Binkun LIU, Zhenyi XU, Yu KANG, Yang CAO, Yunbo ZHAO, 2025. Multisensor contrast neural network for remaining useful life prediction of rolling bearings under scarce labeled data. *Frontiers of Information Technology & Electronic Engineering*, 26(7):1180-1193. https://doi.org/10.1631/FITEE.2400753

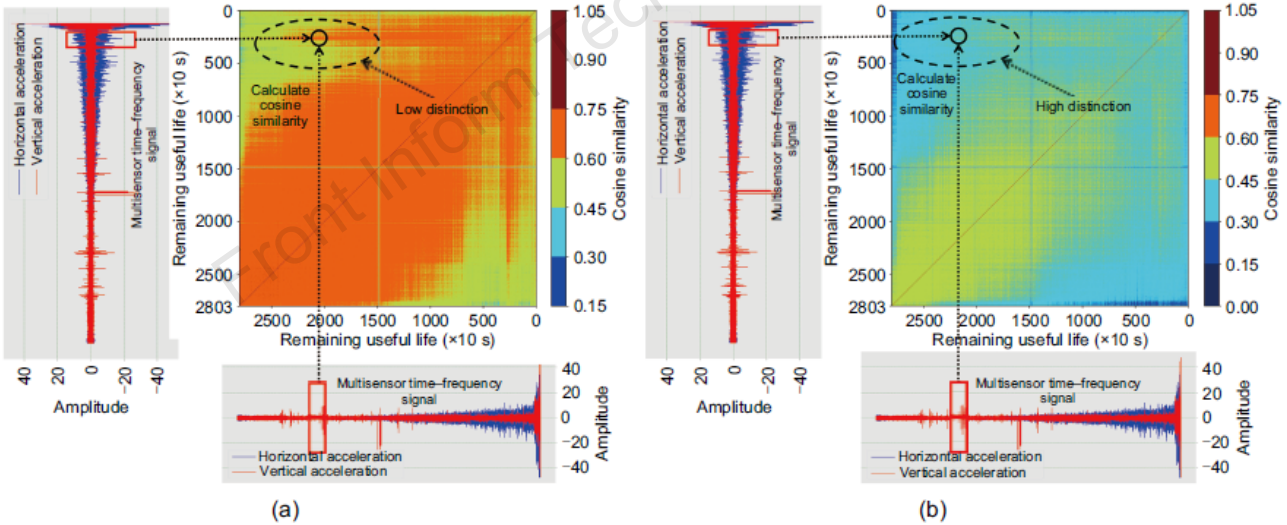
Multisensor contrast neural network for remaining useful life prediction of rolling bearings under scarce labeled data

Key words: Self-supervised; Remaining useful life prediction; Contrast learning

Zhenyi XU
E-mail: xuzhenyi@mail.ustc.edu.cn
ORCID: https://orcid.org/0000-0002-5804-882X
Yunbo ZHAO
E-mail: ybzhao@ustec.edu.cn
ORCID: https://orcid.org/0000-0002-3684-5297

Motivation

- Current methods treat each sensor signal as a channel and mine the temporal autocorrelation of multisensors from massive unlabeled sensor data during pretraining. Temporal autocorrelation is then used as a representation and finetuned with the limited labeled data to achieve RUL prediction. However, methods using stacked channels may have the weakness in possessing similar sensor signals in different degradation states, which is not favorable for RUL prediction.

