LSTM-based health estimation of electronic components subjected to repeated high-energy impacts

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Methodology | Experimentation | Results and Discussion | Future work

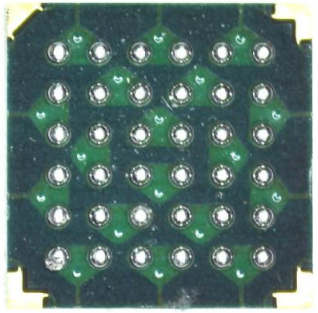
Outline:

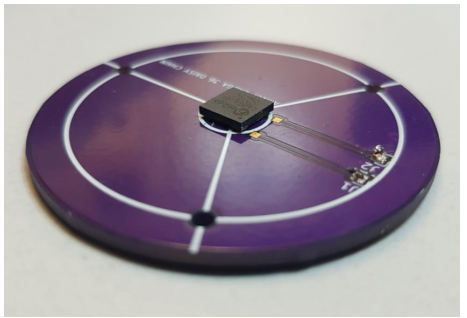
Methodology
- effect of high-rate dynamics on electronic components
- PCB health state estimation

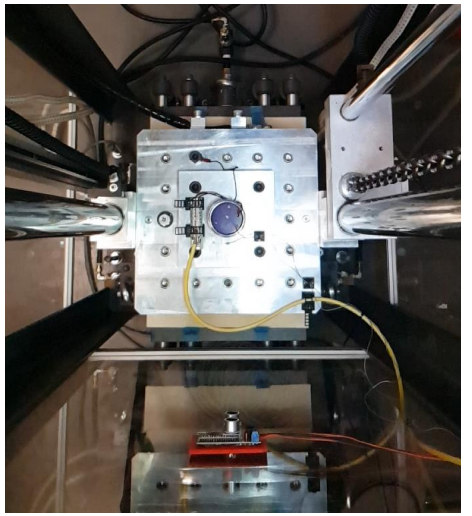
Experimentation
- experimental setup
- daisy chain PCB impedance

Results and discussion
- time and frequency domain
- feature extraction
- impedance vs. number of impacts
- model design and training
- model performance

Future work
- multi-connection impedance measurement
- raise sampling rate and impact magnitude

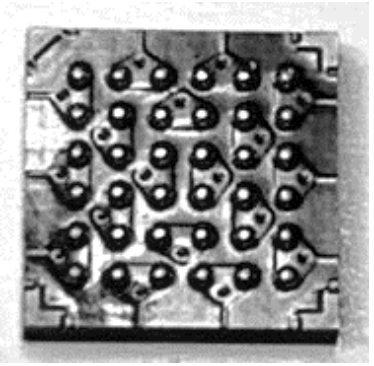


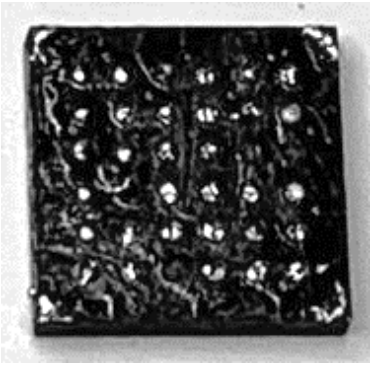


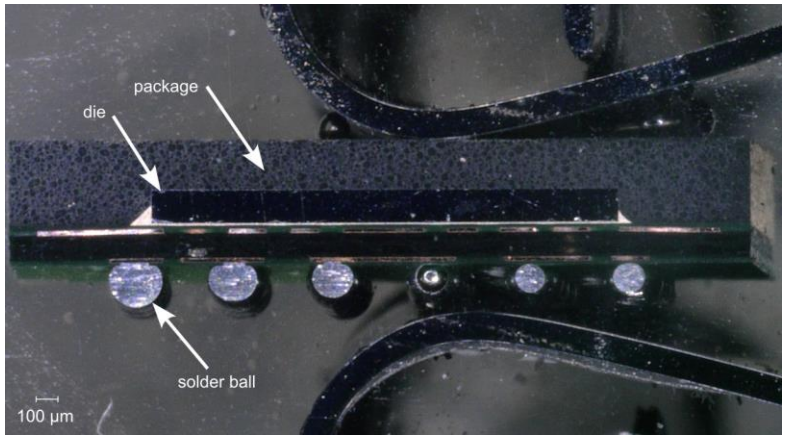


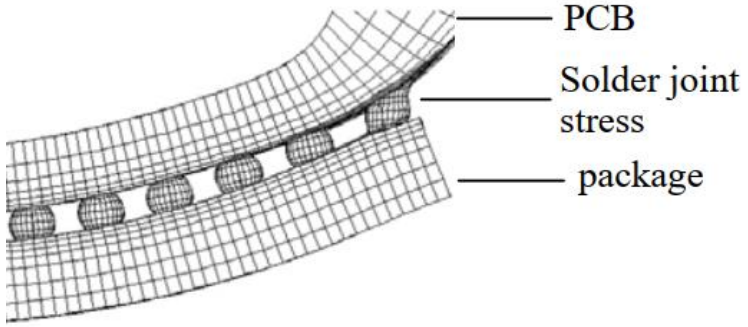
High-rate dynamics

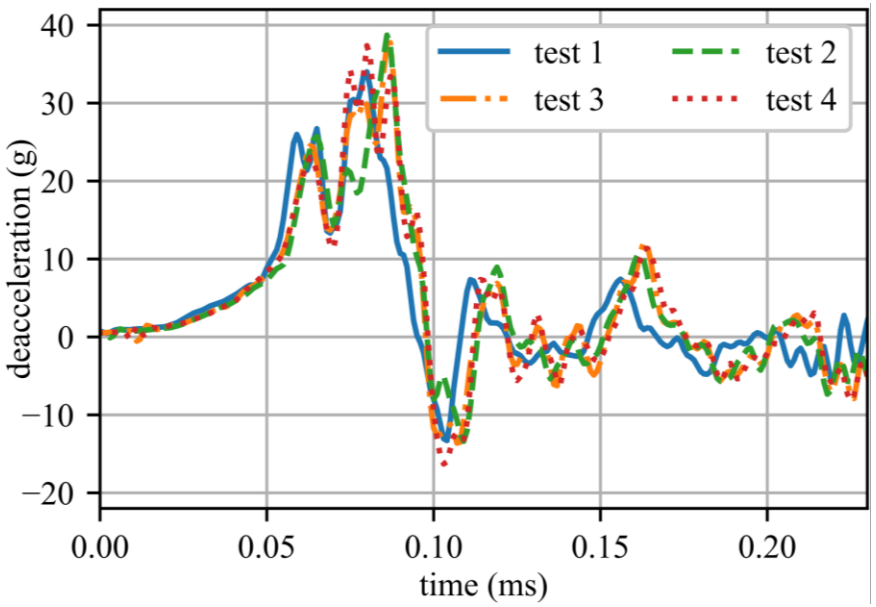
1) large uncertainties in the external loads;
2) high levels of non-stationarities and heavy disturbances; and
3) generated unmodeled dynamics from changes in system configuration.

