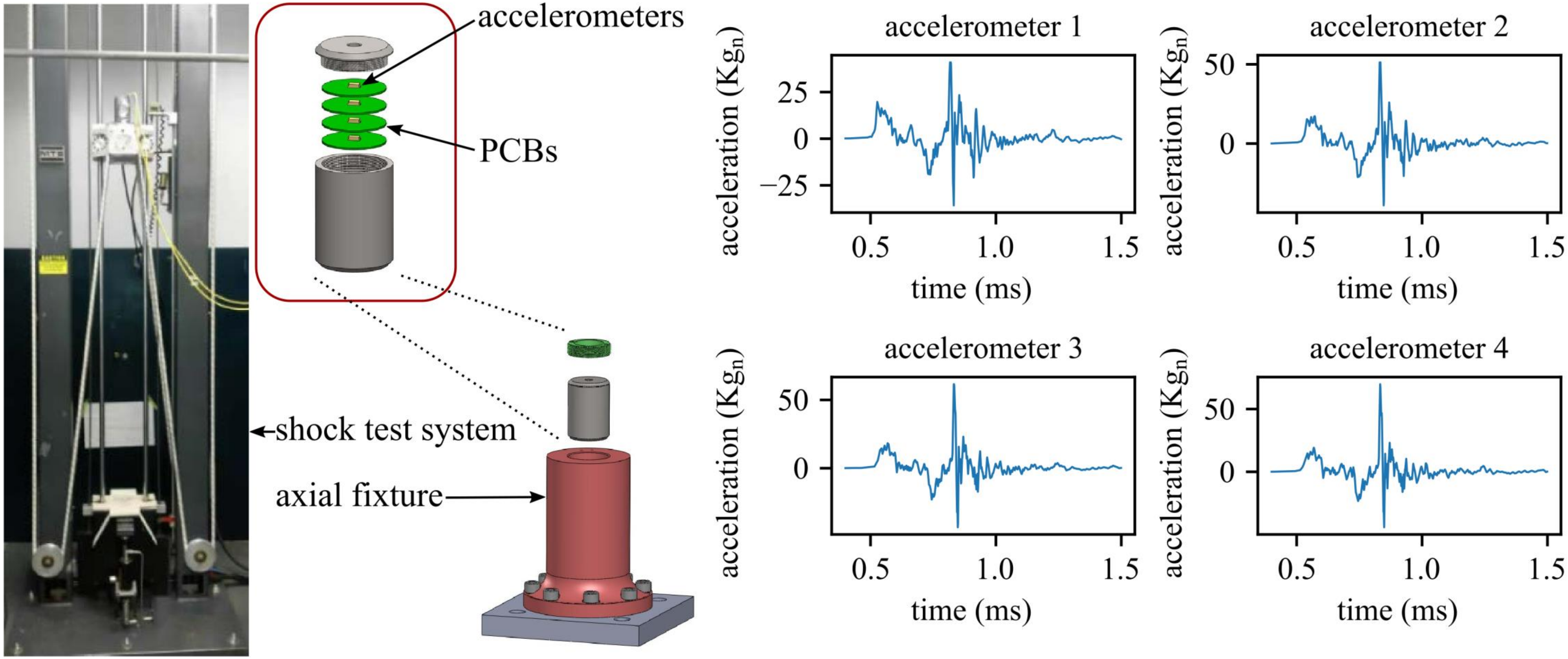
High-rate Dynamic Events

- High-rate dynamic events [1]
  - time scale of less than 100 milliseconds
  - high amplitude exceeding 100 g_n
- High-rate Structural Health Monitoring[3]
  - “Monitor functional integrity and remaining life”
  - “Maximize function, minimize risk”

Car collision [2]

Shock Test System Demonstration

Experiment Setup



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GAN Introduction

- Thispersondoesnotexist.com
- Generative Adversarial Network
- Two player game with opposing goals
- Flaws in glasses, artifacts, hair, teeth, etc.
- Efficient, consistent evaluation requires quantitative measure

Thispersondoesnotexist[4]

Challenges of GANs

- Training setup
  - Model combination
  - Hyperparameters
  - Training regime
- Detecting/Preventing mode collapse
  - Generator may only produce one example repeatedly
  - Prevent model from failing this way
- Turn quality to quantity for evaluation
  - Need computational way of evaluating model
  - Evaluation tends to be per model

WGAN explanation

- Changes objective function to energy distance
- Wasserstein distance – actual definition
- Cost to go from left to right

Photo by Phil Hearing on Unsplash[5]

Photo by Kit Suman on Unsplash[6]

Latent Dimension

- Typically vector of gaussian noise
  - Point chosen from n-dimensional gaussian distribution
  - i.e. (0.02, 0.00, -1.7, 2.4, …, 0.03)
- Label included for conditional generation
  - Tuple/List of integers converted to fixed-size binary array
  - i.e. (1, 3, 5) -> [1, 0, 1, 0, 1]
- During inference, fixed-weights lead to consistent generation of data

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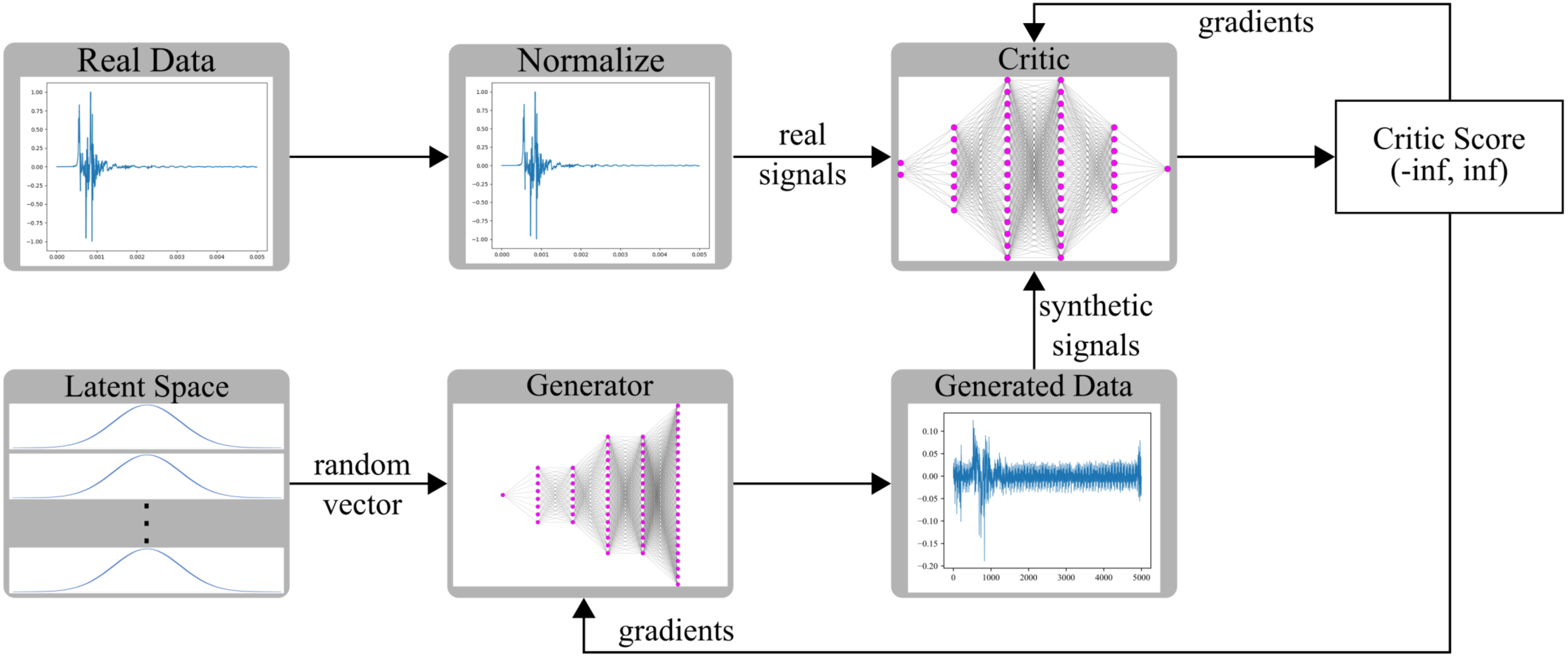
Generic Training example

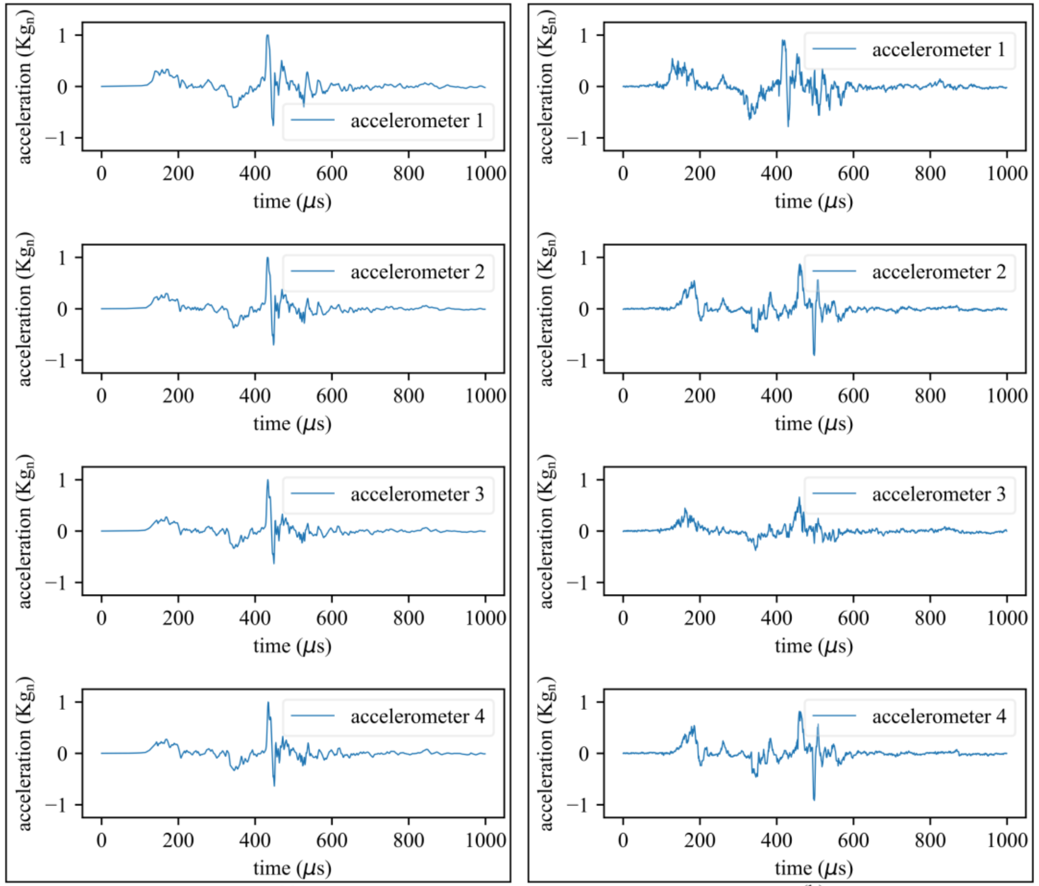
- Find good pair of critic and generator
- Generated examples:
  - Vector of gaussian noise fed into generator (along with labels for conditional)
  - Vector size is referred to as latent dimension
  - Latent space is fixed
- Train critic:
  - Feed real and generated samples for training
- Train generator:
  - Feed generated samples into critic
  - Generator trains

