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著者(和文)	LI CHAO
Author(English)	LI CHAO
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	電気電子 系 電気電子 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of	（ 学術 ）
学生氏名： Student's Name	LI CHAO	指導教員（主）： Academic Supervisor(main)	伊藤 浩之	
		指導教員（副）： Academic Supervisor(sub)		

要旨（英文 800 語程度）

Thesis Summary（approx.800 English Words ）

This doctoral thesis is entitled "Data Augmentation for Time Series Data in Edge AI Devices for Cattle Behavior Estimation". It consists of six chapters written in English.

Chapter 1, entitled "Introduction: Edge AI, time series and real-world challenges", explains the general situation and the need for data augmentation in deep learning and machine learning. It points out that, while data augmentation techniques are widely used in deep learning for image processing, the literature on augmenting time series such as acceleration data is limited, and discusses the need for research in this area.

Chapter 2, entitled "From livestock management to neural networks: the need for data augmentation", discusses the problems caused by the small size and class imbalance in the time series datasets often used as training data for edge AI and internet-of-things devices, and the need for research in this area. It also covers the latest developments in the related data augmentation techniques, providing an overview of the state of the art. Then, as a representative example of how these issues can arise and their impact, an edge AI-based behavior estimation system for the detection of disease and other conditions such as estrus in cattle and other livestock animals is presented. The importance of this technology, its potential impact on livestock management and animal welfare, and the related trends, are surveyed.

Chapter 3, entitled "Random rotation-based data augmentation", presents an initial data augmentation technique based on the specific features of and requirements for cattle behavior estimation systems. In particular, it considers the problem of positional rotation of collar-type devices, and consequently proposes a method for augmenting the least frequent behaviors through generating additional data using rotation techniques to simulate additional measurements. It is shown that this method can considerably improve the generalization performance during network training, thanks to the fact that the time series data generated after simulated collar rotation can have completely different temporal features, even though no new information is introduced. When this method is applied to a dataset of two cows, the accuracy of the behavior estimation is improved from 77% to 98%.

Chapter 4, entitled "Data augmentation based on combining multiple empirical methods", considers a situation wherein a more limited amount of data per cow is available. It consequently introduces a more advanced set of data augmentation methods, which allow for achieving high accuracy in this situation. A dataset of six cows is considered. In addition to simulating collar rotation, other transformation operations are introduced, such as time reversal, recombination, and data loss compensation. Compared to the method in the previous chapter, these are more advanced methods, as they include many empirical considerations about the actual properties of signals and behaviors, not just the physical phenomenon of collar rotation. When applied to the training of convolutional neural networks, the combination of time reversal and data loss compensation improves the average accuracy from a baseline of 83% to 94%. Furthermore, the results suggest that linear signal features such as autocorrelation, cross-correlation, and value distribution contain important information for behavior estimation.

Chapter 5, entitled "Improving abstraction by combining Fourier surrogates and sampling schemes", details more general and theoretically supported data enhancement techniques. Since Fourier surrogates can be seen as generalizations of time reversal, this chapter focuses on the fact that phase randomization can provide a virtually unlimited amount of new uncorrelated time series data while maintaining autocorrelation, cross-correlation, and value distribution, and proposes data augmentation techniques based on this. These techniques are more abstract than those considered in the previous chapters, since they are not grounded on problem-specific features such as the possibility of collar rotation. In addition, a novel technique of bias sampling, which can provide different combinations of data samples at each network training epoch, regardless of the frequency distribution of the occurrence of the behaviors, is introduced. As a result of combining these two advancements, an accuracy as high as 96% is achieved. Additional analyses are reported to show which signal features actually support the classification of the behaviors. Furthermore, it is explained that the proposed method can in principle be applied to the augmentation of other types of time series data. To give an example of this, some results are also shown for publicly available data sets: a human behavior data set, a machine and electric motor failure data set, and an electroencephalography data set. Considerable accuracy improvements are documented in all these three quite different situations.

Chapter 6, "Conclusion and Future Work", summarizes the results obtained throughout this thesis and, as an outlook for concrete application, proposes a conceptual scheme for choosing among the data augmentation techniques presented in the previous chapters, which have rather different features and levels of complexity. Furthermore, the potential and usefulness of extending this research to other applications are described, and the aspects necessitating future research are considered.