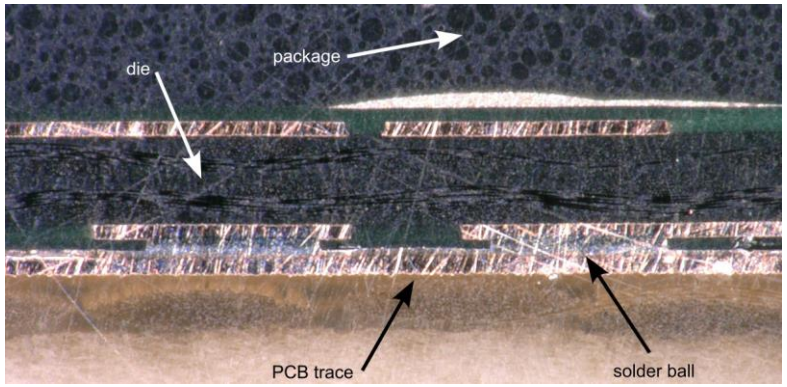






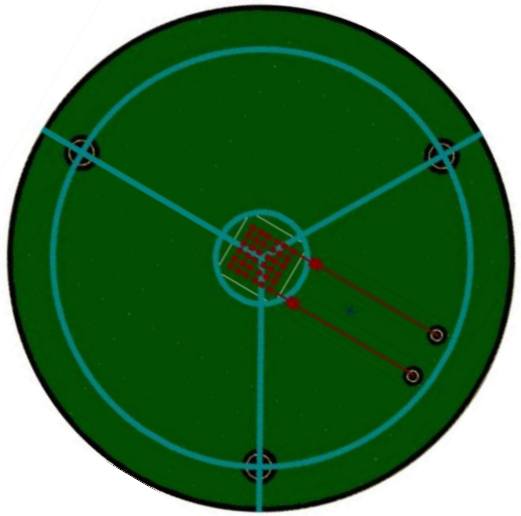


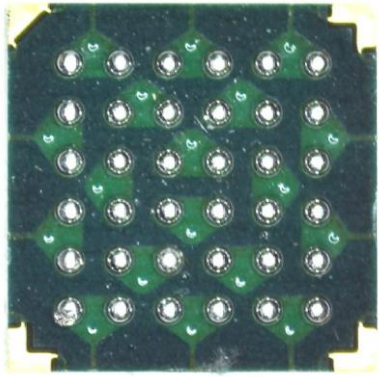


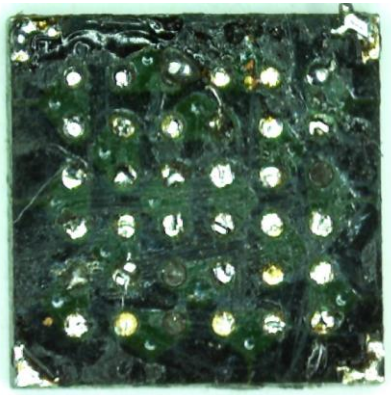


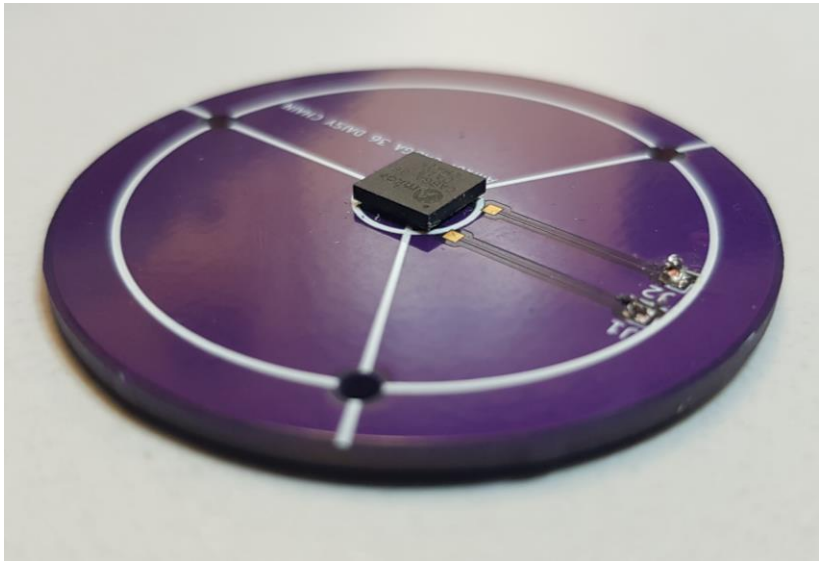
PCB health state estimation

- estimate the state of electrical connections
- using acceleration and impedance
- predict health class (healthy, unhealthy)
- supervised learning framework