Training the time-series WGAN



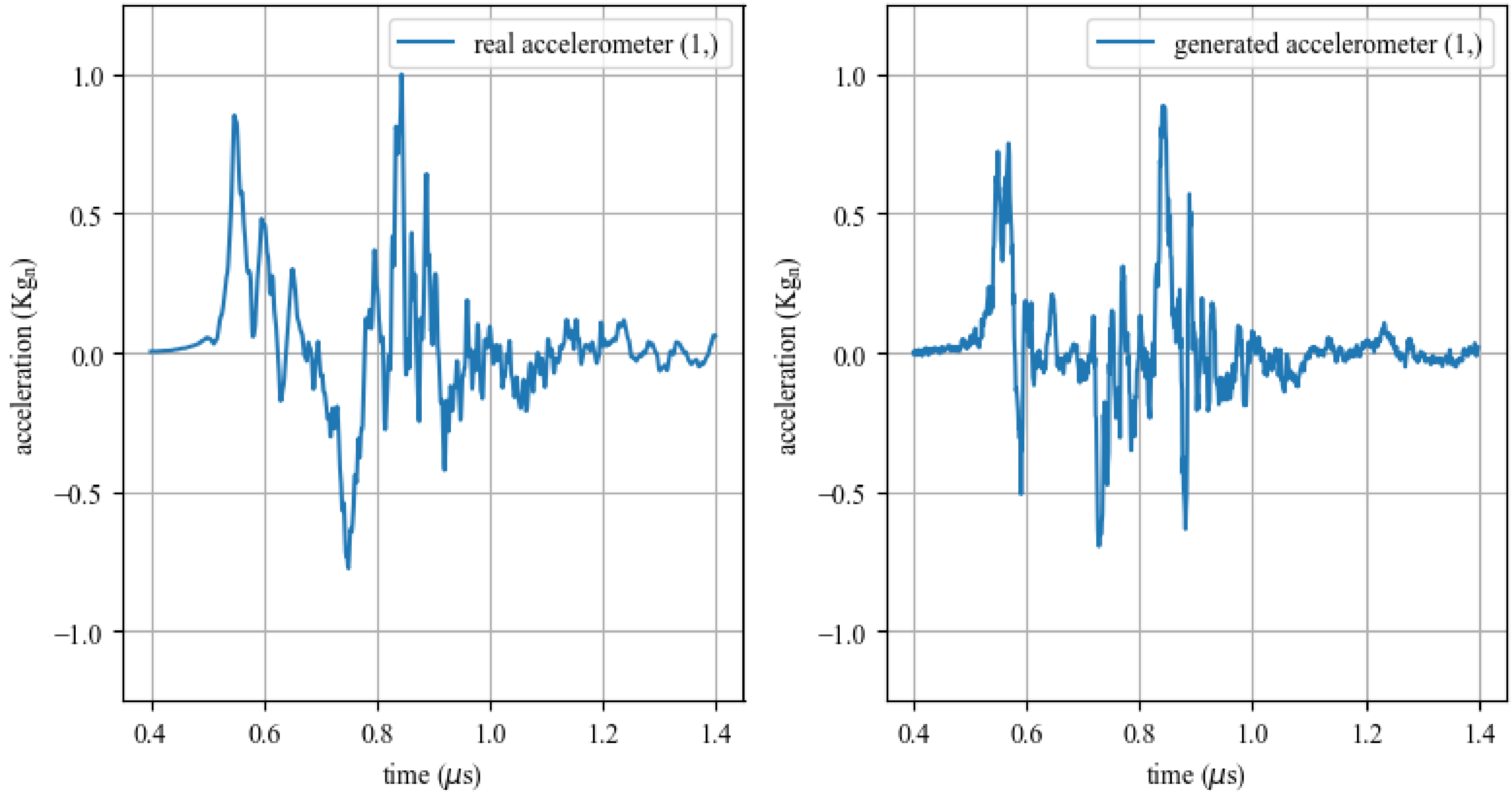
Time Plots

- Reference signals on left
  - Each row is different accelerometer
  - L2 normalized
  - Closest match to generated by lowest mean squared error
- Generated signals on right
  - Raw generated signals
  - Rows are based on same accelerometer
- All subsection of whole signal
  - Excluded ends have little new information
  - Can focus on most significant time period



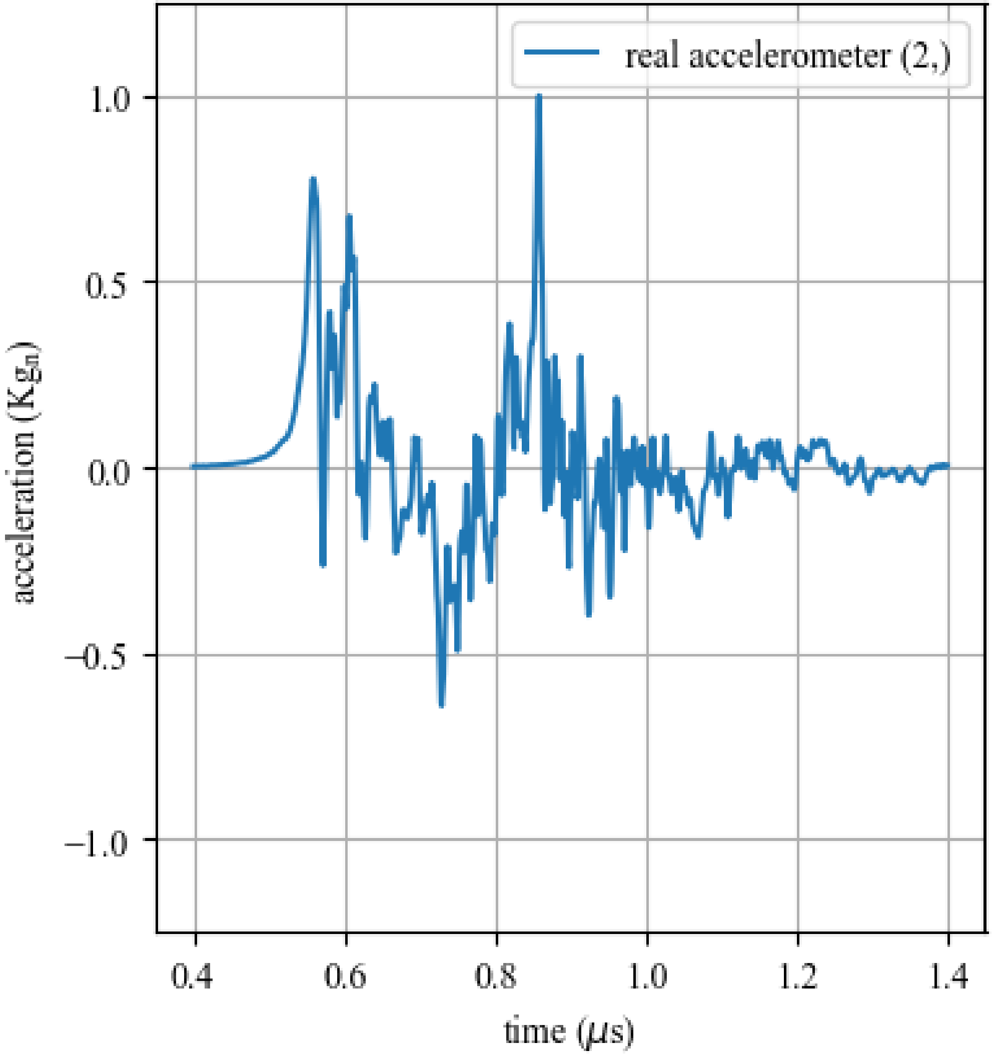
(a)
(b)

