2版

様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

令和　４ 年　 ６ 月 ２２ 日現在

機関番号：３２６１２

研究種目：基盤研究(B)（一般）

研究期間：2018～2021

課題番号：１８Ｈ０３２７８

研究課題名（和文）Deep Learning the Human Mind - Recognising and Augmenting Cognitive Performance Fluctuations

研究課題名（英文）Deep Learning the Human Mind - Recognising and Augmenting Cognitive Performance Fluctuations

研究代表者

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交付決定額（研究期間全体）：（直接経費）　　12,800,000円

研究成果の概要（和文）：本プロジェクトでは生理信号センサを用いて人のこころの特性を定量化・管理するツールを提供します（睡眠や認知負荷過多から運動や画面酔い、アクセシビリティの問題に向けて）。
第一段階では装着しやすい生理信号センサと機械学習技術を使用し、認知的変動の評価方法を実装。主に入眠、睡眠の質、注意力、認知負荷変化の検出です。第二段階ではこれらの認知的変動を改善・管理するインタラクションを実装。仮眠アシスタント、運転中の状況認識向上、画面酔いの軽減などです。また人の身体とより統合されたシステムの実現に向け、「認知機能拡張」と「ヒューマンコンピュータインテグレーション」という二つの新しいパラダイムを開発しました。

研究成果の学術的意義や社会的意義
Our project introduces the novel paradigm of cognitive augmentation. We enable a tighter feedback loop taking the user’s real time cognition model into account. Making systems more accessible. Accessibility is a core concept emphasized in nearly all 17 of the UN’s SDGs.

研究成果の概要（英文）：This project provides tools to quantify and manage properties of our mind better using physiological sensing (from sleep, over cognitive load, towards problems related to motion/cyber-sickness and accessibility issues). In a first step, we implemented several methods to assess cognitive fluctuations using unobtrusive physiological sensing and deep learning/machine learning techniques. Highlights include the detection of sleep onset, sleep quality, alertness (while driving), and cognitive load changes. In a second step, we implemented interactions to improve or manage these cognitive fluctuations, highlights include a nap assistant, Increased situational awareness while driving, and a reduction in motion- cyber sickness.
We also developed two novel paradigms: Cognitive Augmentation and Human Computer Integration, for implementing systems that are more integrated with the human body. Overall, we present significant contributions to the human computer interaction and related fields.

研究分野：Human Computer Interaction

キーワード：Cognitive Augmentation　Wearable Computing　Adaptable Interfaces　Cognitive Fluctuations

１．研究開始当初の背景

With technology becoming more and more ubiquitous in our lives (mobile phones, wearable computing, IoT devices etc.), our behavior patterns become more and more separated from natural rhythms developed by evolution over a long time. Our mind has ebb and flow and is affected by various factors (time of day, light, ambient sounds etc.), some of which we do not even realize.
These fluctuations manifest in patterns in human behavior and physiological signals (body temperature, eye movements, galvanic skin response etc.) related to the Autonomous Nervous System (ANS).
It is a large problem to model these patterns and adapt interfaces accordingly. The standard human computer interaction paradigms do not suffice to enable seamless interactions. Computer systems capable of cognitive user modelling are more highly coupled to the human and require new approaches (as mistakes cannot easily be debugged and the feedback loop is very tight).

２．研究の目的

This project provides tools to quantify and manage properties of our mind better using physiological sensing embedded in unobtrusive devices deployable in everyday scenarios (from sleep, over cognitive load, towards problems related to motion/cyber-sickness and accessibility issues). In a first step, we implemented several methods to assess cognitive fluctuations using unobtrusive physiological sensing and deep learning/machine learning techniques. Highlights include the detection of sleep onset, sleep quality, alertness (while driving), and cognitive load changes. In a second step, we implemented interactions to improve or manage these cognitive fluctuations, highlights include a nap assistant, increased situational awareness while driving, and a reduction in motion- cyber sickness. We also developed two novel paradigms: Cognitive Augmentation and Human Computer Integration, for implementing systems that are more integrated with the human body.
We focus on several assessment areas of personalization, interface adaption based on cognitive model estimation as well as productivity increase to name the most important. This project extends the field of human computer interactions towards Cognitive Augmentation.

３．研究の方法

The project took an experimental research approach and followed a user-centered methodology. The overall process is cyclic but non-directed and includes inspiration, exploration, and validation phases. Based on findings from cognitive science, from ethnographic observations we conducted short exploratory studies　and identified promising areas for learning deeply about the human mind and cognitive augmentation. We shifted focus from large scale in person recordings to virtual reality experimentation due to COVID-19.