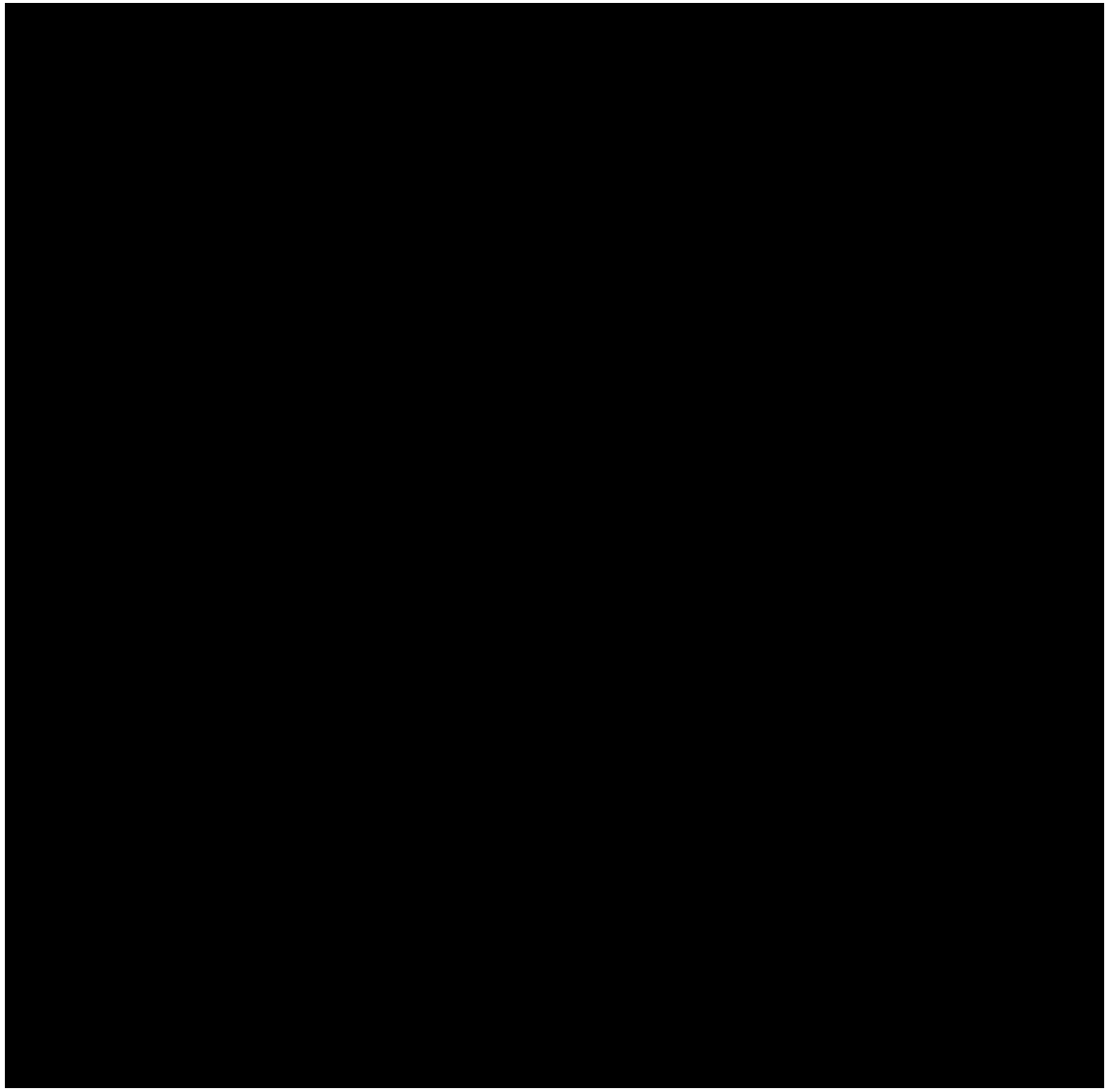


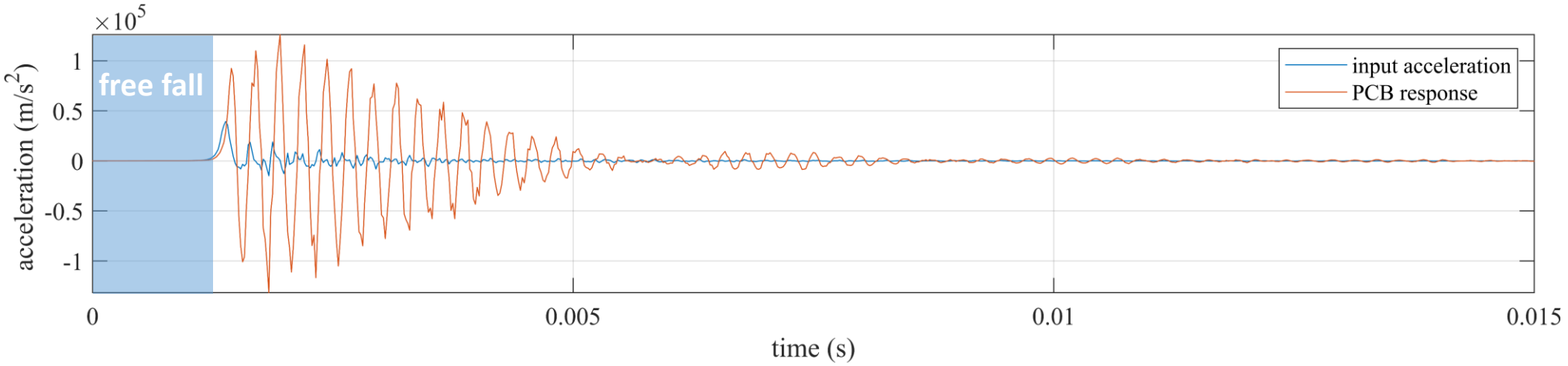


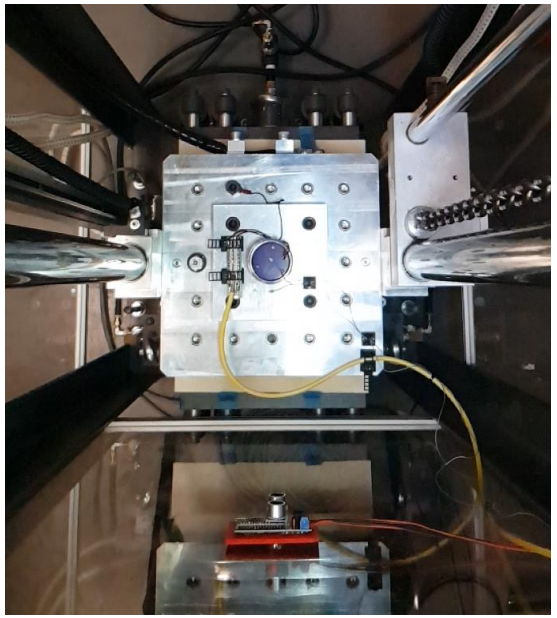


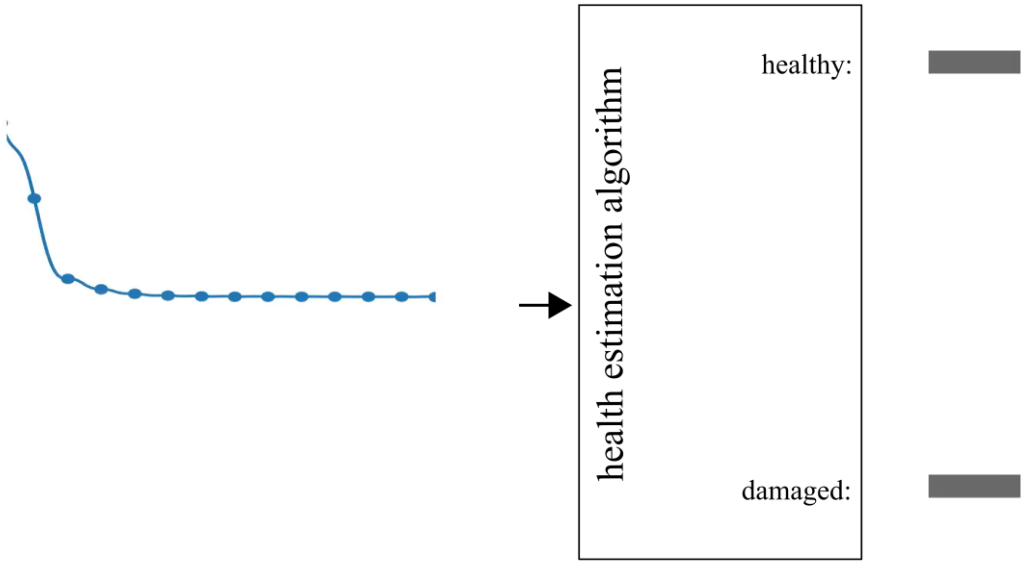


PCB health state estimation

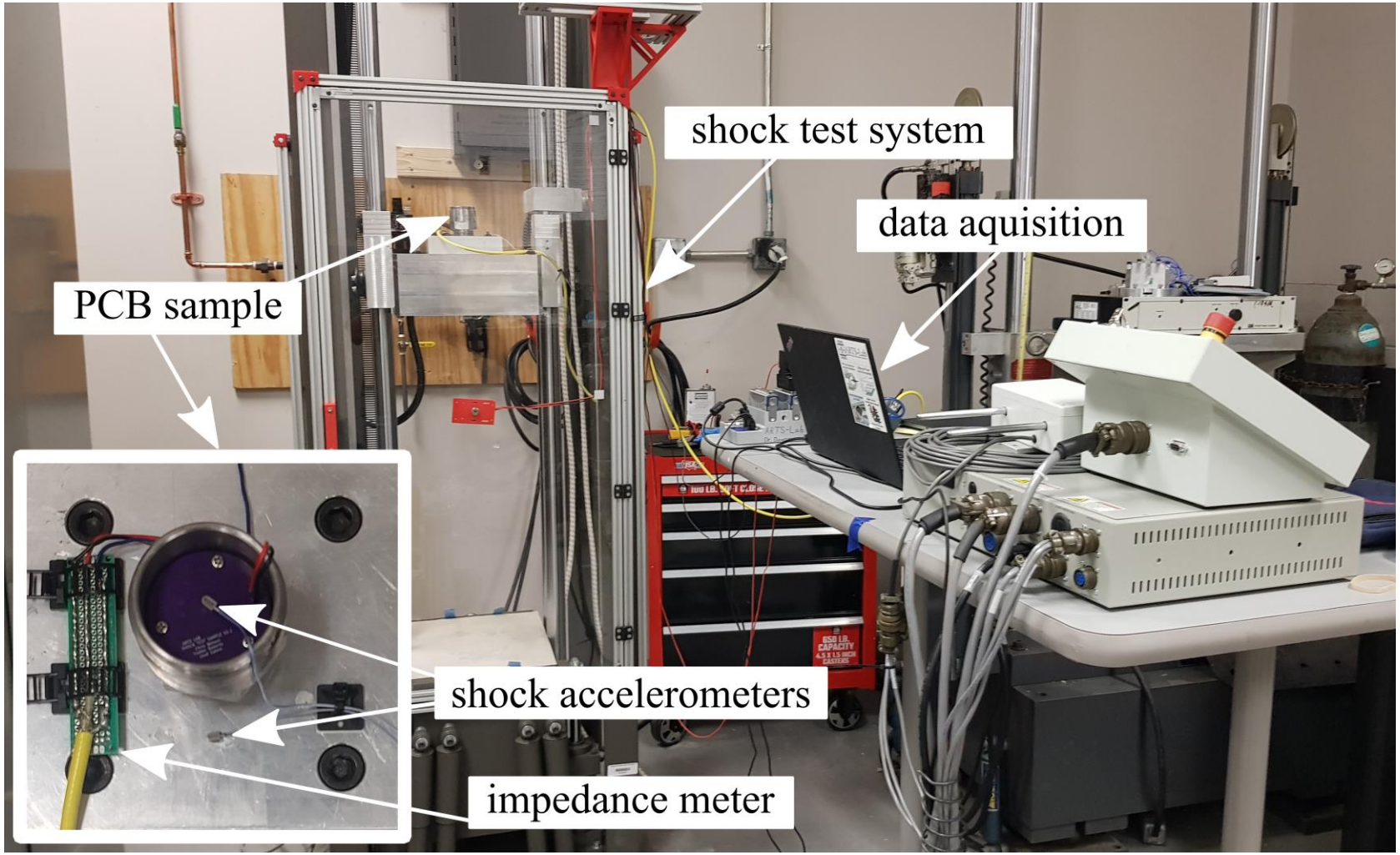



×10^5
1
0.5
0
-0.5
-1
acceleration (m/s^2)
free fall
input acceleration
PCB response
0
0.005
0.01
0.015
time (s)

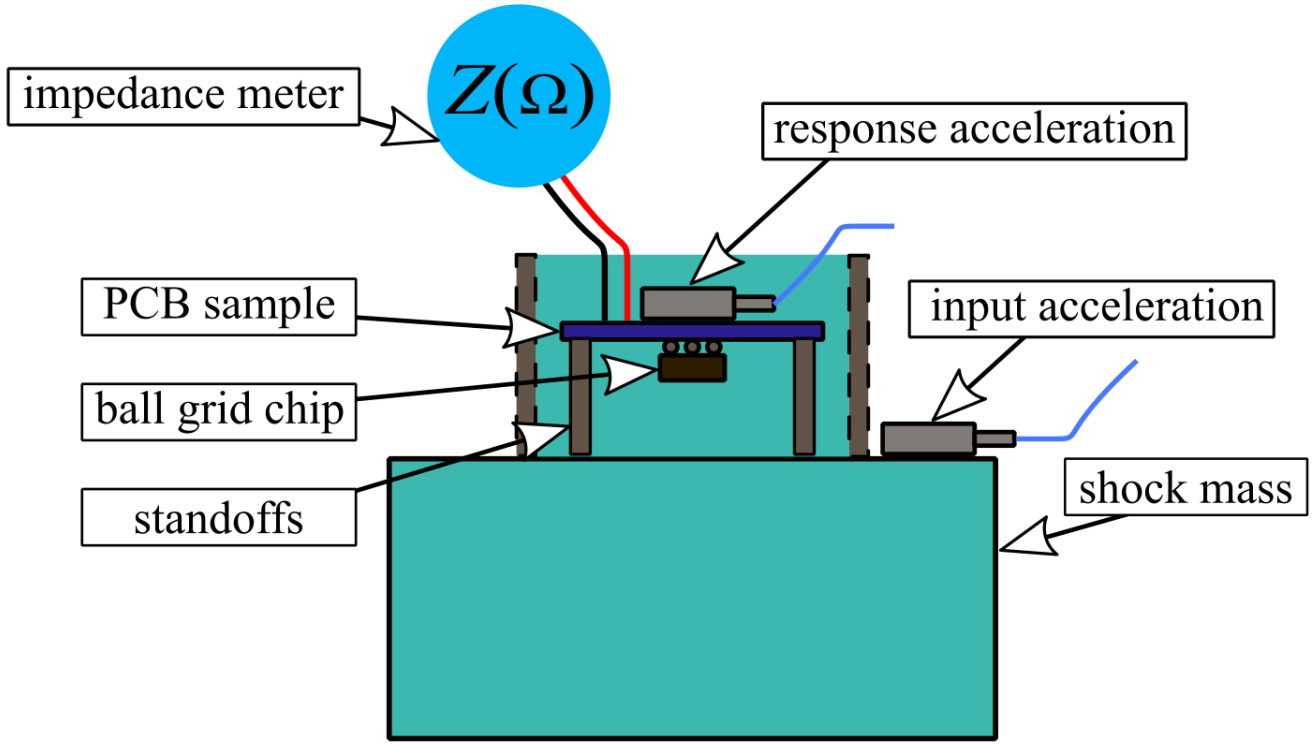


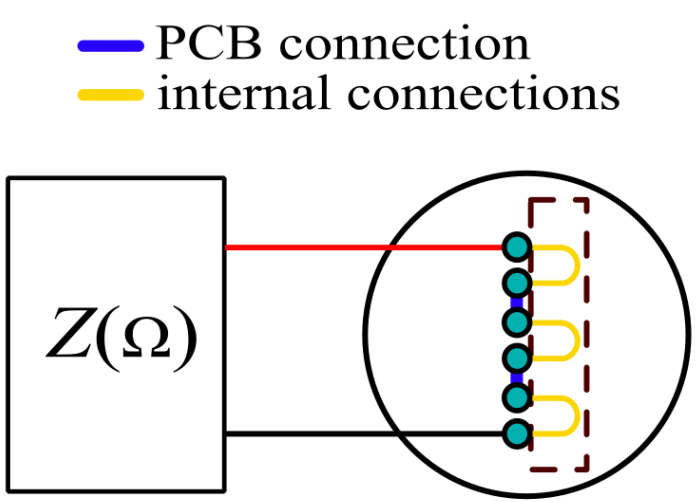

health estimation algorithm
healthy:
damaged:

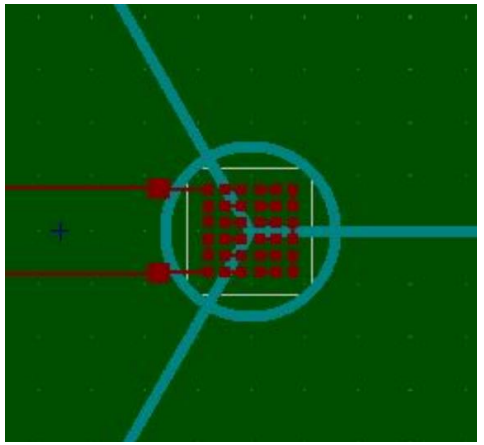
Experimental setup

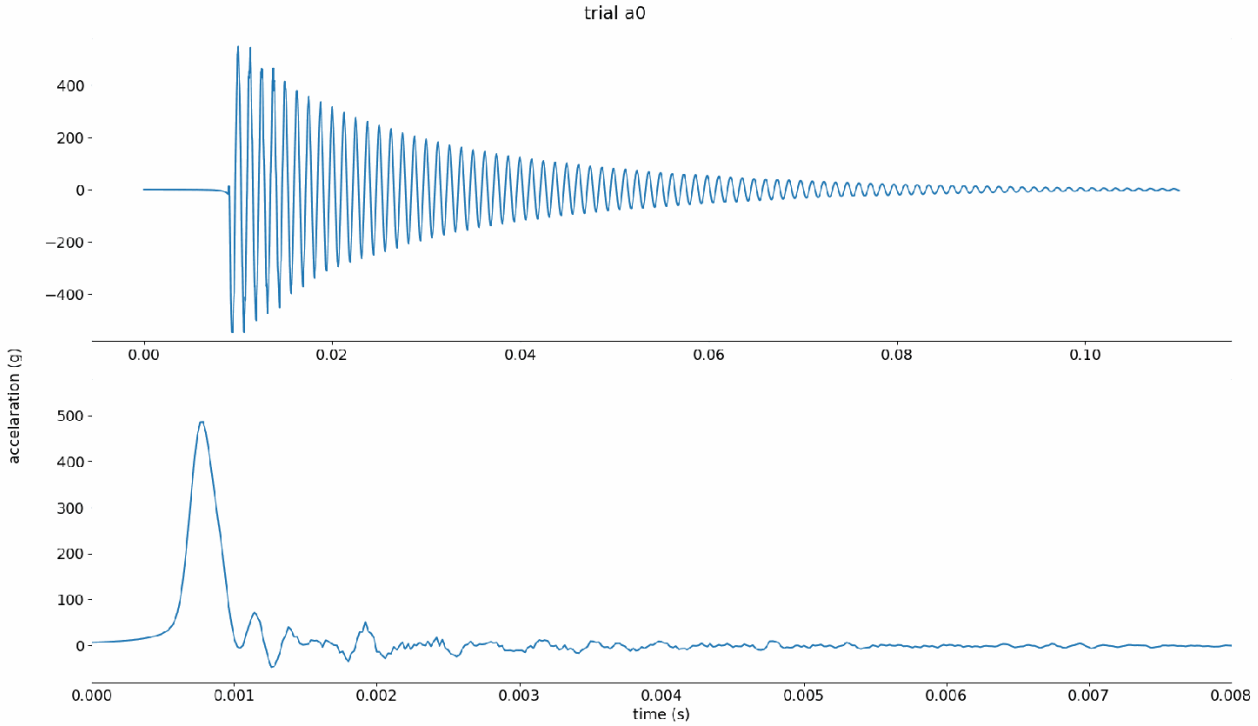


Daisy chain PCB impedance








trial a0
400
200
0
−200
−400
0.00
0.02
0.04
0.06
0.08
0.10
accelaration (g)
500
400
300
200
100
0
0.000
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
time (s)

Common Datasets - a Method for Collaboration

https://github.com/High-Rate-SHM-Working-Group

Dataset-1-High-Rate-Drop-Tower-Data-set Public
A data set focused on quad PCBs under shock.
Python 0 0 0 0 Updated on Jun 23, 2021

Dataset-1a-Shock-Test-GAN-model Public
Generating model trained on Dataset 3
Python CC-BY-SA-4.0 0 0 0 0 Updated on Jun 24, 2022

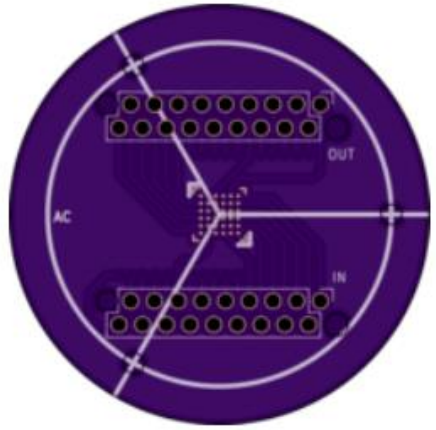
Dataset-2-DROPBEAR-Acceleration-vs-Roller-Displacement Public
Acceleration-vs-Roller-Displacement Dataset for DROPBEAR
Python CC-BY-SA-4.0 1 1 0 0 Updated on Nov 23, 2022

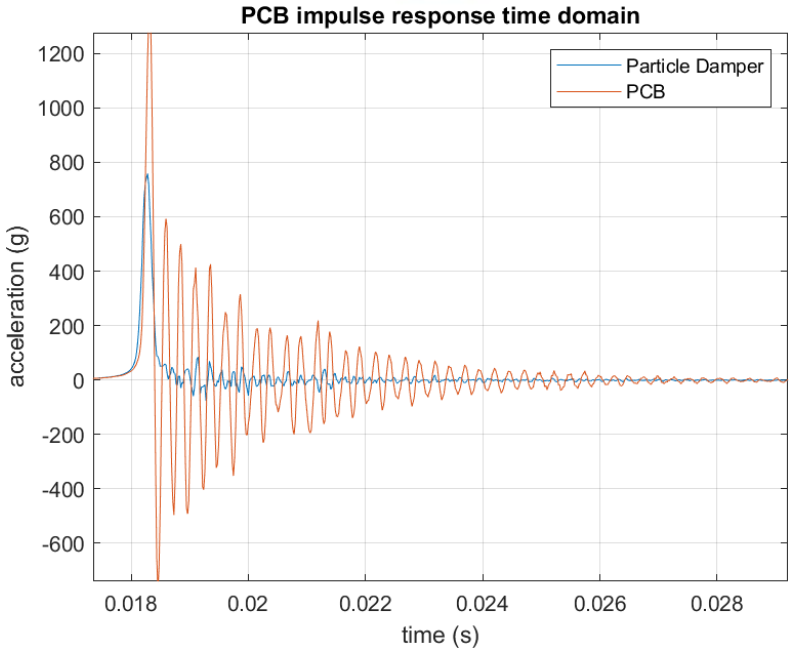
Dataset-3-High-Rate-In-Situ-Damage-of-Electronics-Packages Public
Drop Tower shock tests of highly-instrumented electronics package
0 0 0 0 Updated on Jun 24, 2021

Dataset-4-Univariate-signal-with-non-stationarity Public
univariate signal with varying levels of non-stationarities
Python CC-BY-SA-4.0 0 0 0 0 Updated on Sep 27, 2022

Dataset-5-Extended-Impact-Testing Public
Roff CC-BY-SA-4.0 0 0 0 0 Updated on Sep 30, 2022

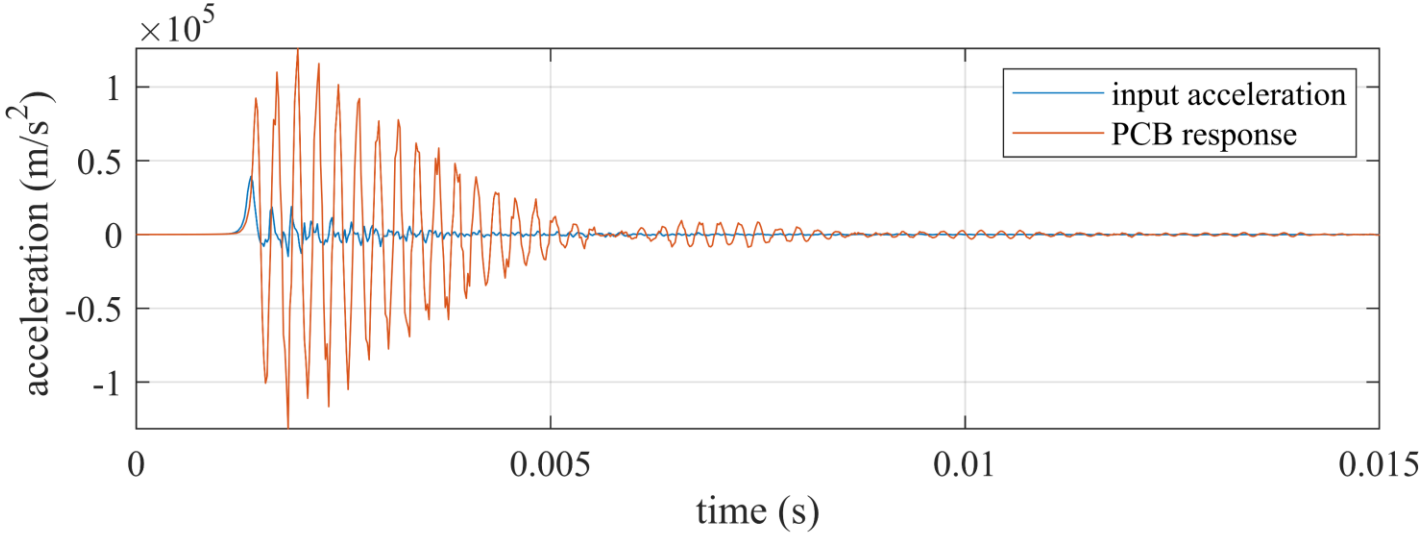
Dataset-6-DROPBEAR_data Public
Data for the paper Generated datasets from dynamic reproduction of projectiles in ballistic environments for advanced research (DROPBEAR)
0 0 0 7 Updated on Jul 24, 2022

