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

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研究課題名（和文）Wear-I: A Multi-Wearable Organic System for Smarter Individual Services

研究課題名（英文）Wear-I: A Multi-Wearable Organic System for Smarter Individual Services

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研究成果の概要（和文）：本研究の目的は、マルチセンサーを利用し、より柔軟で信頼性の高いサービスを実現することです。そのために人の感覚器官の使用メカニズムを参考にしています。IMU、EEG、ECG、EOG、GSR、呼吸、圧力などの多様なセンサーデバイスを、有線および無線通信を介して動的かつ同時に管理できる統合型の有機的プラットフォームを開発しました。ウェアラブルデバイスから取得したデータは、行動認識と感情認識における様々なウェアラブルアプリケーションの研究に応用されています。さらに、研究対象は人の被験者から犬などのペットにも拡大しています。主要な研究成果は、11本の学術誌論文および18本の会議論文を発表しました。

研究成果の学術的意義や社会的意義
本研究は、人が感覚器官や運動器官を使用するように、マルチウェアラブルデバイスを有機的に使用および管理する最初のシステムです。開発されたウェアラブルプラットフォームは、さまざまな種類と数のウェアラブルデバイスを管理できる拡張性を示しました。マルチセンサーと機械学習を使用することで、行動、感情、および生理学的状態の認識性能が向上しました。このような有機システムは、ヒューマン・コンピュータ・インタラクション（HCI）におけるより優れたウェアラブルアプリケーション、より効果的な仕事や教育、子供や高齢者およびペットのヘルスケアなどにおいて重要な役割を果たすと期待されます。

研究成果の概要（英文）：This research has been targeted mainly at using multi sensors for more flexible and reliable services referring to the usage mechanism of human sensing organs. We have developed an integrated organic platform, which can dynamically and simultaneously manage various kinds of sensing devices, such as IMU, EEG, ECG, EOG, GSR, respiration and pressure, via wired and wireless communications. The sensed data from wearables have been applied for studying various wearable applications covering both activity recognition and emotion recognition. Our research has been extended from human subjects to pets like dogs. The major research achievements have been published in 11 journal papers and 18 conference papers.

研究分野：Ubiquitous Computing

キーワード：Wearable　Activity　Emotion　Physiology　Recognition

１．研究開始当初の背景

There have been a multitude of various wearable devices, and more wearables are coming onto the market. Much of the current research in wearable computing or systems has fallen into two basic categories, device-specific and application-specific. A device-specific wearable system is to provide various applications around a specific wearable device such as an iWatch. An application-specific system is to use a set of fixed wearable devices for a specific application such as healthcare. One of major problems in the current wearable systems is that wearable devices are bound closely to specific applications, therefore without sufficient adaptivity and scalability to flexibly support rich wearable services by reusing, sharing, and coordinating all devices worn by a user.

Each human has a set of sense and action organs that are working collaboratively to achieve a vast array of possible human activities by precise adaptation. All these organs are connected by the body system and controlled by the human brain. In some sense, wearable devices can be also seen as extended artificial 'organs', and they may work coordinately in an organic manner as the human organs. This basic idea has motivated us to put forward a general-purposed multi-wearable organic system, known as Wear-I.

２．研究の目的

Wear-I is aimed at a novel wearable system with multi wearable devices that are worn in different body parts of an individual or a user in daily life. These wearables and their wearing states may change dynamically in a day, and thus should be monitored and controlled in an organic manner like the human sense and action organs do. Different from other systems using fixed wearables for specific applications, the proposed Wear-I is a general-purposed system for smarter personal services by sharing and using these multi wearables. The control of changing wearables and their coordination in various wearable applications are one of the main issues in this research.

This project is to provide a new computing scheme and smarter applications in wearable technology. The Wear-I system has been developed based on a wearable-gateway-cloud architecture for adaptivity and scalability. Representative smart services/applications in human activity and emotion recognition have been made to test and improve the multi-wearable organic system during its development. This research is to provide a new paradigm in wearable computing.

３．研究の方法

The Wear-I system is much more complex compared to conventional device-specific and application-specific wearable systems, and must be usually involved with multiple wearable devices and many function modules that work together. Therefore, our research has been done step-by-step based on a general model that consists of five functional layers of device, data, information, task, and application.

The *device layer* at the bottom is for monitoring and controlling all devices including their identifications, forms, states, executions, operations, etc. The *data layer* is for handling data, which includes general data format, medium, representation, storage and management of heterogeneous data from/to various devices. Data quality, synchronization and cleansing are also key research topics in this layer. The *information layer* is for processing data and fusing data from different sources to extract useful information about devices' states and users' activities/behaviors. The *task layer* is to provide a set of reusable function modules to easily make an application that is often involved with a set/sequence of tasks. The *application layer* is to provide many concrete wearable services flexibly amenable to a user's request and available devices.