In an agile iterative process, functional prototypes were used to study how digital technologies can model and improve users’ cognitive abilities. Interventions using the prototypes were designed and conducted. The performance when using the prototypes with different metrics was compared to established baseline metrics.　The project was structured in three major work packages:　Modeling and Using Cognitive Fluctuations, Cognition-Aware Interactions in VR/AR, Cognitive Augmentation Paradigm Definition. We always started with iterative prototypes and smaller lab studies before larger scale in-situ data sets　where recorded.

４．研究成果
For Modeling and Using Cognitive Fluctuations, we explored several application cases and found sleep, napping the most promising. As fatigue is directly related to alertness, reaction time, and ultimately productivity.

	Precision	Recall	f1-score	support
Awake	0.80	1.00	0.89	596752
Asleep	1.00	0.43	0.60	256894
Average/Total	0.86	0.83	0.80	853646

Figure 1 (left) An illustration of the prototype that combines EOG sensors from JINS Meme with Google Daydream, (right) and a participant of the study using the prototype on a reclining office chair with a smartphone for a finger tapping task to record sleep onset as baseline.

As a highlight in this work package, over several studies we implemented NapWell (see Fig.1), a sleep assistant using virtual reality (VR) to decrease sleep onset latency by providing a realistic imagery distraction prior to sleep onset (see Fig. 2). Our proposed prototype was built using hardware and with relatively low cost (ca. Yen 23000), making it replicable for future works as well as paving the way for more low cost EOG-VR (Electrooculography) devices for sleep assistance. We conducted several surveys (n=15) and user studies (n= 20) by comparing different sleep conditions; no devices, sleeping mask, VR environment of the study room and preferred VR environment by the participant. During this period, we recorded the electrooculography (EOG) signal and sleep onset time using a finger tapping task (FTT). We found that VR was able to significantly decrease sleep onset latency. We also developed a machine learning model based on EOG signals that can predict sleep onset with a cross-validated accuracy of 70.03¥%. The presented study demonstrates the feasibility of VR to be used as a tool to decrease sleep onset latency, as well as the use of embedded EOG sensors with VR for automatic sleep detection.
We also explored several eyewear sensing approaches, cognitive load detection (over FNIRS), as well as interactive generation of personal vibrotactile patterns adopted to the cognitive needs of the users, in this workpage.

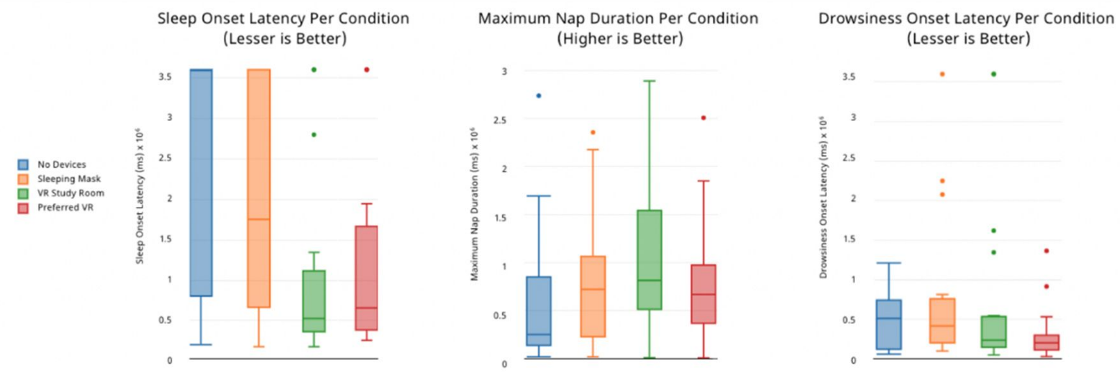

Figure 2 Extracted results using an FTT estimate on tapping (baseline) and electrooculography, which shows the sleep onset latency (left), maximum nap duration (middle) and drowsiness onset latency (right) for all 20 participants.