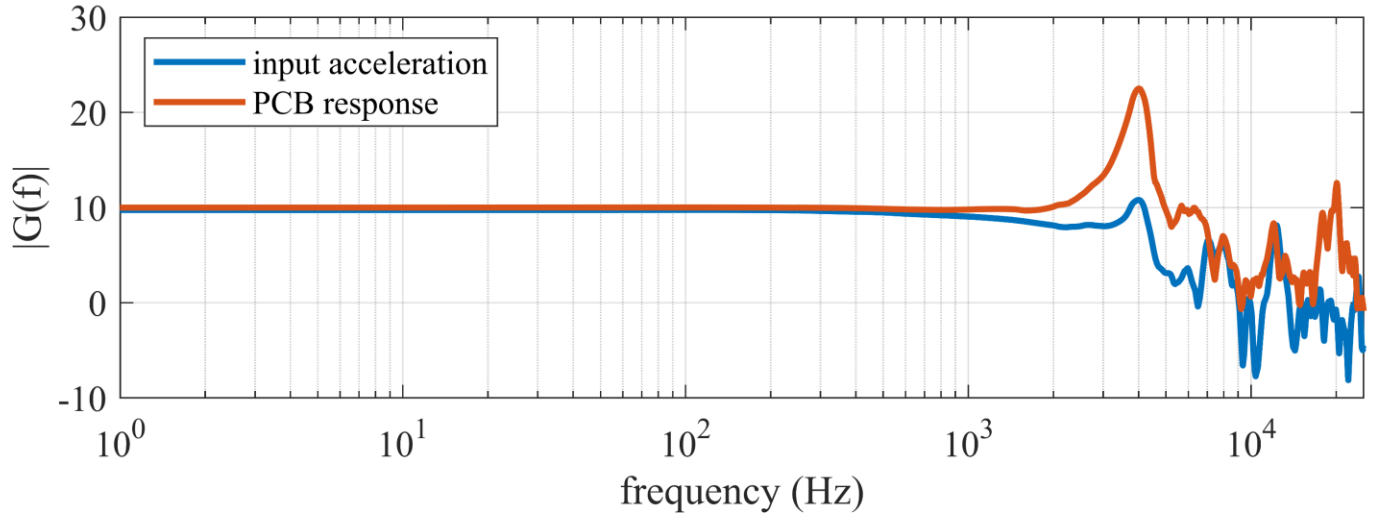




https://github.com/High-Rate-SHM-Working-Group/Dataset-5-Extended-Impact-Testing/tree/main/data/dataset-2

Time and frequency domain response





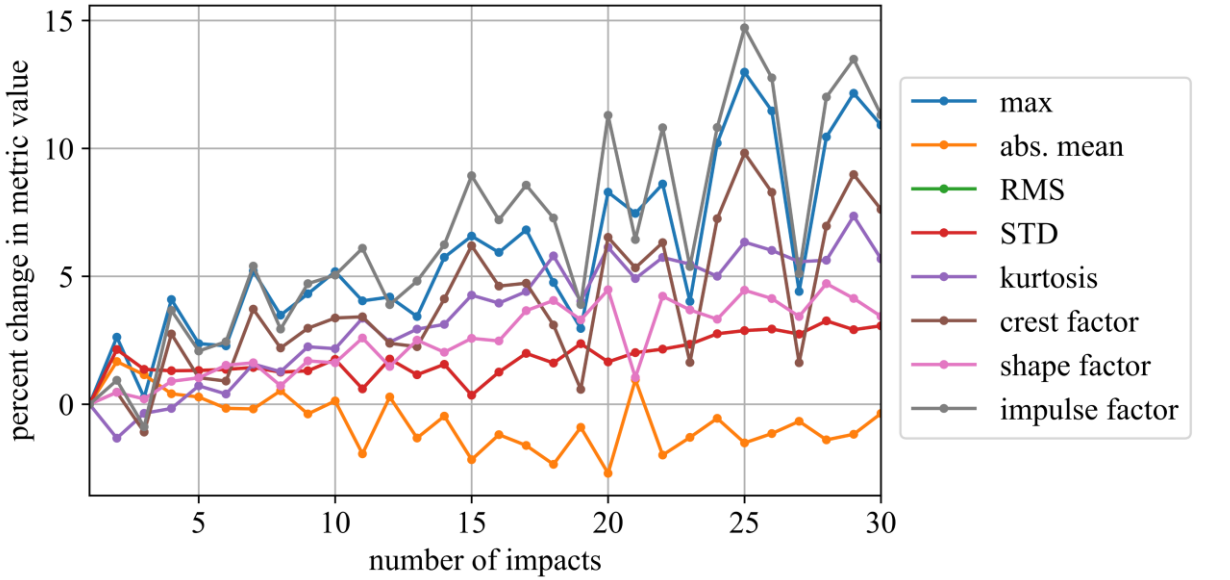
Acceleration feature extraction (X)

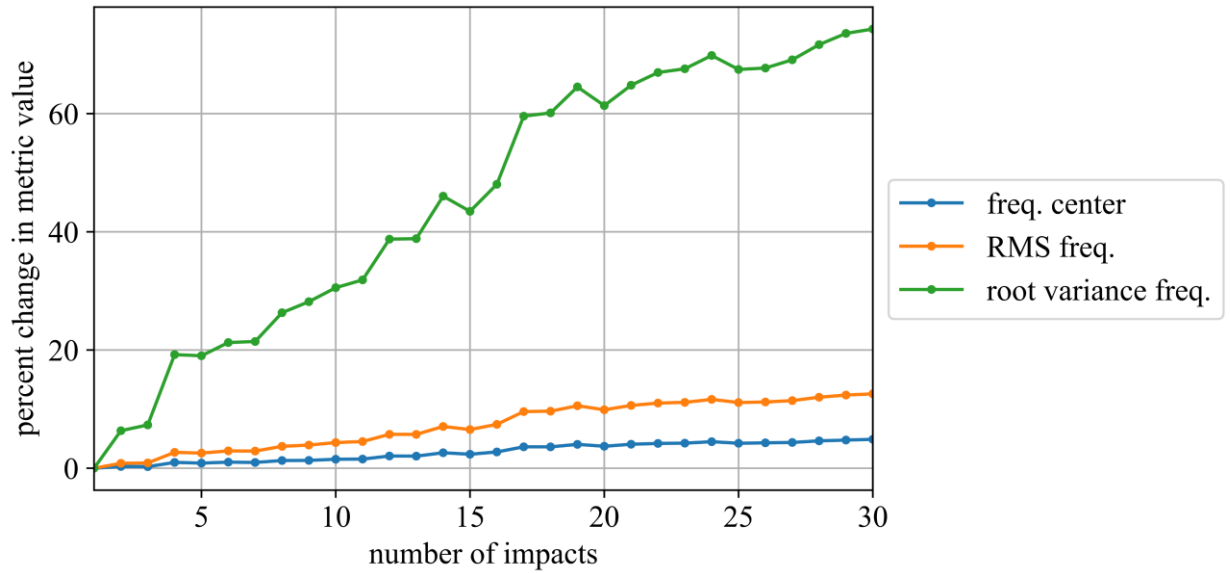
Table 1 Time-domain features

No.	Features	Description	Physical interpretation
T1	Maximum	$\mathrm{Max}(X_i)$	Kinetic energy related
T2	Absolute Mean	$\mathrm{Mean}(\lvert X_i \rvert)$	
T3	RMS	$\sqrt{\frac{\sum X_i^2}{N}}$	
T4	Skewness	$\frac{\sum (X_i - \bar{X})^3}{(N-1)s^3}$	Data statistics related
T5	Kurtosis	$\frac{\sum (X_i - \bar{X})^4}{(N-1)s^4}$	
T6	Crest Factor	$\frac{\mathrm{Max}(X_i)}{X_{rms}}$	Sinusoidal wave shape related
T7	Shape Factor	$\frac{X_{rms}}{\mathrm{Mean}(\lvert X_i \rvert)}$	
T8	Impulse Factor	$\frac{\mathrm{Max}(X_i)}{\mathrm{Mean}(\lvert X_i \rvert)}$	