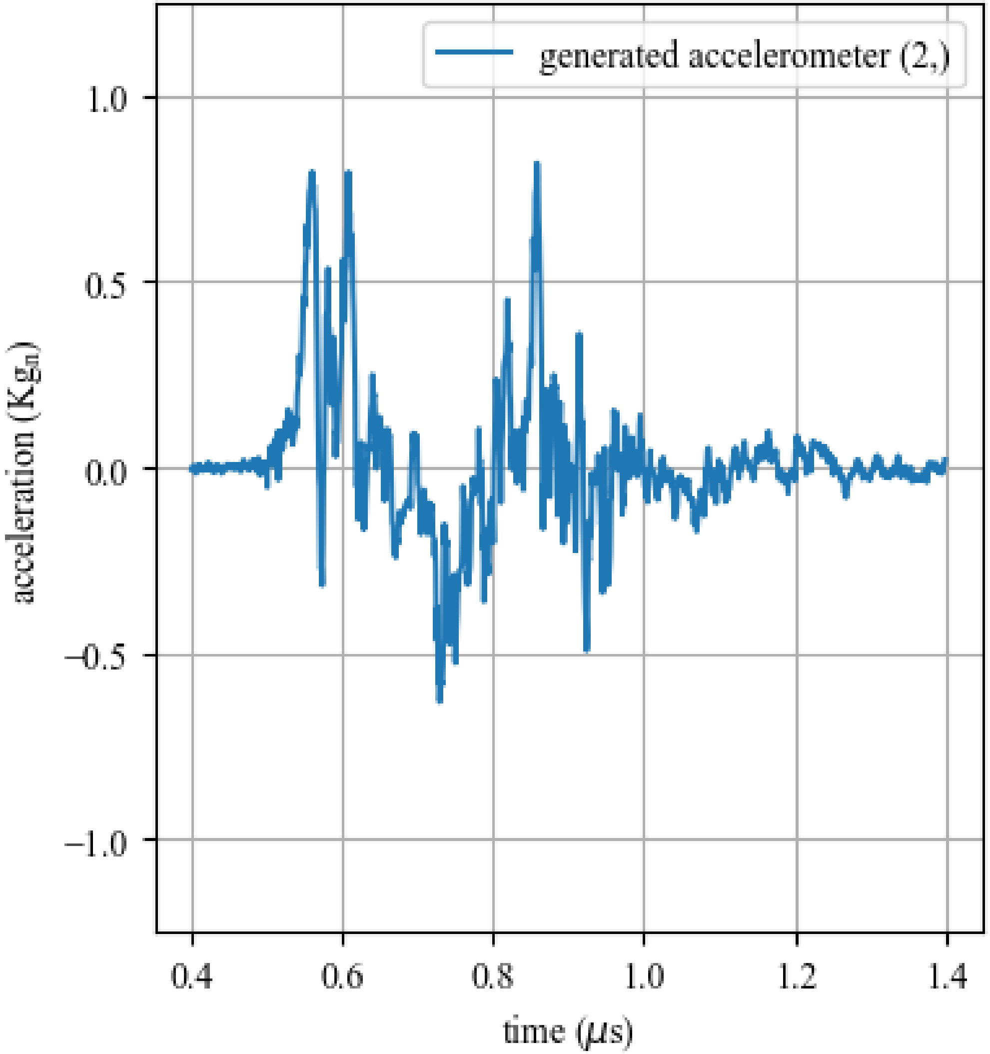
Time Plots



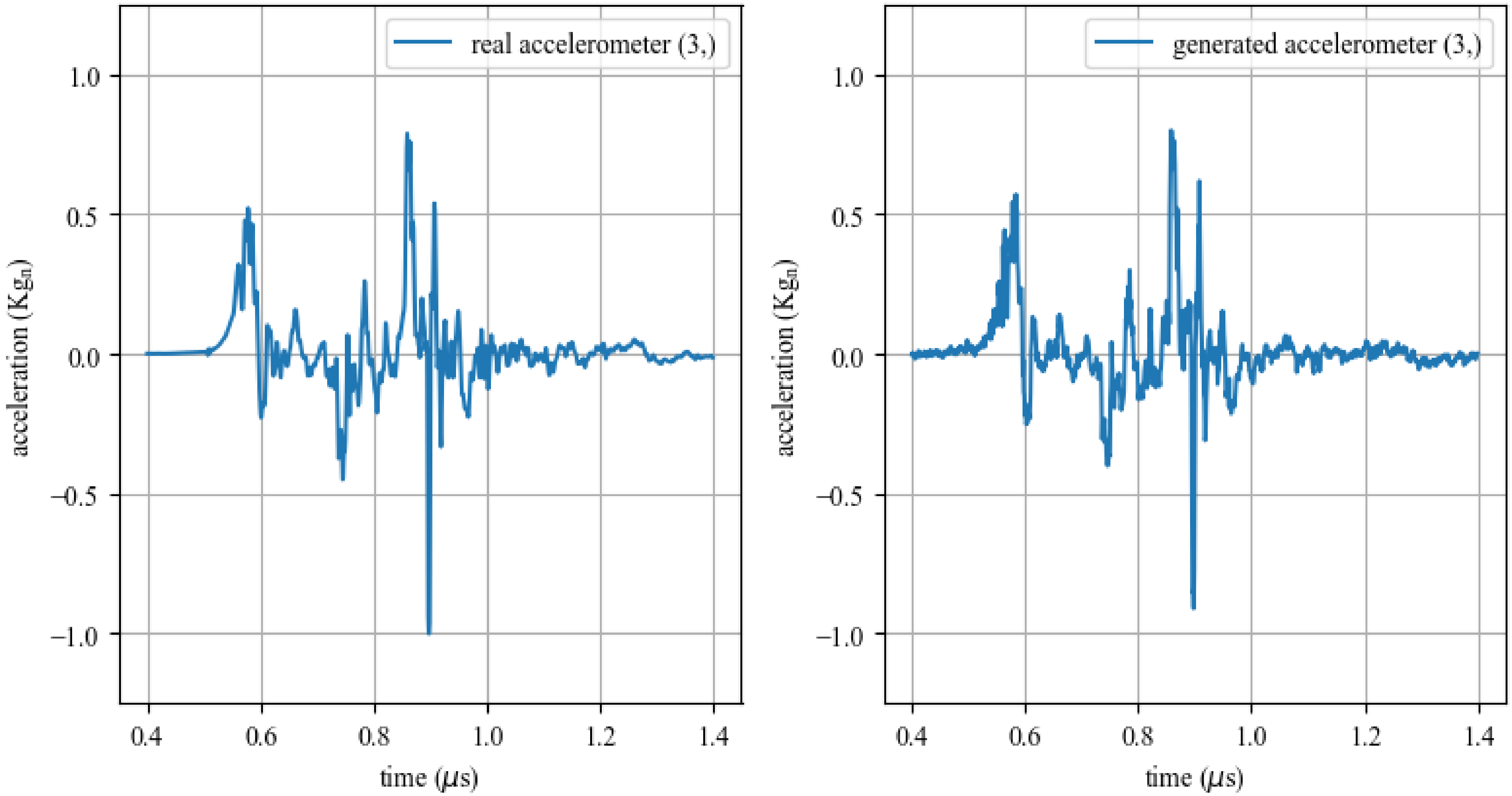
real accelerometer (1,)
generated accelerometer (1,)
acceleration (Kgn)
time (μs)
1.0
0.5
0.0
−0.5
−1.0
0.4
0.6
0.8
1.0
1.2
1.4

Time Plots

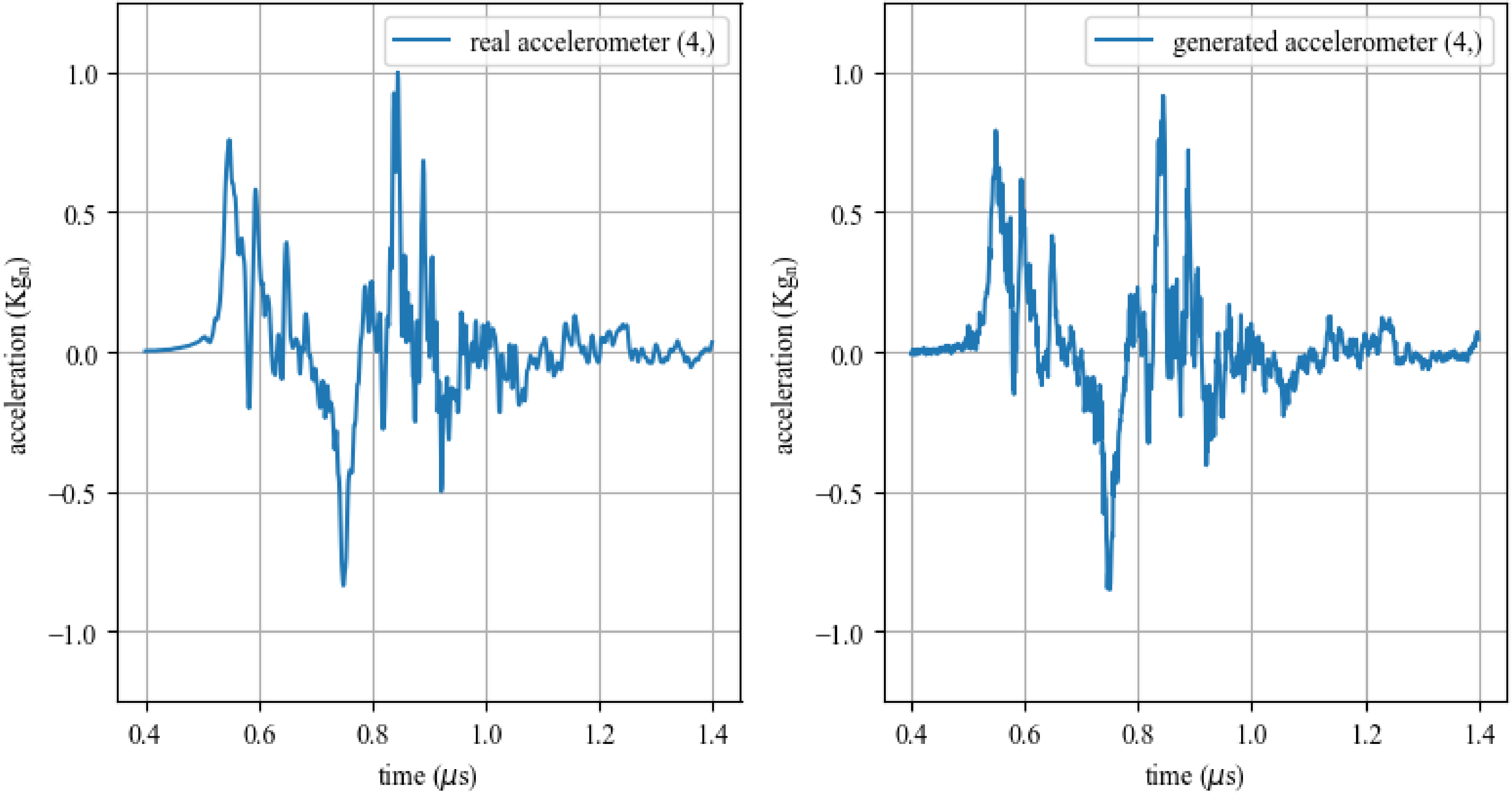

real accelerometer (2,)
1.0
0.5
0.0
−0.5
−1.0
acceleration (Kg$_n$)
0.4
0.6
0.8
1.0
1.2
1.4
time (μs)


generated accelerometer (2,)
1.0
0.5
0.0
−0.5
−1.0
acceleration (Kg$_n$)
0.4
0.6
0.8
1.0
1.2
1.4
time (μs)

Time Plots


real accelerometer (3,)
generated accelerometer (3,)
acceleration (Kg$_n$)
time (μs)
1.0
0.5
0.0
−0.5
−1.0
0.4
0.6
0.8
1.0
1.2
1.4

Time Plots



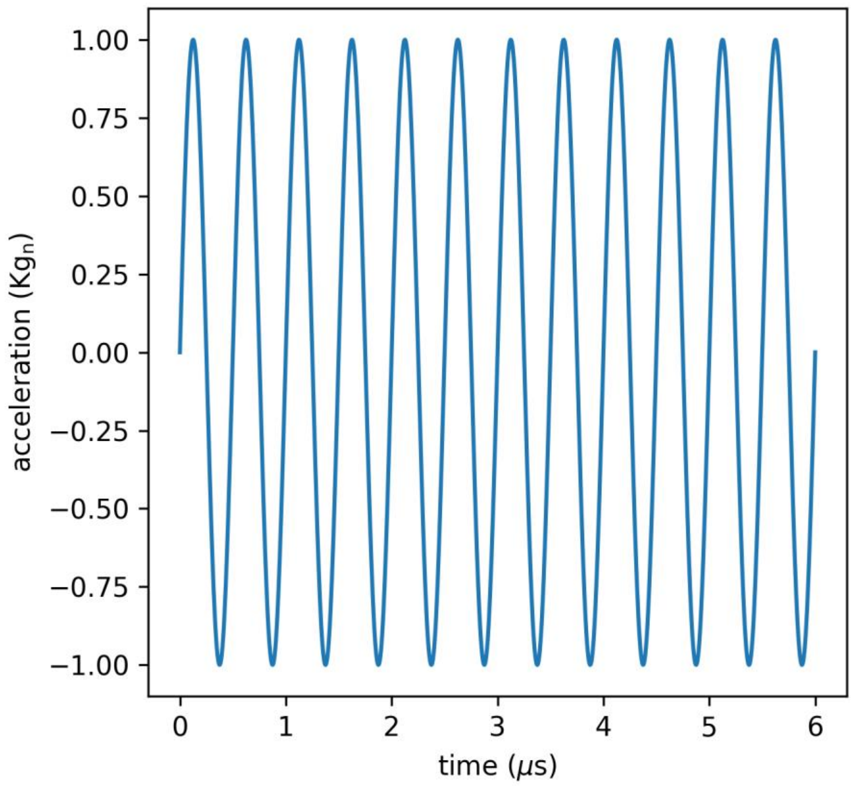
real accelerometer (4,)
generated accelerometer (4,)
acceleration (Kg$_n$)
time (μs)
1.0
0.5
0.0
−0.5
−1.0
0.4
0.6
0.8
1.0
1.2
1.4