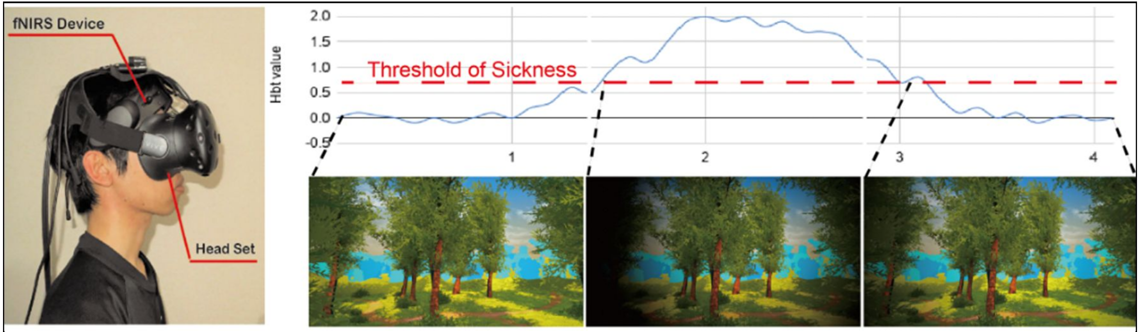

Figure 3 HemodynamicVR concept: Using hemoglobin changes measured by fNIRS to determine cybersickness symptoms and limiting the field of view during walking segments

In Cognition-Aware Interactions in VR/AR, we explore how to seamlessly integrate feedback based on measured cognitive fluctuations. We were assessing different hands free interactions on their cognitive load, perceived task load, and overall performance (fitts law tests) and we also recorded larger scale locomotion datasets comparing different movement types in VR/AR on their cognitive load for the user and their likely cyber sickness.
Yet, the highlight in this work package are adjustable peripheral vision for Virtual reality and real world applications.
Problems with virtual reality systems often arise due to a mismatch between a user's perception of motion and the system's corresponding rendering of motion. Sensory conflict theory provides a framework to understand these problems. We implemented HemodynamicVR, a virtual reality headset combinedwith functional near-infrared spectroscopy (fNIRS). We believe that sensing brain activity will enable novel interactions in virtual reality.
We assess a user's cybersickness based on the change of their total hemoglobin concentration measured via an fNIRS device, and we try to mitigate that by changing the field of view (FOV) in real-time. In this experiment, participants experienced VR locomotion with an added variable FOV controlled by velocitychanges and by fNIRS. The results suggest that our system can detect cybersickness as registered by the qualitative SSQ test.
We also implemented a similar setup for train/car rides or other situations a person might be affected by motion sickness. In a continuation of this work package we also assessed situational awareness in driving scenarios.

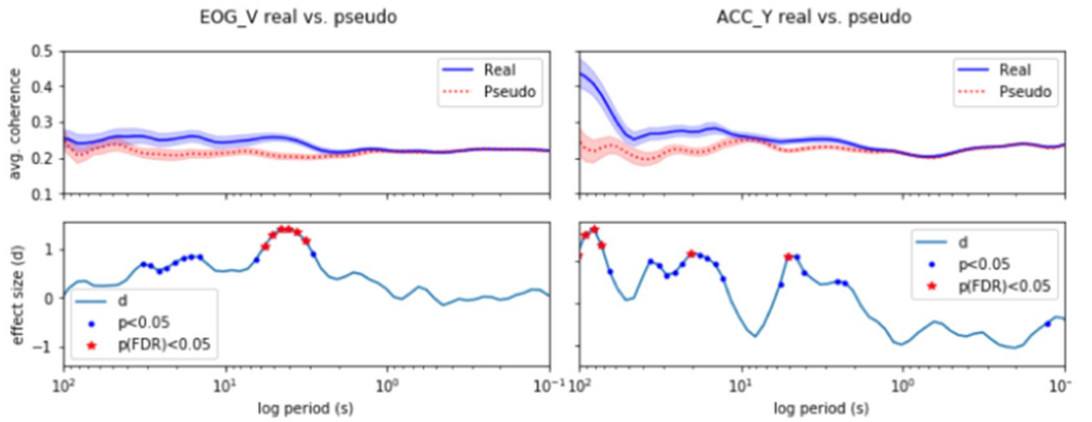

Figure 4. Real conversation vs. pseudo for blinks (EOG-V) and nods (ACC-Y). Average coherence for each condition is shown (with standard mean error, SME, in the shaded regions). Effect size (Cohen-d) is also shown with significance levels highlighted.This shows 1) we synchronise our blinks at periods of greater than 2s during conversation, and 2) we synchronise head nods over similar frequencies.