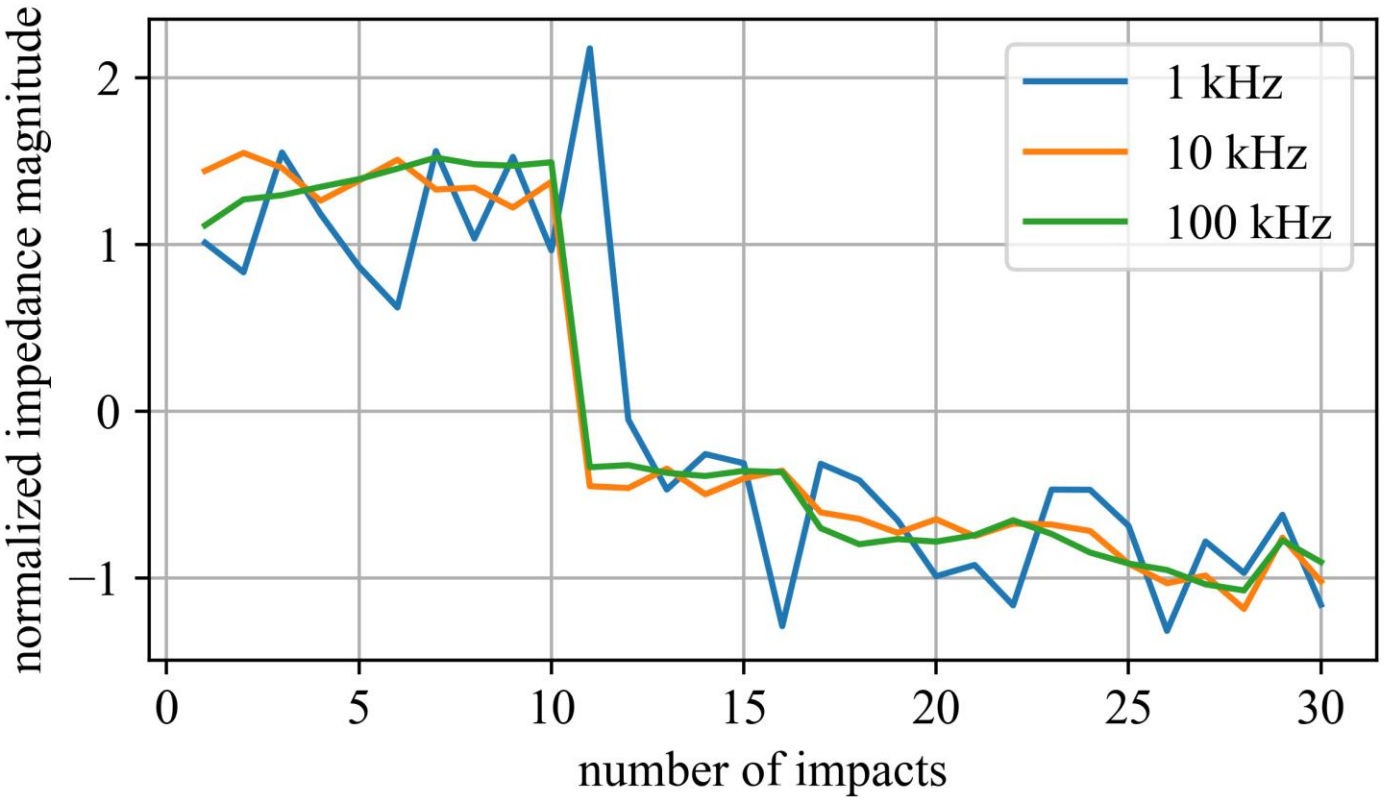
Table 2 Frequency-domain features

No.	Features	Description	Physical interpretation
F1	FC	$\frac{\int f \times s(f) df}{\int s(f) df}$	Position change of main frequencies
F2	RMSF	$\left[\frac{\int f^2 \times s(f) df}{\int s(f) df}\right]^{1/2}$	

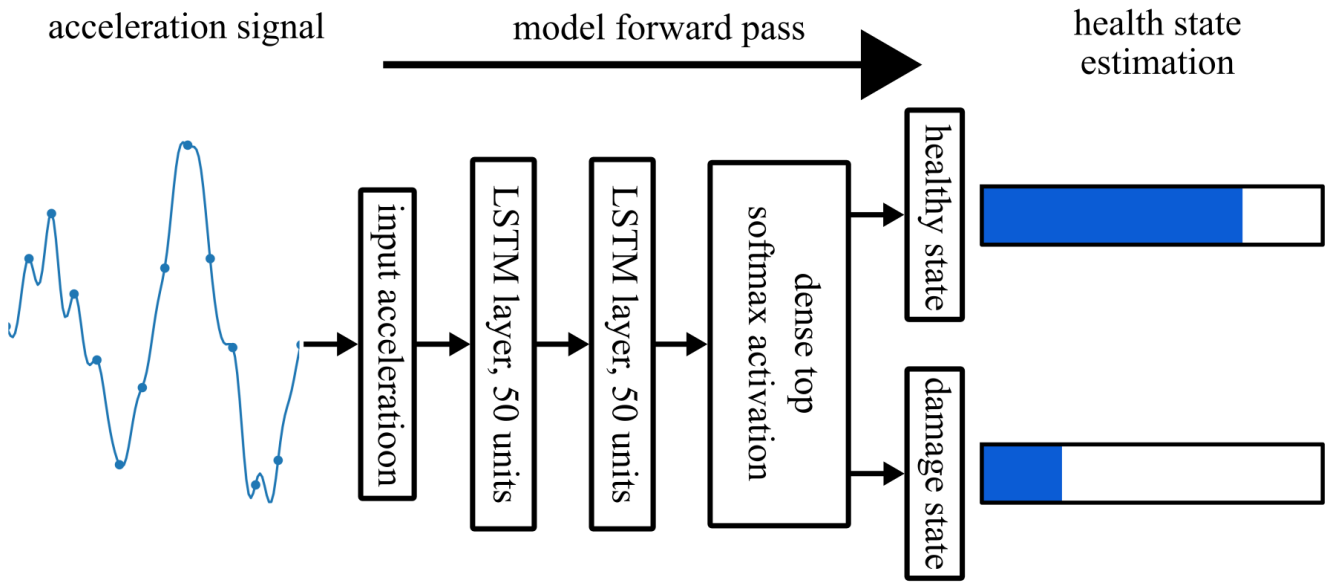


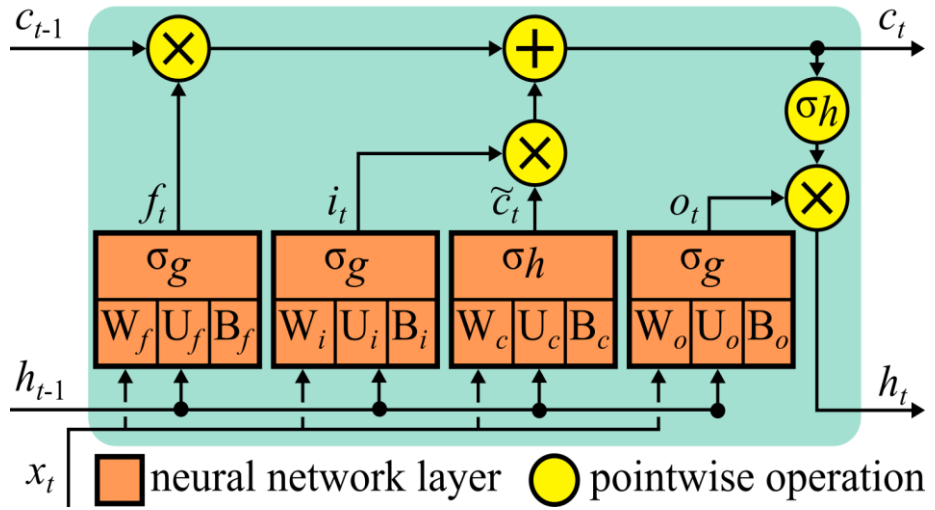


Electrical feature extraction (*y*)