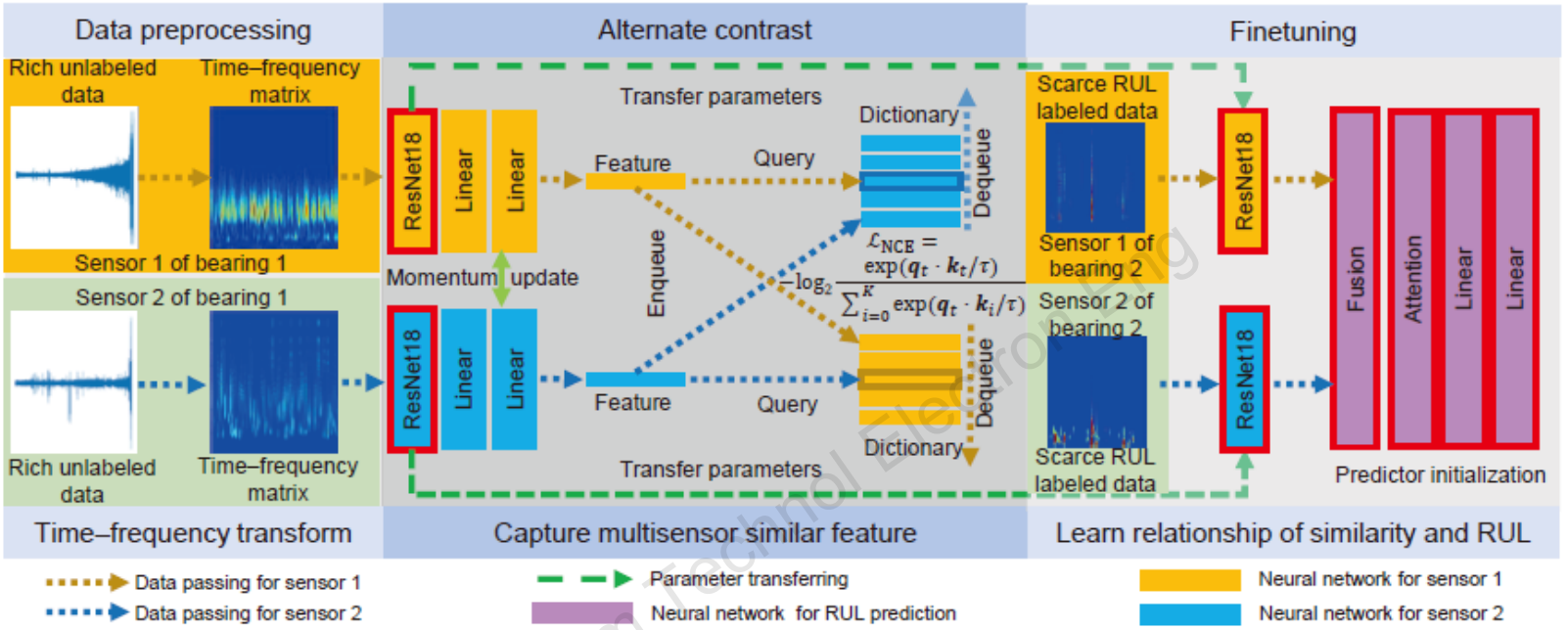


(a) the cosine similarity matrix between stacked signals at any two moments of bearing 1_1;
(b) the correlation between the vertical and horizontal acceleration time–frequency signals calculated using the dot product, and the cosine similarity matrix between correlations at any two moments of bearing 1_1

Main idea

- Given that cross-sensor similarity improves the discrimination of degradation features, we propose a **multisensor contrast method** for RUL prediction under scarce RUL-labeled data, in which we use **cross-sensor similarity** to mine multisensor similar representations that indicate the machine health condition from rich unlabeled sensor data in a co-occurrence space.

Method

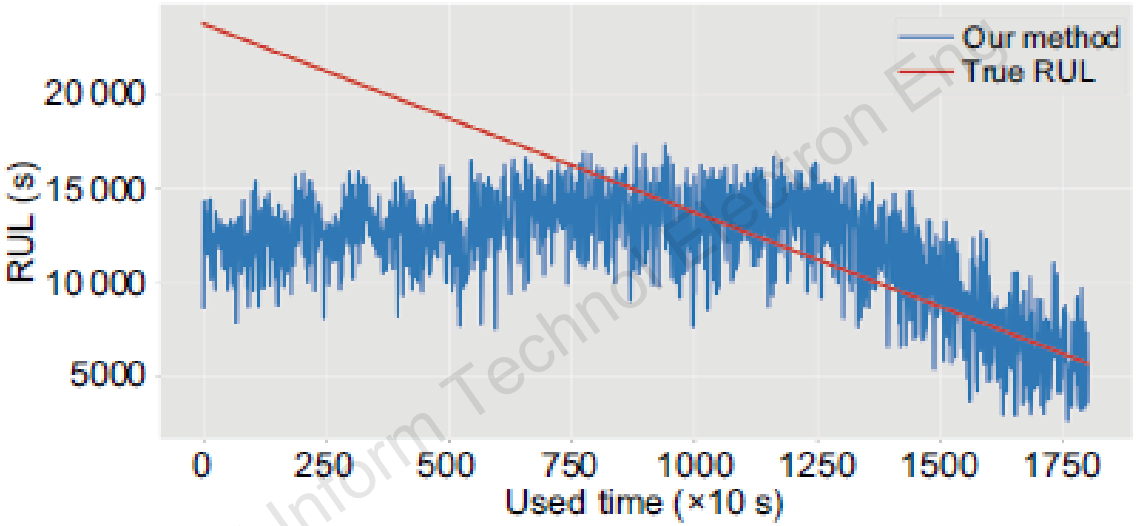


The data preprocessing step transforms the original signal into a time–frequency domain to extract the features of the time and frequency domains. Alternative contrast alternately captures similar features between multisensors. Finetuning reuses the parameters of the feature extractor and initializes the predictor, thereby reducing the need for labeled data in the finetuning stage.