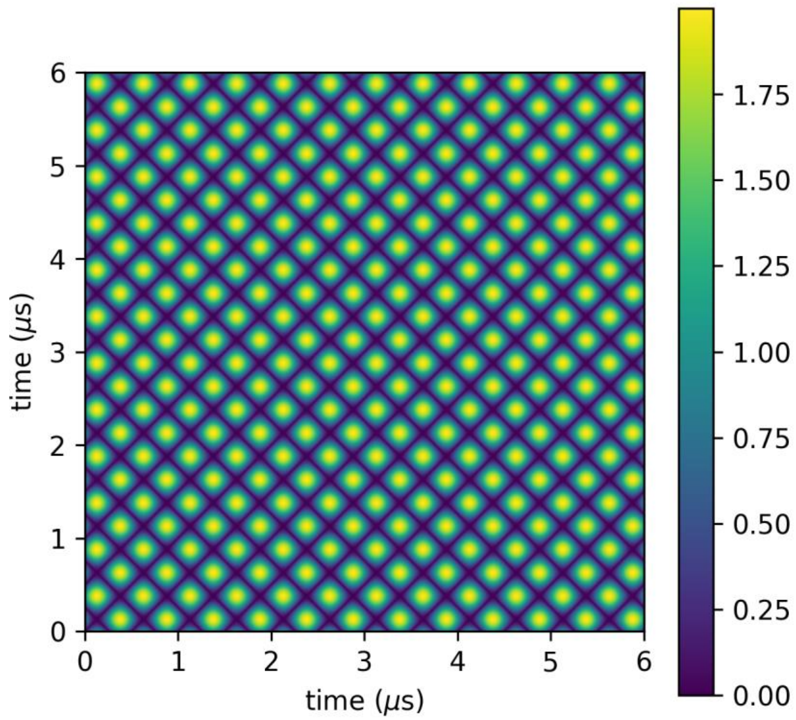
Simple Recurrence Plot Examples

- Sine wave
- Disrupted sine wave
- Gaussian noise wave

Sine wave with recurrence plot

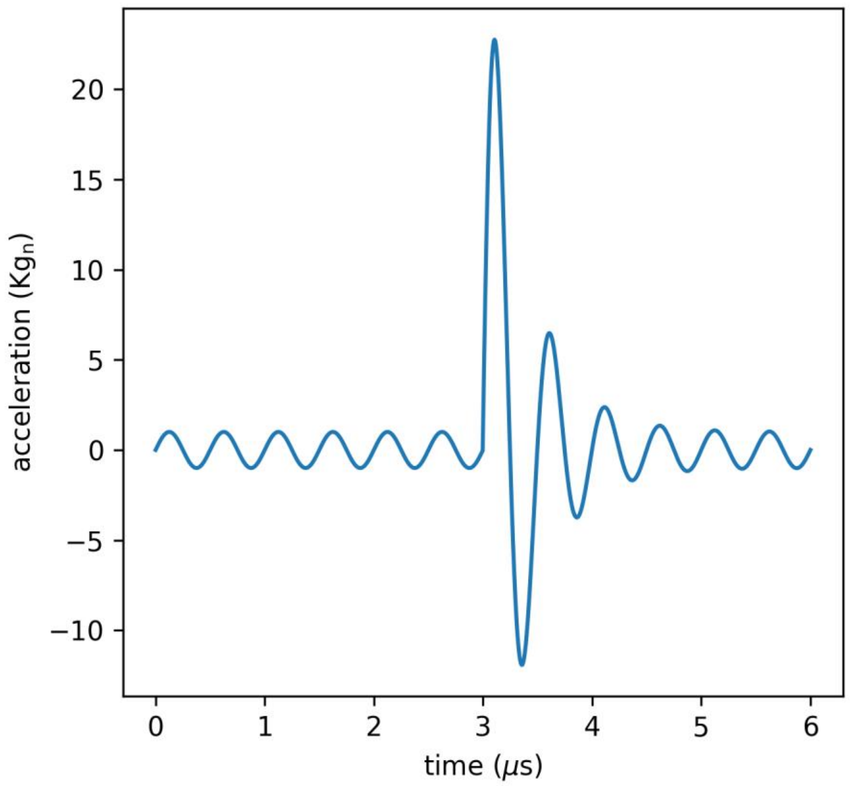
- Amplitude: 1
- Frequency: 2
- Shows pattern repeating consistently

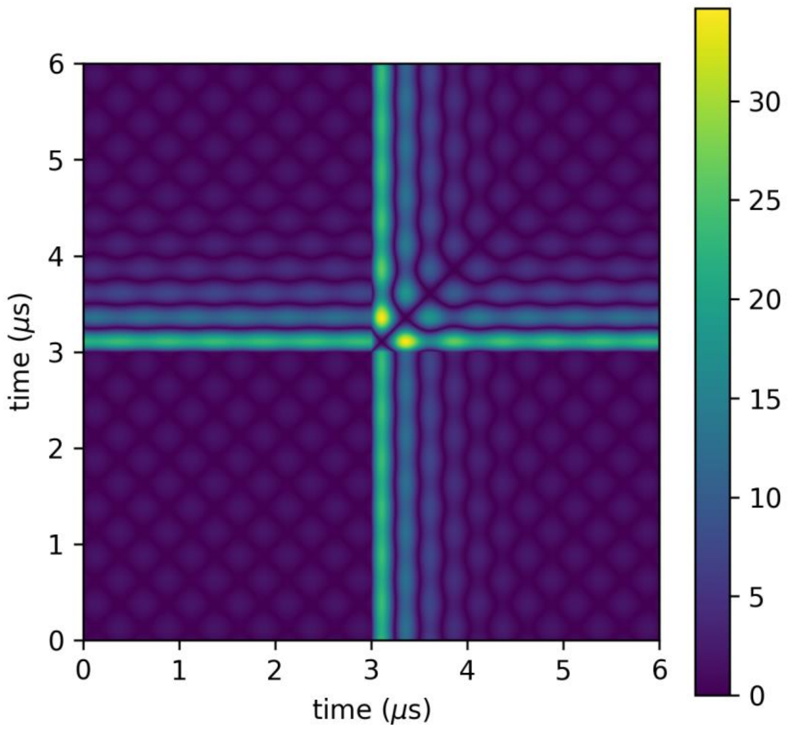




Sine wave (excited) with recurrence plot

- Amplitude: 1
- Frequency: 2
- Impulse applied with amplitude 30
- Vertical, wiggly bar implies drastic change in signal
- Pattern returns with decay





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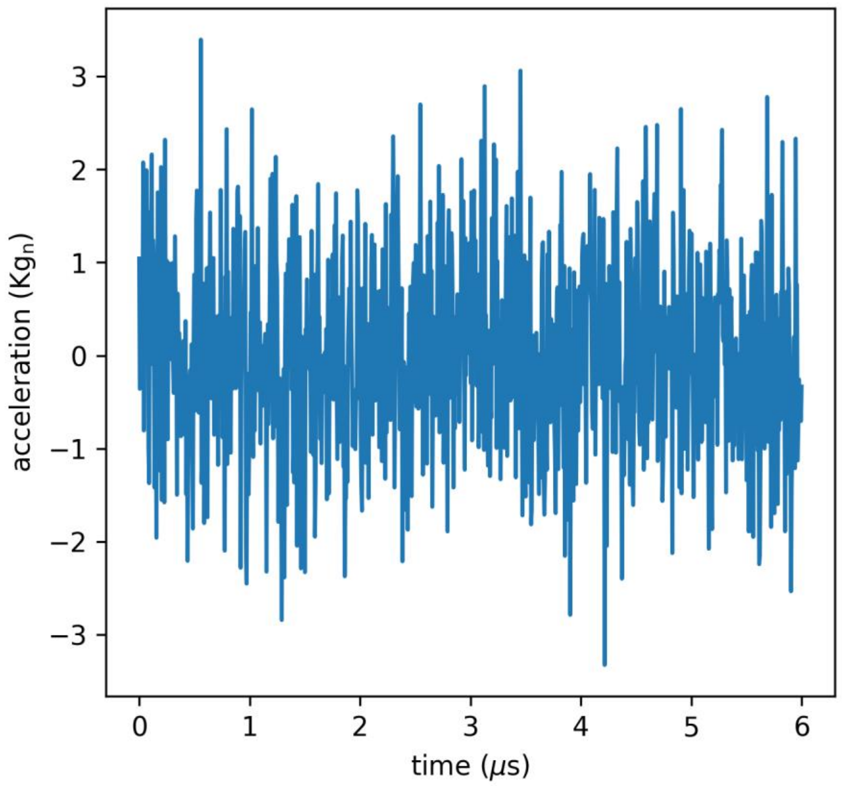
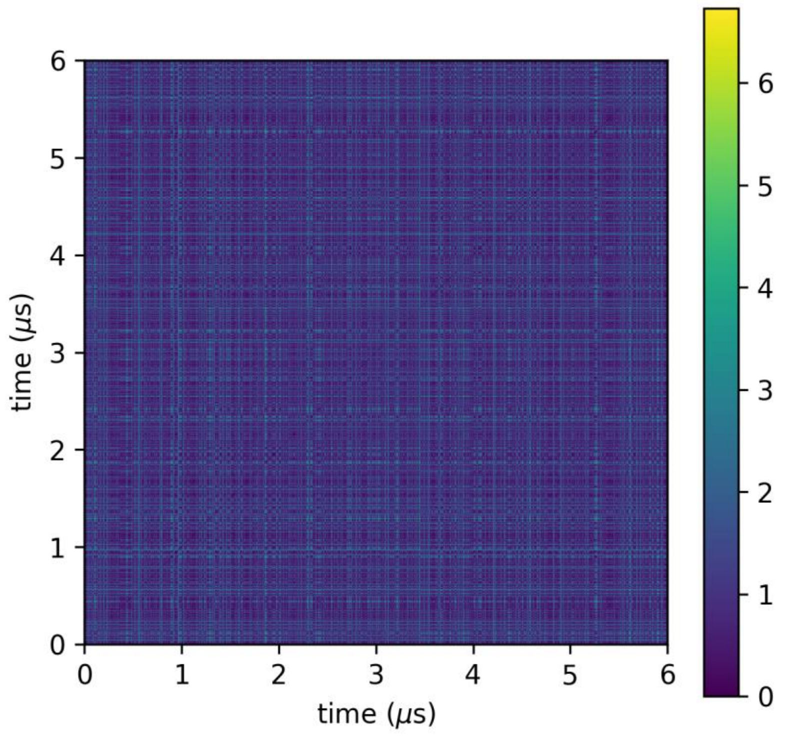
Gaussian wave