Due to the dynamically changing wearables, heterogeneous data and complex controls to serve many users, the Wear-I system must be flexible, extensible and scalable. We have adopted a wearable-gateway-cloud architecture system architecture that is divided into the three levels: Device Control (DC), Local Controller (LC) and Remote Controller (RC). An individual's wearables shown in the bottom are connected, via their corresponding DCs, to respective LCs specifically for the individual/user. An LC will contain some organic control function modules, often residing in a smartphone or a tablet carried by a wearer, or temporally in a nearby note PC or a WiFi-enabled smart watch. A RC for an individual/user is to manage the individual's all LCs, which may also dynamically change according to their availability. A wearable database (W-DB) is embedded in the wearable, a local database (L-DB) is inside an LC for keeping data from connected wearables, and a remote big database (R-DB) is to keep all users' data persistently.

In addition, various types of wearable devices are used in this research and many kinds of wearable applications including activity and emotion recognition are studied to test and demonstrate the potential of the multi-wearable systems.

４．研究成果

Thanks to JSPS support, this project has made a series of research achievements that are summarized as the following.

A. Use a number of wearables and deal with their heterogeneity. As a multi-wearable system, a lot of devices have been used in this research. The devices are very heterogeneous in terms of forms, functions, communications, data, and so on. These devices cover different sensors, such as (1) IMU (Inertial Measurement Unit) including acceleration, gyroscope, orientation, and barometer; (2) Vital signs including breathing, heartbeat, and eyeblink; (3) Physiological data such as GSR (Galvanic Skin Response) and EMG (ElectroMyoGraphy); (4) Brain signals from brainwave devices such as Emotiv, Muse, and MindWave. These devices are worn in different body parts and their data modalities and formats are quite different. A unified data format has been adopted to first sort the heterogeneous data by a corresponding gateway and then keep the data in a common server/cloud with a large storage space in about 20 TB.

B. Develop an integrated system to connect and manage all devices. Since the diverse wearables exist and their usage and working states are changing, we have developed an integrated open platform for synchronous and auto-tagged data collection from diverse sensors, which is very useful and efficient in experiments using multi wearables. The synchronization is particularly important when collecting data from multiple devices. The system can also automatically monitor the connection and working states of devices for handling their abnormalities. The system has been tested and improved by integrating a number of wearable devices including M5Stick, Myo, Polar, Venier, Muse2 and smartwatches as well as other noncontact devices including camera, mic and radar

C. Activity recognition and related human attribute estimation. Daily activity logging is important for life record and assistance. We have researched on wearable-based recognition of various activities including postures, gym workout types and eating actions. Because of COVI-19 we have studied the handwashing and toothbrushing activities using multiple wearables sensors. We have also conducted research on estimations of human attributes such as gender, heigh, weight and mountain track conditions. In particular, the dog's activities are further studied using small wearables. Multiple devices have been worn simultaneously in different positions of a human or a dog for investigating which position(s) or what combination(s) will be better for more accurate recognition/estimations when using machine or deep learning models.

D. Emotion recognition and human physiological state detection. Emotion intelligence (EI) as one of the next generational AI has gotten increasing attention in recent years. Human emotions are closely correlated with the physiological data. We have applied wearable sensors of respiration, heartrate (HR), heart rate variability (HRV), galvanic skin response (GSR), electrocardiogram (ECG), electroencephalography (EEG), and electrooculography (EOG) in this research. IMU and radar sensors have also used to extract vital signs of respiratory and heartbeat signals. These data and convolutional neural network (CNN) have been used for recognition of various emotional states/levels including stress, concentration, arousal, valance, fatigue, downness, etc. We have compared the recognition performance in using different physiological sensors and their combinations.

In summary, we have caried our research from the multi-wearable system development and its applications in recognition of daily activities and emotional states. Our major research achievements in conducting this project have been published in 10 journal papers and 12 conference papers.