Contrast loss can be describe as

$$\mathcal{L}_{\mathrm{NCE}} = -\sum_{j} \log_2 \frac{\exp\left(\frac{\mathrm{Sim}_{t,t}^{j}}{\tau}\right)}{\exp\left(\frac{\mathrm{Sim}_{t,t}^{j}}{\tau}\right) + \sum_{k=0,k\neq t}^{K} \exp\left(\frac{\mathrm{Sim}_{t,k}^{j}}{\tau}\right)} + \mu_{\mathrm{c}} \left\|\theta_{\mathrm{m}}\right\|_2 ,$$

Results



RUL prediction for bearing 1_3. The horizontal axis is the used time and the vertical axis is the predicted RUL

Conclusions

- In this paper, for RUL prediction, we propose a multisensor contrast method that uses abundant unlabeled sensor data to assist a small amount of sensor data with RUL labels. Typically, current methods stack multisensor signals and mine the multisensor temporal autocorrelation from a large amount of unlabeled sensor data during pretraining, but suffer from poor discrimination of degradation features. Our approach uses an alternate contrast process to capture similar features (machine health conditions) among multisensors, and can effectively improve the discrimination of degradation features. The attention mechanism is used for finetuning to establish an association between degradation features and RUL. We fully evaluate our approach using the open FEMTO-ST bearing dataset, where the test dataset contains 11 sets of bearing degradation data under three different operating conditions. The proposed model outperforms state-of-the-art baselines on test data, showing that, for RUL prediction, our proposed model can use rich unlabeled sensor data to assist some sensor data with RUL labels.

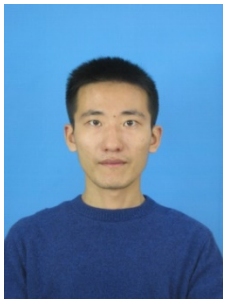
Author Bio

Binkun LIU is currently pursuing his PhD degree at the University of Science and Technology of China, Hefei. He received his bachelor's degree from Hefei University of Technology in 2019. His research interests include machine learning and artificial intelligence.

Yun KANG received the Dr. Eng. degree in Control Theory and Control Engineering from the University of Science and Technology of China, Hefei, in 2005. From 2005 to 2007, he was a post-doctoral fellow in the Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing, China. He is currently a professor in the Department of Automation, University of Science and Technology of China. His current research interests include adaptive/robust control, variable structure control, and Markovian jump systems.

Yang CAO received the B.S. and Ph.D. degrees in Information Engineering from Northeastern University, Shenyang, China, in 1999 and 2004, respectively. Since 2004, he has been in the Department of Automation, University of Science and Technology of China, Hefei, China, where he is currently an associate professor. He is a member of the IEEE Signal Processing Society. His current research interests include machine learning and computer vision.

Yunbo ZHAO (Senior Member, IEEE) received the B.S. degree in Mathematics from Shandong University, Jinan, China, in 2003, the M.S. degree in Systems Sciences from the Key Laboratory of Systems and Control, Chinese Academy of Sciences, Beijing, China, in 2007, and the Ph.D. degree In Control Engineering from the University of South Wales, Pontypridd, U.K., in 2008. He is currently a Professor in the Department of Automation, University of Science and Technology of China, and also in the Institute of Artificial Intelligence, Hefei Comprehensive National Science Center, Hefei, China. He has authored or coauthored more than 100 research articles, as well as two English monographs on networked intelligent control and one Chinese monograph on human–machine autonomy. His current research interests include AI-driven control and automation, specifically, AI-driven networked intelligent control, AI-driven human–machine autonomy, and AI-driven machine gaming.



Zhenyi XU received the Ph.D. degree in Control Science and Engineering from the Department of Automation, University of Science and Technology of China, Hefei, China, in 2020. He is currently an Associate Research fellow in the Institute of Artificial Intelligence, Hefei Comprehensive National Science Center (Anhui Artificial Intelligence Laboratory). His research interests are deep learning, urban computing, intelligent transportation, machine learning, and data mining.