- Values are variable
- No discernable patterns in recurrence plot
- Vertical bars exist, but less pronounced





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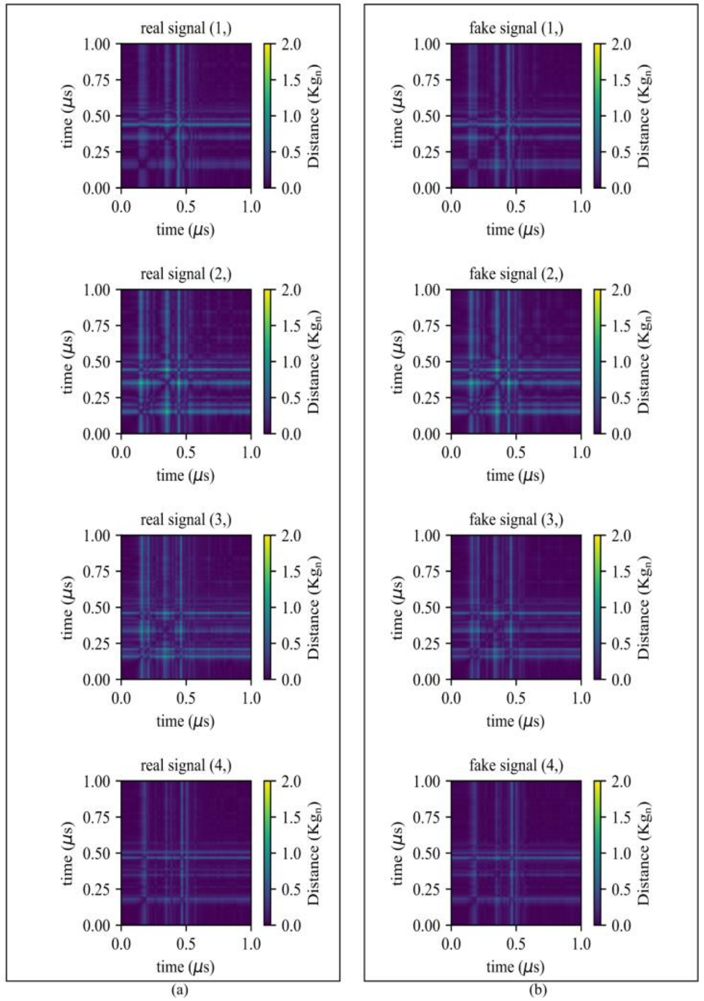
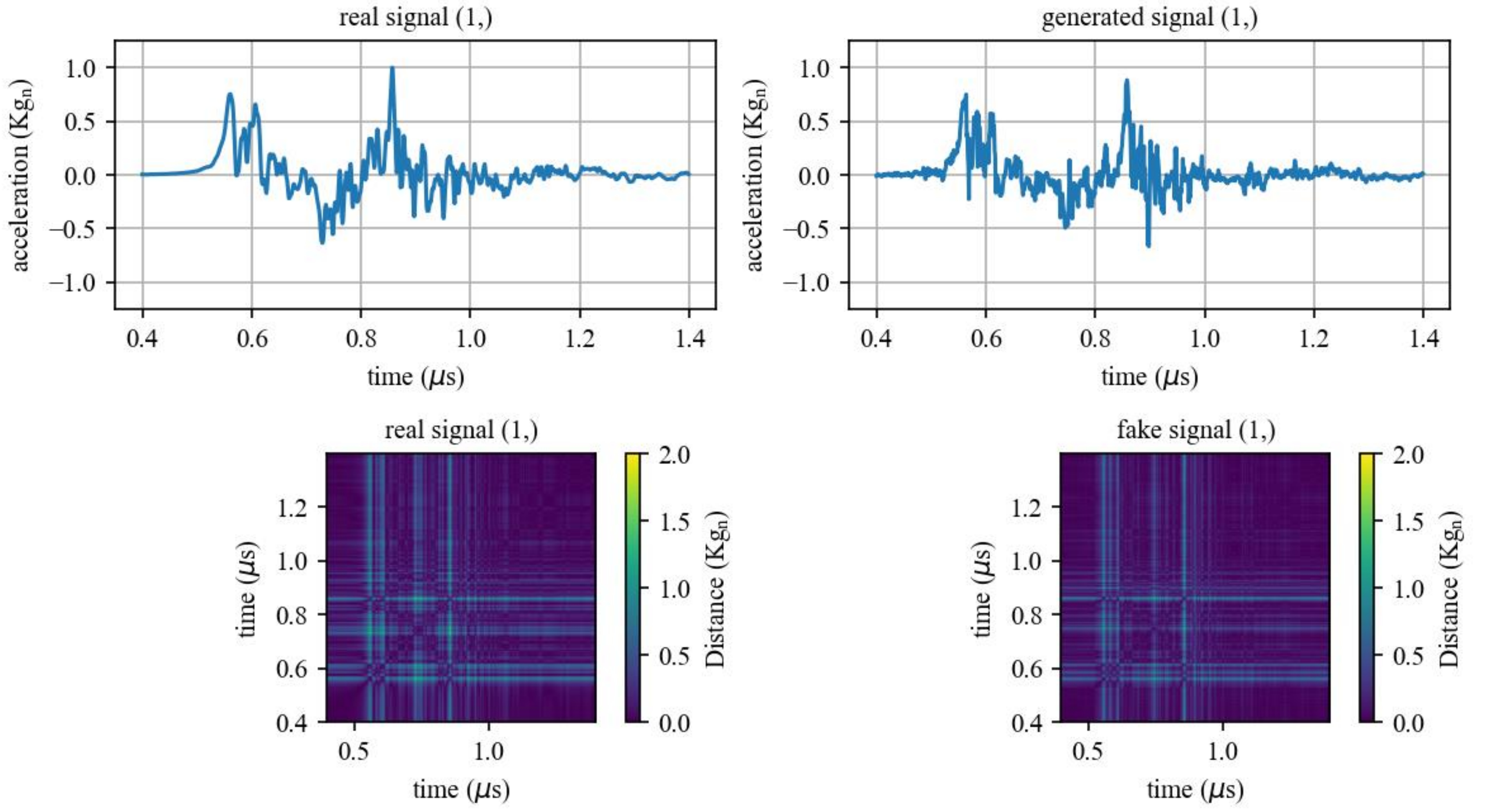
Recurrence Plots

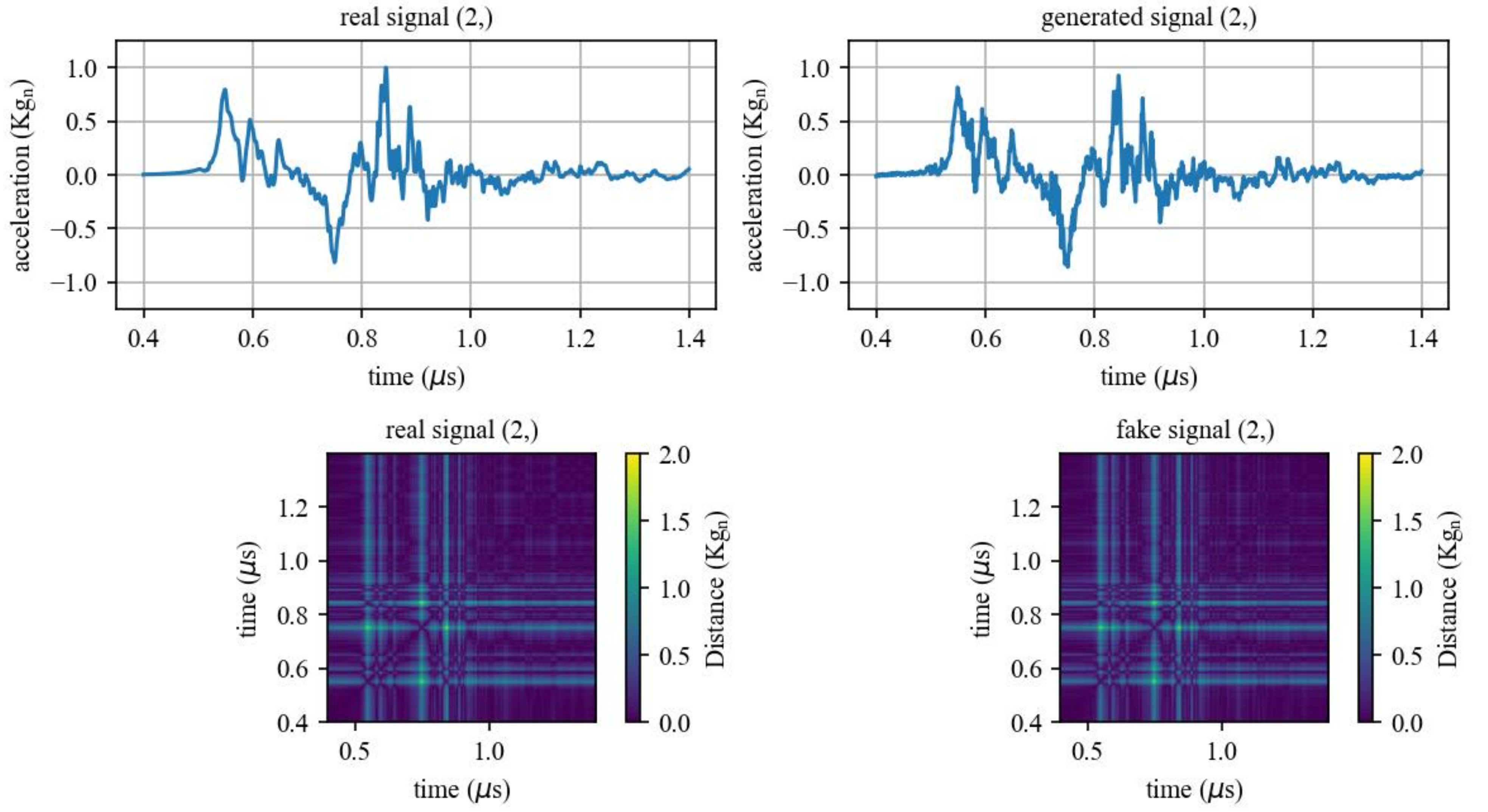
- Recurrence plots
  - Graphical representation of correlations in data
    - Point(I, j) is difference between acceleration at time I and acceleration at time j
    - Normalization theoretically limits possible range of values to [0, 2]
  - Brighter dots are greater distance between points
  - Greater distance in some areas can “dim” distance in others
  - Minimum threshold is possible but not used here
- Implementation
  - Real signals always on left
  - Plot is of subsection of whole signal