５．主な発表論文等

〔雑誌論文〕　計11件（うち査読付論文　11件／うち国際共著　8件／うちオープンアクセス　1件）

１．著者名 Zhou Xiaokang、Liang Wei、Ma Jianhua、Yan Zheng、Wang Kevin I-Kai	４．巻 9
２．論文標題 2D Federated Learning for Personalized Human Activity Recognition in Cyber-Physical-Social Systems	５．発行年 2022年
３．雑誌名 IEEE Transactions on Network Science and Engineering	６．最初と最後の頁 3934～3944
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/TNSE.2022.3144699	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 Zhou Xiaokang、Liang Wei、Yan Ke、Li Weimin、Wang Kevin I-Kai、Ma Jianhua、Jin Qun	４．巻 10
２．論文標題 Edge-Enabled Two-Stage Scheduling Based on Deep Reinforcement Learning for Internet of Everything	５．発行年 2023年
３．雑誌名 IEEE Internet of Things Journal	６．最初と最後の頁 3295～3304
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/JIOT.2022.3179231	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 Hu Ruimin、Wang Xiaochen、Ma Jianhua、Pan Hao、Xu Danni、Wu Junhang	４．巻 25
２．論文標題 Urban Hierarchical Open-up Schemes Based on Fine Regional Epidemic Data for the Lockdown in COVID-19	５．発行年 2021年
３．雑誌名 Big Data Research	６．最初と最後の頁 100243～100243
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.bdr.2021.100243	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 Guo Kehua、Hu Bin、Ma Jianhua、Ren Sheng、Tao Ze、Zhang Jian	４．巻 8
２．論文標題 Toward Anomaly Behavior Detection as an Edge Network Service Using a Dual-Task Interactive Guided Neural Network	５．発行年 2021年
３．雑誌名 IEEE Internet of Things Journal	６．最初と最後の頁 12623～12637
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/JIOT.2020.3015987	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 Zhou Xiaokang、Liang Wei、Shimizu Shohei、Ma Jianhua、Jin Qun	4．巻 17
2．論文標題 Siamese Neural Network Based Few-Shot Learning for Anomaly Detection in Industrial Cyber-Physical Systems	5．発行年 2021年
3．雑誌名 IEEE Transactions on Industrial Informatics	6．最初と最後の頁 5790～5798
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/TII.2020.3047675	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 Dhelim Sahraoui、Ning Huansheng、Aung Nyothiri、Huang Runhe、Ma Jianhua	4．巻 8
2．論文標題 Personality-Aware Product Recommendation System Based on User Interests Mining and Metapath Discovery	5．発行年 2021年
3．雑誌名 IEEE Transactions on Computational Social Systems	6．最初と最後の頁 86～98
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/TCSS.2020.3037040	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 Xiao Li, Yufeng Wang, Bo Zhang, Jianhua Ma	4．巻 16
2．論文標題 PSDRNN: An Efficient and Effective HAR Scheme Based on Feature Extraction and Deep Learning	5．発行年 2020年
3．雑誌名 IEEE Trans. Ind. Informatics	6．最初と最後の頁 6703-6713
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/TII.2020.2968920	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 Ao Guo, Jianhua Ma, Guanqun Sun, Shunxiang Tan	4．巻 81
2．論文標題 A personal character model of affect, behavior and cognition for individual-like research	5．発行年 2020年
3．雑誌名 Computers and Electrical Engineering	6．最初と最後の頁 106544.1-16
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.compeleceng.2019.106544	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 Ao Guo, Jianhua Ma, Shunxiang Tan, Guanqun Sun	4．巻 23
2．論文標題 From affect, behavior, and cognition to personality: an integrated personal character model for individual-like intelligent artifacts	5．発行年 2020年
3．雑誌名 World Wide Web	6．最初と最後の頁 1217-1239
掲載論文のDOI（デジタルオブジェクト識別子） 10.1007/s11280-019-00713-w	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 Yufeng Wang, Min Gu, Jianhua Ma, Qun Jin	4．巻 7
2．論文標題 DNN-DP: Differential Privacy Enabled Deep Neural Network Learning Framework for Sensitive Crowdsourcing Data	5．発行年 2019年
3．雑誌名 IEEE Transactions on Computational Social Systems	6．最初と最後の頁 215-224
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/TCSS.2019.2950017	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 Runhe Huang, Peter Kimani Mungai, Jianhua Ma, Kevin I-Kai Wang	4．巻 92
2．論文標題 Associative Memory and Recall Model with KID Model for Human Activity Recognition	5．発行年 2019年
3．雑誌名 Future Generation Computer Systems	6．最初と最後の頁 312-323
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.future.2018.09.007	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 －

〔学会発表〕　計18件（うち招待講演　1件／うち国際学会　15件）

1．発表者名 Walid Brahim, Jianhua Ma, Muxin Ma, Alex Qi, Yunlong Luo, Yihong Qi
2．発表標題 An Integrated Platform for Synchronous and Auto-Tagged Data Collection From Diverse Sensors
3．学会等名 The 19th IEEE International Conference on Ubiquitous Intelligence and Computing（国際学会）
4．発表年 2022年

１．発表者名
Miho Miyawaki, Walid Brahim, Yosuke Iida, Jianhua Ma

２．発表標題
Recognition of Psychological Stress Levels Using Wearable Biosensors

３．学会等名
The 9th International Symposium on Affective Science and Engineering（国際学会）