Cognitive Augmentation Paradigm Definition. We also explore how to extend human computer interaction towards cognitive augmentation. The by the principle investigator co-developed paradigm of Human Computer Integration is highly related to the work in this project, as it defines how computational and human systems can be closely interwoven. Integrating computers with the human body is not new. However, we believe that with rapid technological advancements, increasing real-world deployments, and growing ethical and societal implications, it is critical to identify an agenda for future research. We present a set of challenges for research, formulated over the course of a five-day workshop consisting of 29 experts who have designed, deployed, and studied HInt systems. The agenda developed aims to guide researchers in a structured way towards a more coordinated and conscientious future of human-computer integration.
In the Cognitive Augmentation paradigm work package we also expanded the scope of cognition from the individual to social interactions.
As last highlight, we developed a measure for interpersonal synchrony based on wearable electrooculography and intertial motion sensors as well as wavelet covariant analysis (using the EOG vertical component and the y- vertical axis acceleration). We tend to synchronize our movements to the person we are talking to during face-to-face conversation. Higher interpersonal synchrony is linked to greater empathy and more effortless interactions. This paper presents a first method and a corresponding dataset to explore synchrony in natural conversation by capturing eye and head movement using commodity smart eyewear. We recorded a 17 hour dataset, using Electrooculography and inertial sensing, of 42 people in conversation (21 dyads: 10 in Japanese, 10 in English, 1 in Chinese). Initial results on 18 dyads show significant interpersonal synchrony of blink and head nod behaviours during conversation (at frequencies of 0.2 to 0.5 Hz). We also find that people are more likely to synchronize blinks at around 1 Hz when conversing back-to-back than when face-to-face.

This project provides significant contributions to quantify and manage properties of our mind better using physiological sensing embedded in unobtrusive devices deployable in everyday scenarios (from sleep, over cognitive load, towards problems related to motion/cyber-sickness and accessibility issues).

５．主な発表論文等

〔雑誌論文〕　計16件（うち査読付論文　15件／うち国際共著　14件／うちオープンアクセス　0件）

１．著者名 Mueller Florian Floyd、et al. Kai Kunze (16th of 42 authors)	４．巻 1
２．論文標題 Next Steps for Human-Computer Integration	５．発行年 2020年
３．雑誌名 CHI Conference on Human Factors in Computing Systems	６．最初と最後の頁 1-15
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3313831.3376242	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Pescara Erik、Dreschner Florian、Marky Karola、Kunze Kai、Beigl Michael	４．巻 1
２．論文標題 GenVibe: Exploration of Interactive Generation of PersonalVibrotactile Patterns	５．発行年 2020年
３．雑誌名 Augmented Humans International Conference	６．最初と最後の頁 1-9
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3384657.3384794	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Hiroo Yamamura, Holger Baldauf, Kai Kunze	４．巻 1
２．論文標題 Pleasant Locomotion--Towards Reducing Cybersickness using fNIRS during Walking Events in VR	５．発行年 2020年
３．雑誌名 Adjunct Publication of the 33rd Annual ACM Symposium on User Interface Software and Technology.	６．最初と最後の頁 1-4
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3379350.3416184	査読の有無 有
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１．著者名 Masai Katsutoshi、Kunze Kai、Sakamoto Daisuke、Sugiura Yuta、Sugimoto Maki	４．巻 1
２．論文標題 Face Commands - User-Defined Facial Gestures for Smart Glasses	５．発行年 2020年
３．雑誌名 ISMAR	６．最初と最後の頁 1-13
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/ISMAR50242.2020.00064	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Ragozin Kirill、Kunze Kai、Marky Karola、Pai Yun Suen	４．巻 1
２．論文標題 MazeRunVR: An Open Benchmark for VR Locomotion Performance, Preference and Sickness in the Wild	５．発行年 2020年
３．雑誌名 CHI Extended Abstracts	６．最初と最後の頁 1-6
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3334480.3383035	査読の有無 有
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１．著者名 Bao Jie、Han Jiawen、Kato Akira、Kunze Kai	４．巻 1
２．論文標題 Sleepy watch	５．発行年 2020年
３．雑誌名 UbiComp Adjunct	６．最初と最後の頁 1-4
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3410530.3414415	査読の有無 有
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１．著者名 Hiroo Yamamura, Holger Baldauf, Kai Kunze	４．巻 1
２．論文標題 HemodynamicVR - Adapting the User’s Field Of View duringVirtual Reality Locomotion Tasks to Reduce Cybersickness usingWearable Functional Near-Infrared Spectroscopy	５．発行年 2021年
３．雑誌名 Augmented Humans	６．最初と最後の頁 1-5
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3458709.3458994	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Florian ‘Floyd’ Mueller, Pedro Lopes, Paul Strohmaier, Kai Kunze et. al.	４．巻 1
２．論文標題 Next Steps in Human-Computer Integration	５．発行年 2020年
３．雑誌名 CHI 2020 Human Factors in Computing Systems	６．最初と最後の頁 1-15
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3313831.3376242	査読の有無 有
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1．著者名 Aman Gupta, Finn L Strivens, Benjamin Tag, Kai Kunze and Jamie A Ward	4．巻 3
2．論文標題 Blink as you sync uncovering eye and nod synchrony in conversation using wearable sensing	5．発行年 2019年
3．雑誌名 International Symposium on Wearable Computers	6．最初と最後の頁 1-6
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3341163	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