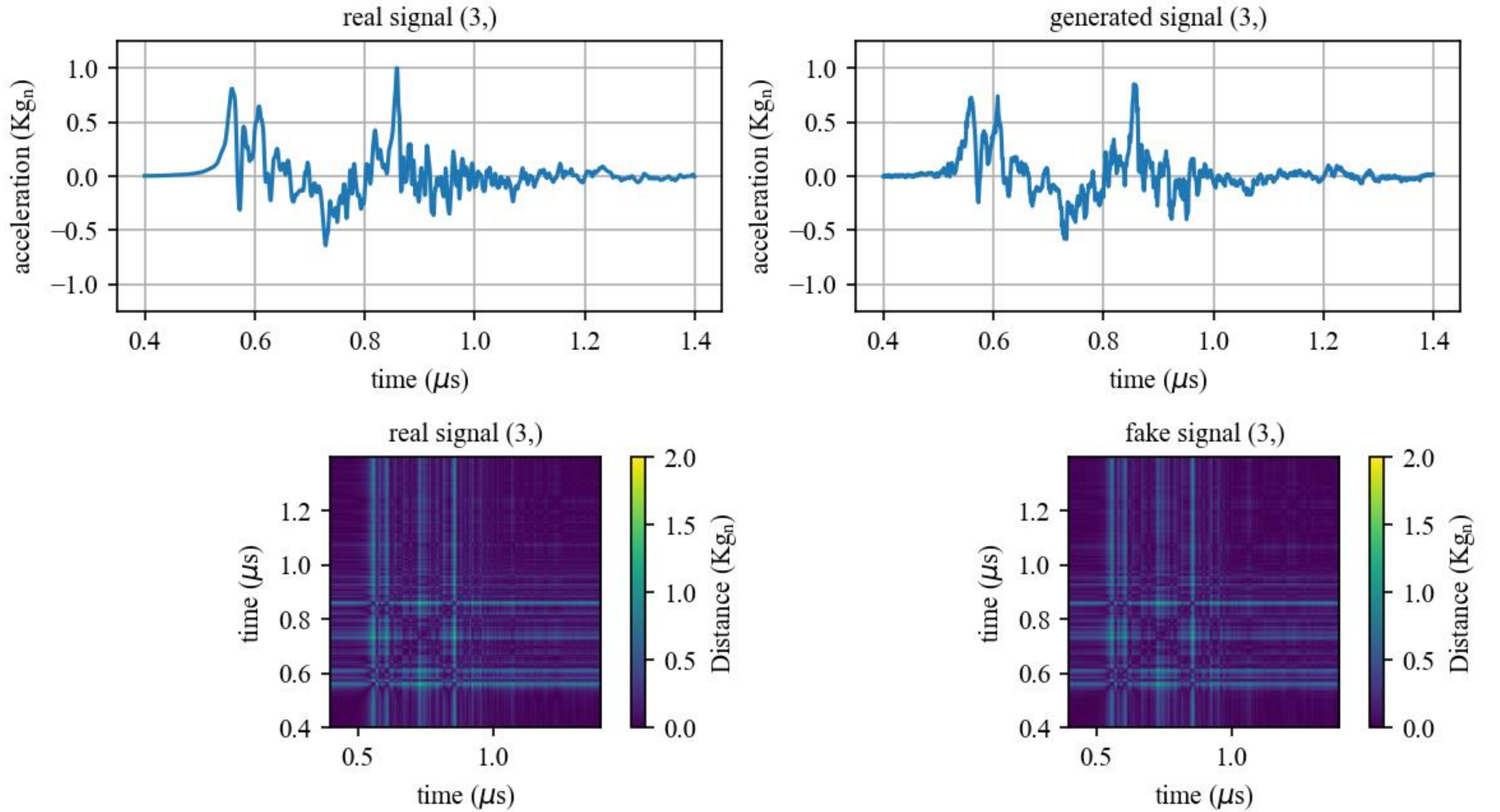
Accelerometer 1 Recurrence Plot



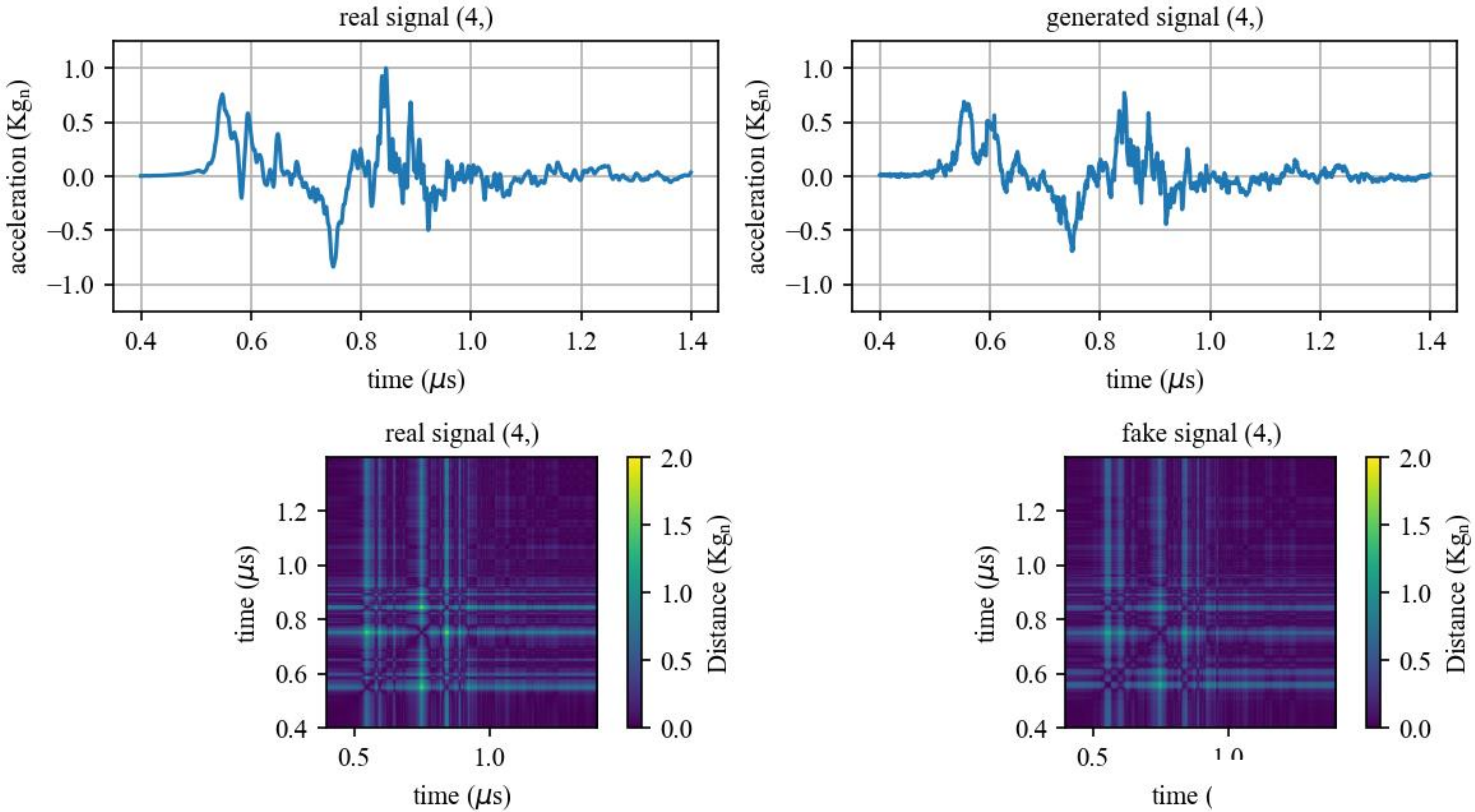
Accelerometer 2 Recurrence Plot



Accelerometer 3 Recurrence Plot



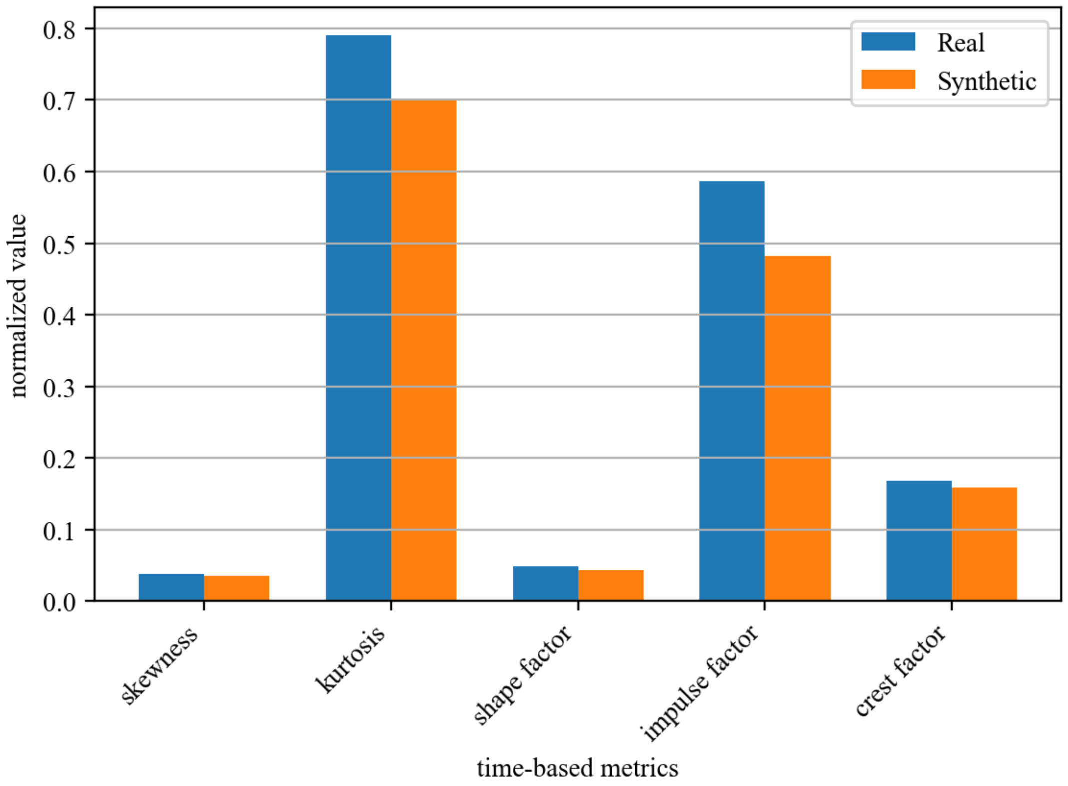
Accelerometer 4 Recurrence Plot



Time-based metrics

- Low peaked-ness implies low amplitude spikes

	Real Signals	Synthetic Signals
Skewness	2.691	2.474
Kurtosis	55.685	49.444
Shape factor	3.452	3.040
Impulse factor	41.339	33.964
Crest factor	11.823	11.193