Model design and training

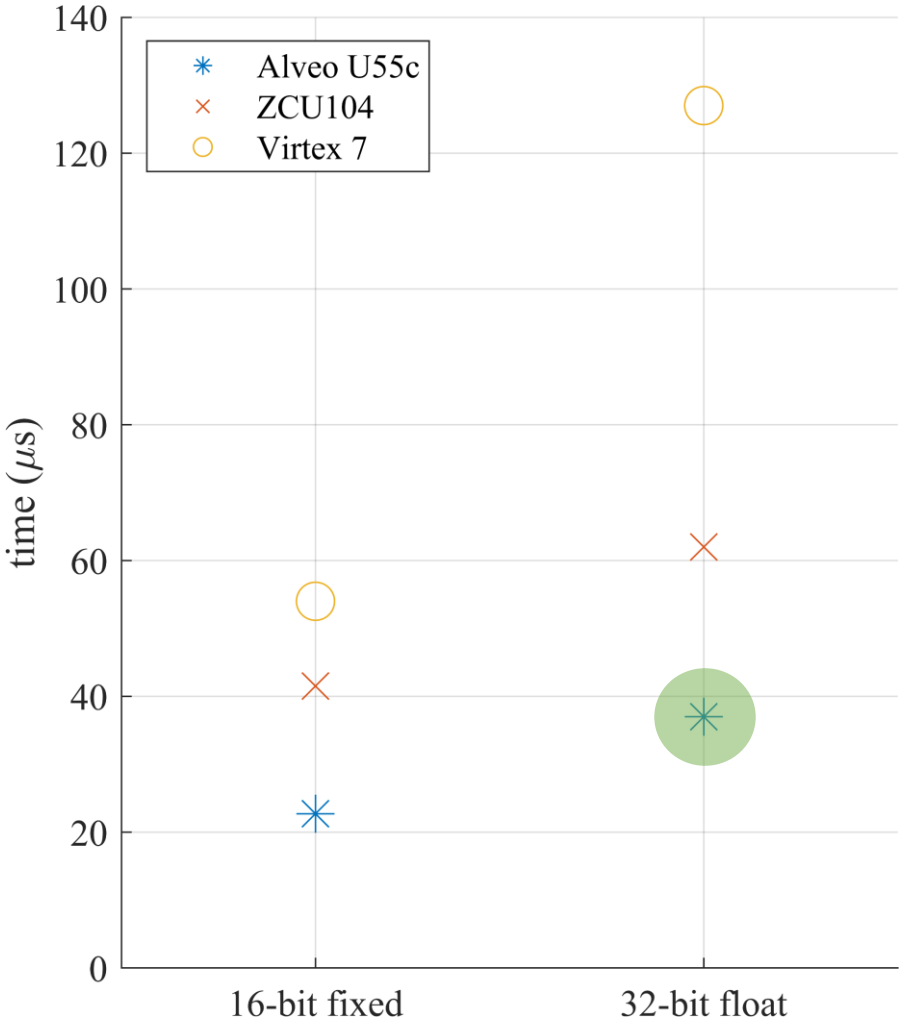




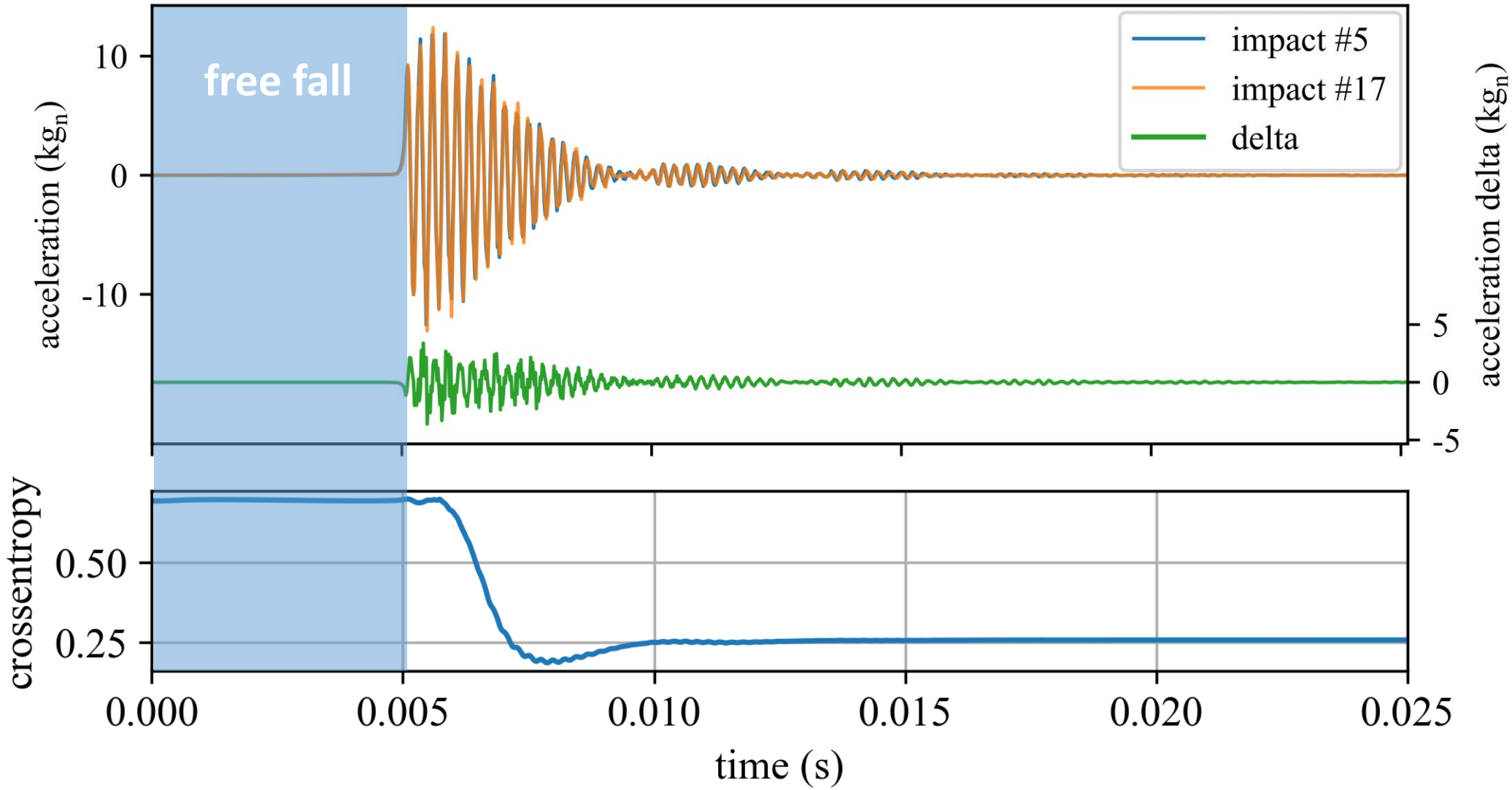
Model FPGA implementation

FPGA	Data Format	DSPs	BRAMs_18k	LUTs	FFs	Frequency (MHz)	Latency (µs)
Alveo U55c		1177	653	142344	242989	300	37
ZCU104	Float 32 bit	769	479	136242	263580	270	62
Virtex 7		769	487	192925	316056	150	127

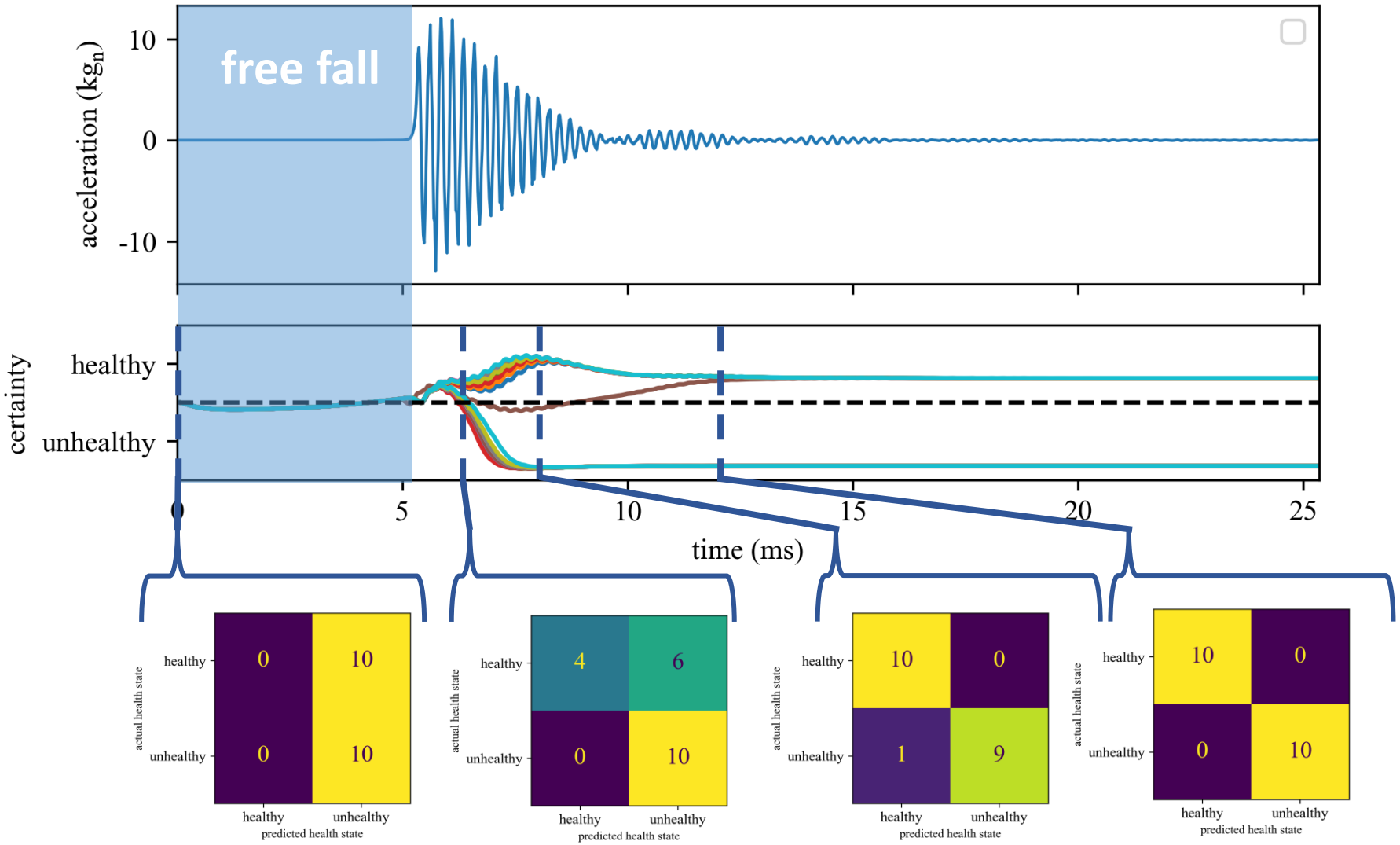
FPGA	Data Format	DSPs	BRAMs_18k	LUTs	FFs	Frequency (MHz)	Latency (µs)
Alveo U55c		470	416	75924	112625	283	22.7
ZCU104	Fixed 16 bit	454	242	32354	57956	280	41.5
Virtex 7		489	254	92534	129839	220	54