1．著者名 Benjamin Tag, Jamie A Ward, Yuji Uema and Kai Kunze	4．巻 2
2．論文標題 Eyewear 2019 third workshop on eyewear computing - focus: social interactions	5．発行年 2019年
3．雑誌名 UbiComp Adjunct Proceedings	6．最初と最後の頁 1-3
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3341162	査読の有無 有
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1．著者名 George Chernyshov, Kirill Ragozin, Benjamin Tag and Kai Kunze	4．巻 4
2．論文標題 EOG Glasses an Eyewear Platform for Cognitive and Social Interaction Assessments in the Wild	5．発行年 2019年
3．雑誌名 International Conference on Human-Computer Interaction with Mobile Devices and Services	6．最初と最後の頁 1-5
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3338286.3344418	査読の有無 有
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1．著者名 George Chernyshov, Kai Kunze, Benjamin Tag, Jamie A Ward and Yuji Uema	4．巻 2
2．論文標題 Demo: http://eyewear.pro An Open Platform to Record and Analyze Large Scale Data Sets from Smart Eyewear	5．発行年 2019年
3．雑誌名 UbiComp Adjunct	6．最初と最後の頁 1-2
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3341162.3343790	査読の有無 有
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1．著者名 Yun Suen Pai, Tilman Dingler, Kai Kunze	4．巻 12
2．論文標題 Assessing hands-free interactions for VR using eye gaze and electromyography	5．発行年 2018年
3．雑誌名 Virtual Reality	6．最初と最後の頁 1-13
掲載論文のDOI（デジタルオブジェクト識別子） 10.1007/s10055-018-0371-2	査読の有無 有
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1．著者名 Zhang Qing、Yamamura Hiroo、Baldauf Holger、Zheng Dingding、Chen Kanyu、Yamaoka Junichi、Kunze Kai	4．巻 14
2．論文標題 Tunnel Vision ? Dynamic Peripheral Vision Blocking Glasses for Reducing Motion Sickness Symptoms	5．発行年 2021年
3．雑誌名 ISWC '21: 2021 International Symposium on Wearable Computers	6．最初と最後の頁 1-8
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3460421.3478824	査読の有無 有
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1．著者名 Ragozin Kirill、Meng Xiaru、Lalintha Peiris Roshan、Wolf Katrin、Chernyshov George、Kunze Kai	4．巻 12
2．論文標題 ThermoQuest - A Wearable Head Mounted Display to Augment Realities with Thermal Feedback	5．発行年 2021年
3．雑誌名 MUM 2021: 20th International Conference on Mobile and Ubiquitous Multimedia	6．最初と最後の頁 1-8
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3490632.3490649	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1．著者名 Meng Xiaru、Han Jiawen、Chernyshov George、Ragozin Kirill、Kunze Kai	4．巻 22
2．論文標題 ThermalDrive - Towards Situation Awareness over Thermal Feedback in Automated Driving Scenarios	5．発行年 2022年
3．雑誌名 IUI '22 Companion	6．最初と最後の頁 1-4
掲載論文のDOI（デジタルオブジェクト識別子） 10.1145/3490100.3516453	査読の有無 無
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

〔学会発表〕　計3件（うち招待講演　2件／うち国際学会　1件）

1．発表者名 Kai Kunze
2．発表標題 Augmenting the Human Mind
3．学会等名 Neurolive Symposium（招待講演）
4．発表年 2021年

1．発表者名 Kai Kunze
2．発表標題 Measuring Cognitive Fluctuations
3．学会等名 Insorcing Workshop collocated with CHI（招待講演）
4．発表年 2020年

1．発表者名 Kevin, Stevanus and Pai, Yun Suen and Kunze, Kai
2．発表標題 Virtual Gaze: Exploring Use of Gaze As Rich Interaction Method with Virtual Agent in Interactive Virtual Reality Content
3．学会等名 Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology（国際学会）
4．発表年 2018年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

－

6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計1件

国際研究集会	開催年
Eyewear 2019 third workshop on eyewear computing collocated with UbiComp	2019年～2019年

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関