４．発表年
2023年

１．発表者名
Rina Amano, Jianhua Ma

２．発表標題
Recognition and Change Point Detection of Dogs' Activities of Daily Living Using Wearable Devices

３．学会等名
IEEE DASC/PiCom/CBDCom/CyberSciTech（国際学会）

４．発表年
2021年

１．発表者名
Brahim Walid, Jianhua Ma, Muxin Ma, Alex Qi, Yunlong Luo, Yihong Qi

２．発表標題
Recent Advances in Radar-Based Sleep Monitoring - A Review

３．学会等名
IEEE DASC/PiCom/CBDCom/CyberSciTech（国際学会）

４．発表年
2021年

１．発表者名
Ao Guo, Hongyu Jiang, Jianhua Ma

２．発表標題
Multi-Scenario Fusion for More Accurate Classifications of Personal Characteristics

３．学会等名
IEEE DASC/PiCom/CBDCom/CyberSciTech 2020（国際学会）

４．発表年
2020年

１．発表者名
Hongyu Jiang, Ao Guo, Jianhua Ma

２．発表標題
Genre-based Emoji Usage Analysis and Prediction in Video Comments

３．学会等名
IEEE DASC/PiCom/CBDCom/CyberSciTech 2020（国際学会）

４．発表年
2020年

１．発表者名
Hongyu Jiang, Ao Guo, Jianhua Ma

２．発表標題
Automatic Prediction and Insertion of Multiple Emojis in Social Media Text

３．学会等名
IEEE iThings/GreenCom/CPSCom/SmartData/Cybermatics 2020（国際学会）

４．発表年
2020年

１．発表者名
河野恵実，馬建華

２．発表標題
ウェアラブルデバイスから得た慣性データを用いた性別・身長・体重分類

３．学会等名
情報処理学会第83回全国大会

４．発表年
2021年

１．発表者名
Jianhua Ma

２．発表標題
From Personal Big Data to Personal Life Assistance

３．学会等名
The 9th International Workshop on Assistive Engineering and Information Technology（招待講演）（国際学会）

４．発表年
2019年

１．発表者名
Jianhua Ma

２．発表標題
Personal Trait Analysis Using Word2vec Based on User-Generated Text

３．学会等名
IEEE International Conference on Ubiquitous Intelligence and Computing（国際学会）

４．発表年
2019年

１．発表者名
Ao Guo

２．発表標題
Towards Integrative Personal Character Modeling Using Multi-strategy Fusion Across Scenarios and Periods

３．学会等名
IEEE Cyber Science and Technology Congress（国際学会）

４．発表年
2019年

１．発表者名
Jianhua Ma

２．発表標題
Integrated Modeling of Personal Character Using Personal Big Data

３．学会等名
IEEE International Conference on Cyber Physical and Social Computing（国際学会）

４．発表年
2019年

１．発表者名
Jianhua Ma

２．発表標題
Personal Affective Trait Computing Using Multiple Data Sources

３．学会等名
IEEE International Conference on Cyber Physical and Social Computing（国際学会）

４．発表年
2019年

1．発表者名
Naoya Kinoshita, Jianhua Ma

2．発表標題
Hierarchical Recognition of Human Activity Using Multiple Wearable Devices

3．学会等名
情報処理学会第82回全国大会

4．発表年
2020年

1．発表者名
Kensuke Nakano, Jianhua Ma

2．発表標題
Human Activity Recognition by Integrating Inertial and Contextual Data from Multiple Wearable Devices

3．学会等名
情報処理学会第82回全国大会

4．発表年
2020年

1．発表者名
Jianhua Ma

2．発表標題
Wear-I: A Multi-Wearable Organic System for Smarter Individual Services

3．学会等名
IEEE Conference on Internet of People（国際学会）

4．発表年
2018年

1．発表者名
Ruiying Cai, Ao Guo, Jianhua Ma, Runhe Huang, Ruiyun Yu, Chen Yang

2．発表標題
Correlation Analyses Between Personality Traits and Personal Behaviors Under Specific Emotion States Using Physiological Data from Wearable Devices

3．学会等名
IEEE Cyber Science and Technology Congress（国際学会）

4．発表年
2018年

1．発表者名 Ao Guo, Jianhua Ma, Kevin I-Kai Wang
2．発表標題 From User Models to the Cyber-I Model: Approaches, Progresses and Issues
3．学会等名 IEEE Cyber Science and Technology Congress（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
研究分担者	Huang Runhe (Huang Runhe) (00254102)	法政大学・情報科学部・教授 (32675)	

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0件

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