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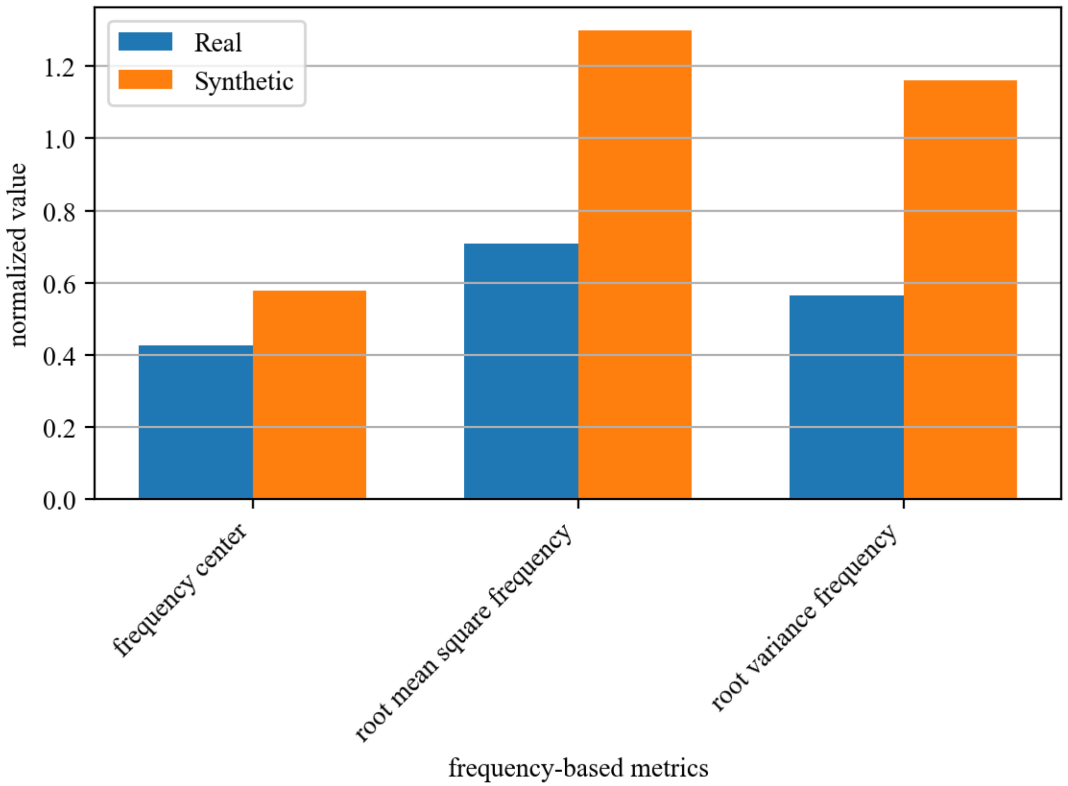
Frequency-based metrics

- Low frequency center with high RMSF suggests energy varies around mean

	Real Signals	Synthetic Signals
Frequency center	22170.812	30027.527
RMSF	36811.092	67507.176
Root variance freq.	29314.880	60308.838



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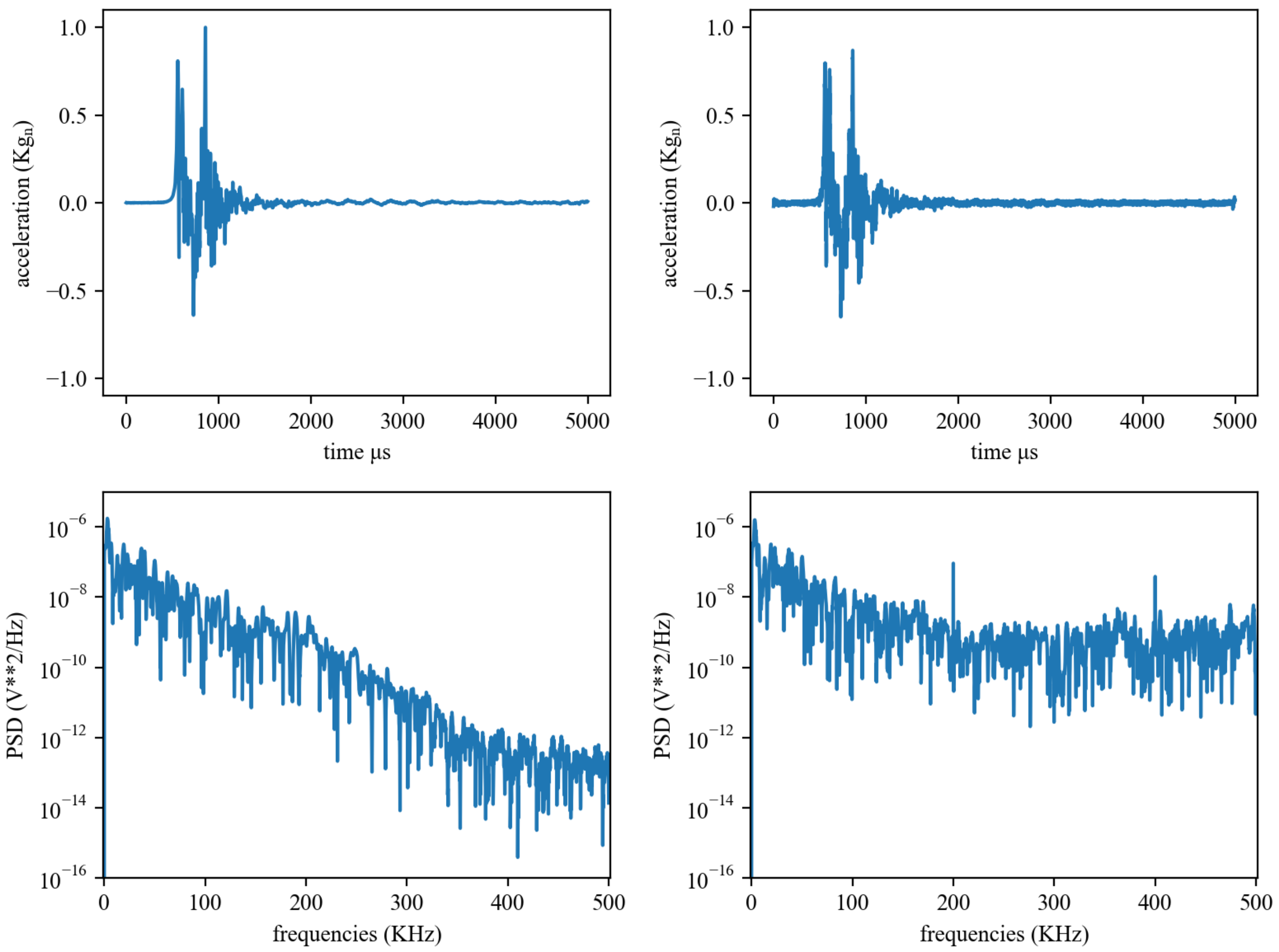
Signal and Power Spectrum



- Left column is data from real test
- Right column is similar generated signal
- Bottom row is power spectrum density plot
- Lower peaks in generated signal
- Higher amounts of high level frequencies (above 250 KHz)
- Generated signals are noisier

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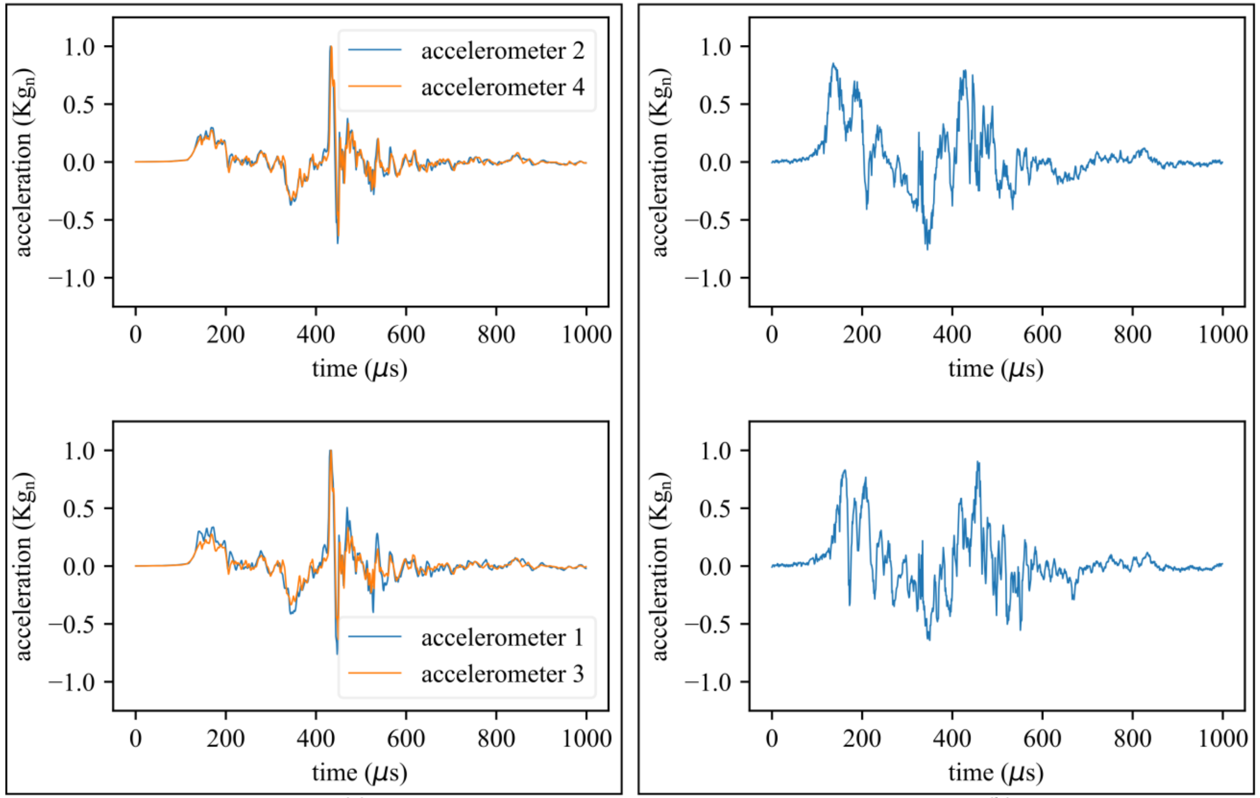
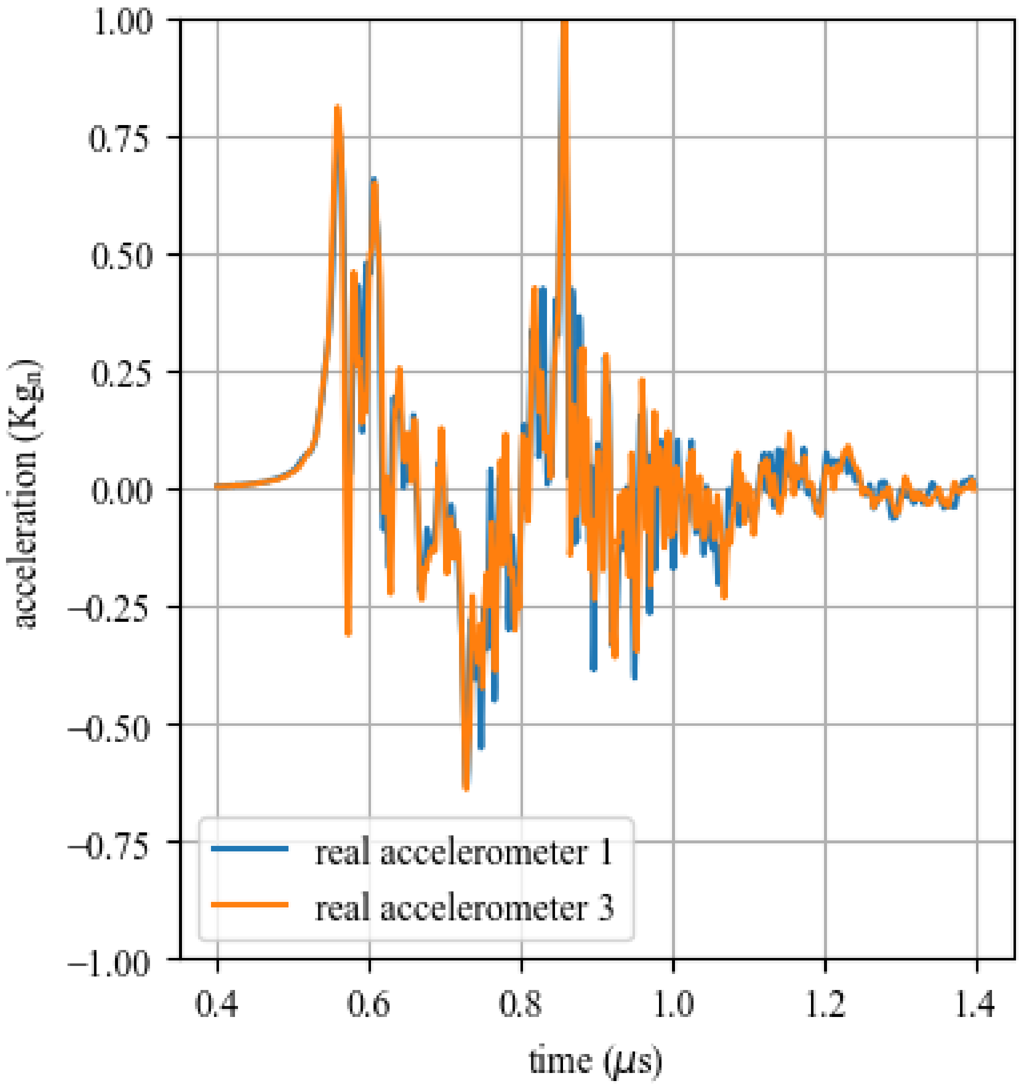
Multimodal

