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Ultra-Wide Band Radar is a Promising Non-Contact Technology for Sleep Stage Classification in Children

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***Abstract*— Unobtrusive sleep monitoring in children presents challenges. We investigated the possibility of using an ultra-wide band (UWB) radar to measure sleep in children. Tested on 32 children undergoing a clinical polysomnography, the use of 38 features extracted from radar signals and an adaptive boosting algorithm led to promising results in estimating sleep stages.**

I. Introduction

Sleep is thought to play a crucial role in infants' and children' brain development [1]. The human sleep cycle has two main stages: rapid-eye-movement (REM) and non-REM (NREM) sleep, where NREM includes light sleep (N1, N2), and deep sleep (N3) [2]. Analyzing the distribution of sleep stages may well offer clinical insights of sleep in children.

Polysomnography (PSG) with clinical evaluation remains the gold standard to study sleep. Yet, it is a very challenging procedure for children, and cannot be performed easily outside a lab setting. These limitations promote the demand for unobtrusive sleep monitoring at home. In children, ultra-wide band (UWB) radar has been considered a promising and reliable technology that can capture human vital signs without contacting the body [3]. The aim of our study was to evaluate pediatric sleep stage classification algorithms based on UWB radar data with PSG as gold standard method.

II. Methods

Thirty-two children (age from 2 months to 14 years) were scheduled to undergo a single-night clinical PSG, with UWB data simultaneously monitored using a XeThru radar module (Novelda, Oslo, Norway) placed at ~1.5 m above the child. The PSG includes multichannel signals, from which sleep stages (on each 30-s epoch) and respiratory events were scored [2]. Details of the study setup, the patients, the radar module used, and the PSG scoring can be found elsewhere [4].

A total of 38 features were extracted from UWB signals, including 9 motion and 29 respiratory features. A tree-based adaptive boosting algorithm was adopted for the classification tasks, including wake and sleep (WS) classification, wake, REM, and NREM sleep (WRN) classification, and wake, REM, light, and deep sleep (WRLD) classification. Based on the leave-one-patient-out cross validations, overall accuracy and Cohen's kappa (κ) were used to evaluate the performance. Results were also compared between patient groups with and without obstructive sleep apnea (OSA), central apnea (CSA), as well as the older (>1 year) and the younger group (<1 year).

III. Results and Conclusion

The summary of the classification performance per patient groups is given in Table I. For all patients, we achieved a κ of 0.67, 0.47, and 0.43 for WS, WRN, and WRLD classification, respectively. The classification performance for non-OSA was higher than that for OSA for all tasks, and for non-CSA it was lower than that for CSA for only WRN classification. We also found that the movement features were more important for WS classification while the respiratory rate features were more important to differentiate between sleep stages.

TABLE I. Performance of Sleep Stage Classifications per Group

Group	WS		WRN		WRLD	
	κ	Acc	κ	Acc	κ	Acc
All	0.67	89.8%	0.47	72.9%	0.43	58.0%
Non-OSA	0.70*	90.7%	0.48*	71.7%	0.43*	58.0%
OSA	0.54	86.1%	0.39	68.8%	0.36	53.7%
Non-CSA	0.60	88.5%	0.38	69.6%	0.35	54.3%
CSA	0.67	89.1%	0.48*	71.5%	0.43	57.7%
Younger	0.69	89.3%	0.48	70.7%	0.44	58.6%
Older	0.66	90.5%	0.45	73.4%	0.38	55.0%

Mean results over patients were presented. Acc: accuracy. *$p<0.05$ (Wilcoxon rank-sum test).

The performance of our algorithm reached was similar to that reported to other studies (mostly in adults, e.g., [5]). Very few sleep staging studies using radar technology have been performed in children. The patients included in this work had a wide range of age and diseases. More data are needed to verify their influence on sleep classification, and to further improve the performance for each patient group.

In conclusion, this pilot study shows that UWB radar is a feasible non-contact method for sleep stage classification in children, paving the way for more in-depth future studies on sleep analysis using radar-technologies.

IV. References

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