Model performance

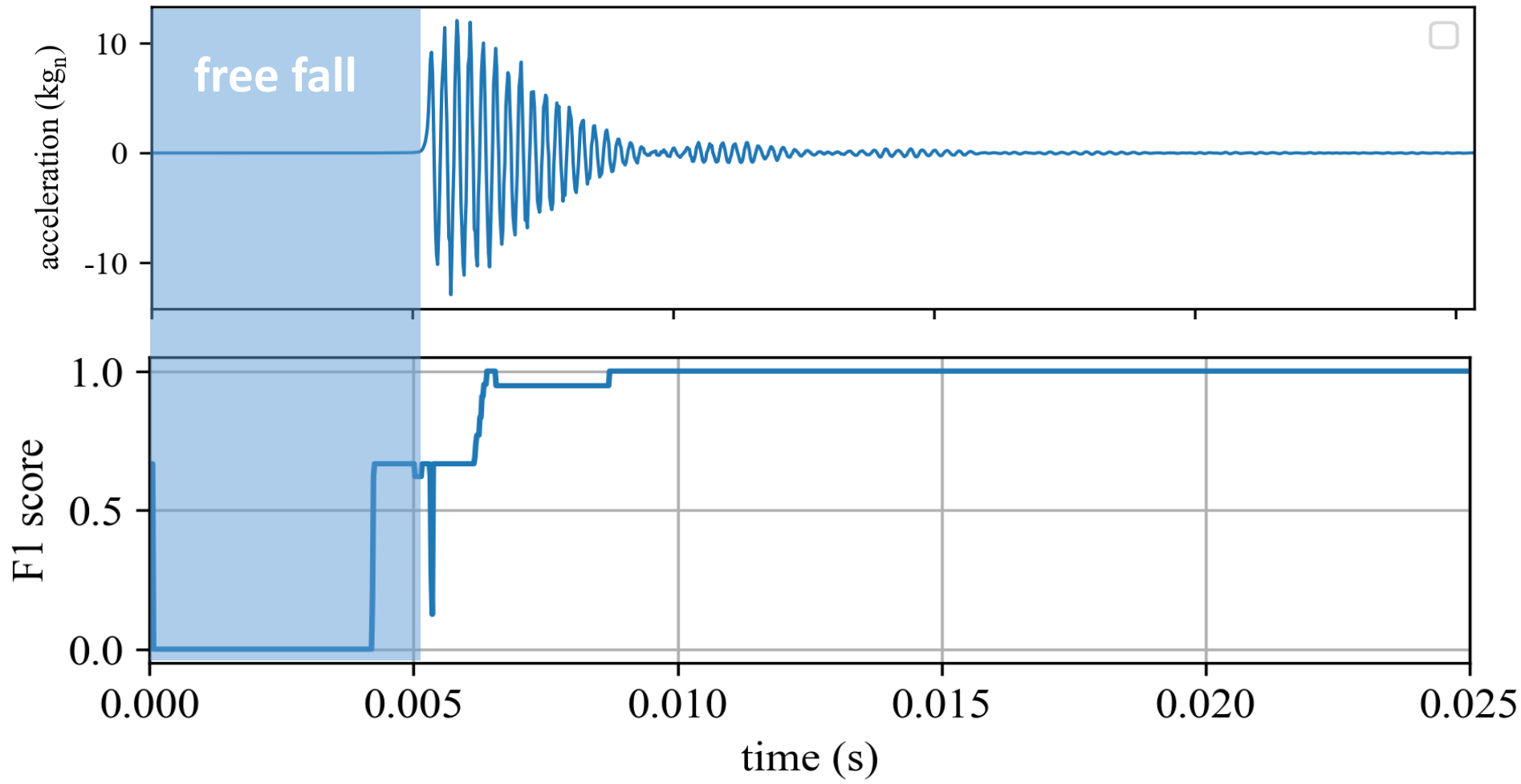


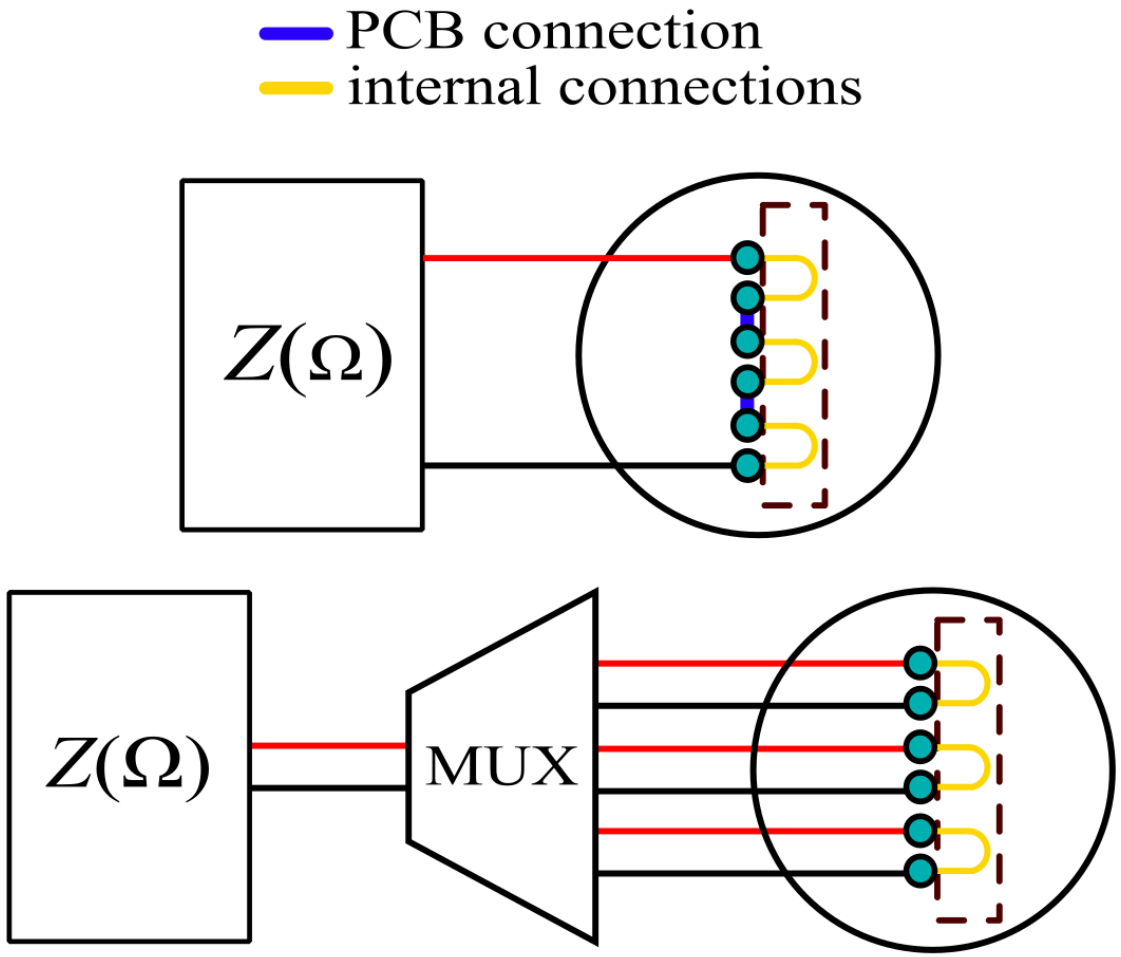
Model design and training

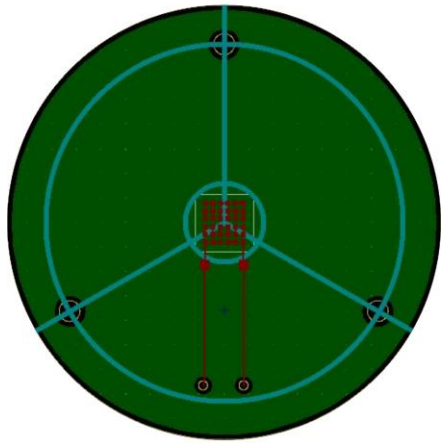


Model performance (F1 score)

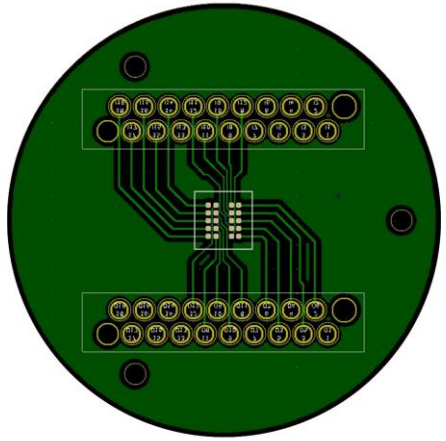
$$\mathbf{F1} = \frac{\mathrm{TP}}{\mathrm{TP} + \frac{1}{2}(\mathrm{FP} + \mathrm{FN})}$$

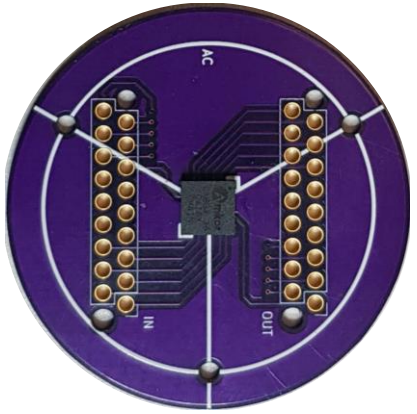



PCB connection
internal connections
Z(Ω)
Z(Ω)
MUX




Amkor CABGA 36 DAISY CHAIN




AC
IN
OUT

ACKNOWLEDGEMENT:

This material is based upon work supported by the Air Force Office of Scientific Research (AFOSR) through award no. FA9550-21-1-0083. This work is also partly supported by the National Science Foundation (NSF) grant numbers 1937535, 1956071, and 2237696. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or the United States Air Force.

Thank you

Questions?

Please consider submitting to IMAC 2025 for a special session on high-rate dynamics.

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