- Generated similarly to unimodal
  - Same gaussian noise vector
  - Different labels

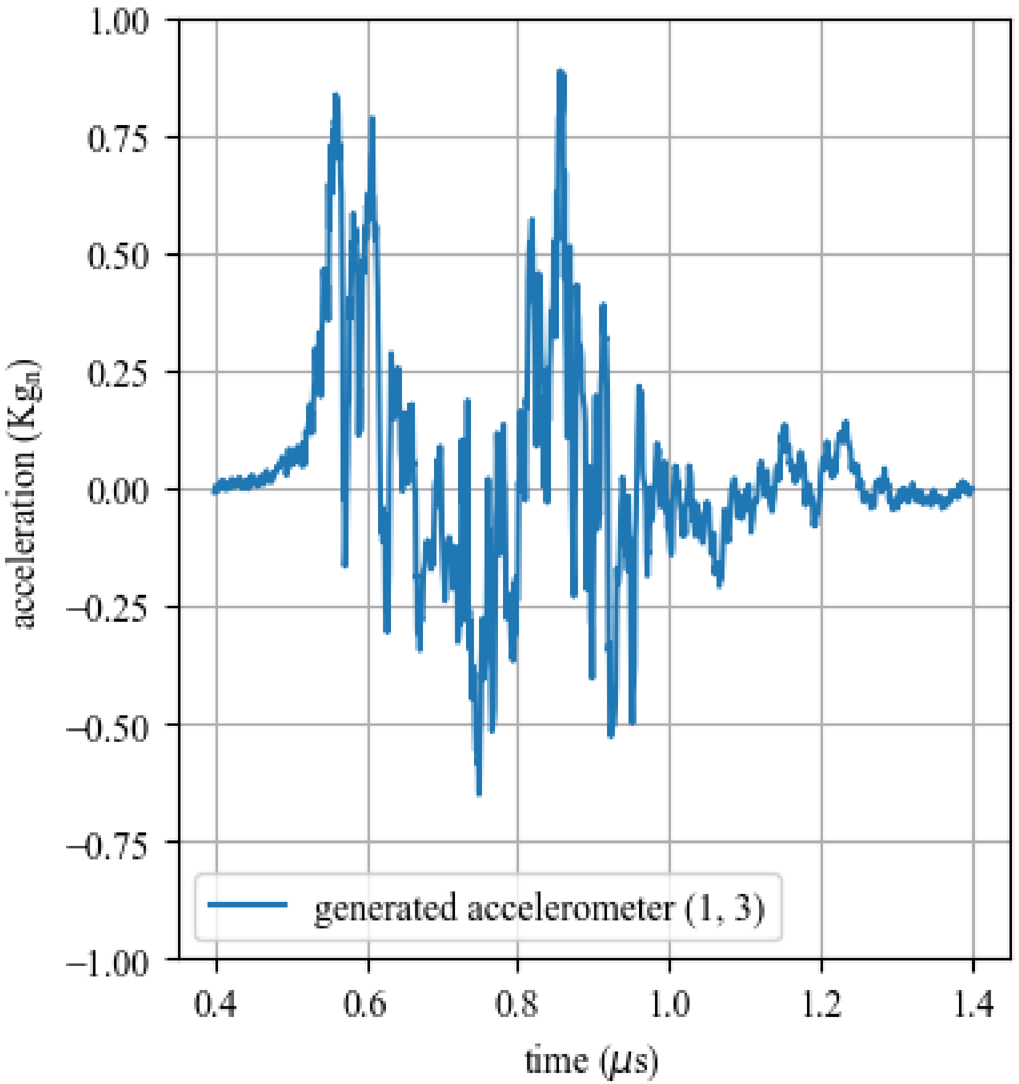


(a) (b)

Time Plots

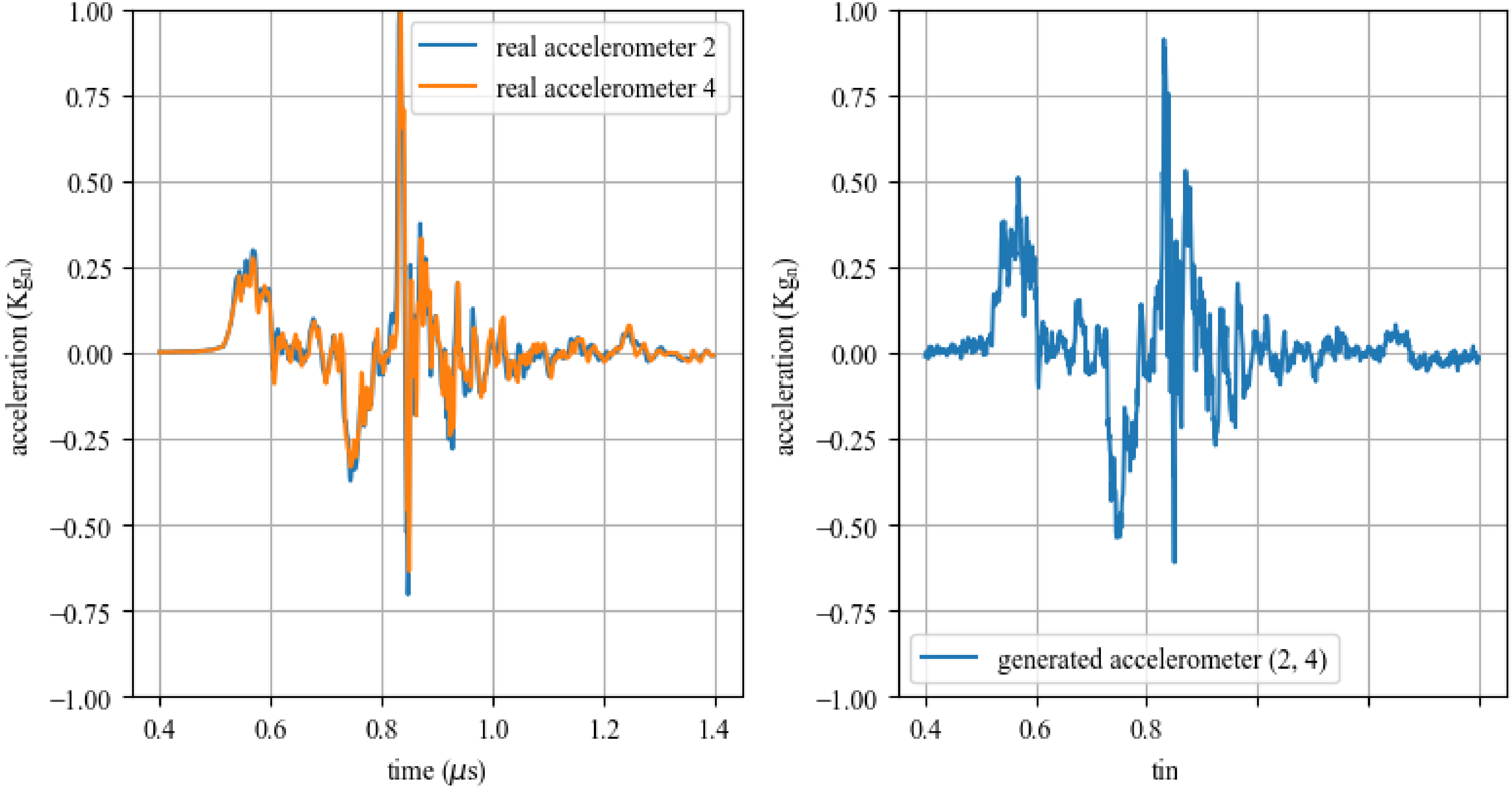


1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
acceleration (Kg$_n$)
0.4
0.6
0.8
1.0
1.2
1.4
time (μs)
real accelerometer 1
real accelerometer 3



1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
acceleration (Kg$_n$)
0.4
0.6
0.8
1.0
1.2
1.4
time (μs)
generated accelerometer (1, 3)

Time Plots



1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
acceleration (Kg$_n$)
real accelerometer 2
real accelerometer 4
0.4
0.6
0.8
1.0
1.2
1.4
time (μs)
acceleration (Kg$_n$)
generated accelerometer (2, 4)
tin

Conclusion

- This paper proposes a solution for the lack of consistency for high-rate events via GANs
- Using a sample of experiments, the generator can find a mapping across the latent space.

References

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Questions

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