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Development of a Portable Infrared-Type Noncontact Blood Pressure Measuring Device and Evaluation of Blood Pressure Elevation during Driving

Toshiya Arakawa [1,*], Noriaki Sakakibara [2] and Shinji Kondo [2,*]

[1] Department of Data Science, Nippon Institute of Technology, Saitama 345-0826, Japan
[2] KANDS Incorporated, Kariya-shi 448-0001, Japan; bara_n@katch.ne.jp
* Correspondence: arakawa.toshiya@nit.ac.jp (T.A.); kands@katch.ne.jp (S.K.); Tel.: +81-480-4111 (T.A.)

Abstract: Hypertension has been established as a major risk factor for cardiovascular morbidity and mortality. Therefore, prevention of hypertension is an urgent matter to maintain people's health and avoid death, and out-of-office blood pressure measurement is said to be an integral part of the diagnosis and management of hypertension. Hypertension not only causes loss of productivity and economic loss but is also a major cause of road accidents. Therefore, it is important to develop an in-vehicle noncontact blood pressure measurement system for drivers. In addition to measurement accuracy, proper detection timing is also important, and there must be no difference between noncontact and contact detection times. In this study, we introduce an infrared cuffless and portable noncontact blood pressure monitoring system, its measurement principle, and performance evaluation. A total of 13 male adults participated in the experiment to evaluate the effect of time lag between the use of the infrared blood pressure monitoring system and the contact blood pressure monitoring system using a driving simulator. The changepoint method was applied to detect the first change point in the blood pressure time series data caused by the unexpected first appearance of the vehicle. The results showed that the detection time of the developed system was about 2.5 s shorter than that of the contact-type continuous blood pressure measurement system, with no significant difference.

Keywords: hypertension; blood pressure; infrared radiation type noncontact blood pressure monitoring system; driving simulator; changepoint method

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1. Introduction

Hypertension is well known as a major risk factor for cardiovascular morbidity and mortality [1]. In 2018, hypertension was a primary or contributing cause in approximately half a million deaths: more than 494,873 people in the United States [2]. Therefore, prevention of hypertension is an urgent matter for maintaining people's health and avoiding death, and it is said that out-of-office blood pressure measurement is an important part of diagnosing and managing hypertension. In the era of advanced digital health information technology, the approach to achieve this is shifting from traditional methods (ambulatory and home blood pressure monitoring) to wearable devices and technology [3]. According to a study of the relationship between hypertension and economic loss, the total cost of treating hypertension in the United States in 2030 will be USD 50.3 billion–USD 37.2 billion in direct medical costs, and USD 13.1 billion in indirect costs, owing to lost productivity related to morbidity and mortality [4]. Thus, it has been identified that hypertension leads to decreased productivity and economic losses.

Hypertension not only decreases productivity and causes economic loss, but it is also a leading cause of traffic accidents [5]. Commercial drivers, in particular, have an increased propensity for the development of hypertension that exceeds the risks seen in other professions [6]. According to Miao et al., sudden death from ischemic heart disease while driving is a major cause of traffic accidents [7]. As an example of the sudden death of commercial drivers, a school bus crashed and the students were injured because the commercial driver suffered sudden cardiac death [8]. Another example shows that the driver of a transit bus suffered sudden death, which could lead to a major accident [9]. As an advanced driving-assistance system, an emergency driving stop system has been developed to prevent such accidents from occurring, which is activated when the driver loses control of the car because of sudden illness [10,11]. In 2018, the system was equipped in a commercial vehicle [12]. It is also preferable for drivers to practice daily physical condition management and judge their own condition before driving a vehicle before the system detects any physical condition abnormality. Considering this, a driver monitoring system is also being developed concurrently with the development of the emergency driving stop system.

Currently, most examples of driver monitoring systems are based on the estimation of wakefulness and fatigue using heartbeat and facial expression detection [13–16]. From the perspective of daily physical condition management of the driver, a blood pressure monitoring device is also necessary. In addition, these systems should be noncontact, as they should not interfere with driving or constrain posture. The same is true for blood pressure monitoring systems, which should measure the driver's blood pressure in a noncontact type rather than the traditional cuff type [5].

However, because the importance of measuring blood pressure in the car may not be recognized, only a few blood pressure measurement systems for driving [17,18] have been developed. To curb sudden deaths while driving, it has become important to encourage drivers to take care of their physical condition on a daily basis and to recognize whether they are adequate to drive. Therefore, a system that can measure the blood pressure by grasping the steering wheel was developed [19,20]. This system is useful because it is noncontact and resilient to body movements. However, this system is not appropriate to launch on the market. If such a driver monitoring system is introduced to the market, it would be more convenient if the driver can install the driver monitoring system, even after he or she comes to own the vehicle. However, because the driver monitoring systems are integrated into, as described above, the steering wheel, they can only be installed when the driver purchases the vehicle, and may not be installed after purchase, even if the driver wanted to. Therefore, a new noncontact type blood pressure monitoring system was developed that can be easily attached to the car and as soon as the driver desires. The system introduced in this study can be attached to any vehicle, regardless of its type, size, etc.; therefore, it is useful for drivers.

However, there is a problem with noncontact sensors. In the case of noncontact sensors, the distance between the sensor and the driver is farther; therefore, the timing of detecting the driver's condition can be slower than with contact sensors. Therefore, the sensors may not be able to evaluate the performance at the desired time and may not be able to indicate that the driver is in an adequate situation for driving at the desired time.

In this study, we describe the development of a portable noncontact blood pressure monitoring system that can be easily attached and show that it is capable of detecting blood pressure changes during near-miss events, and that the timing of blood pressure changes is comparable to that of a contact sensor, based on experiments using a driving simulator. It was also demonstrated that the timing of the blood pressure change was comparable to that of contact sensors. As a secondary contribution, a method for detecting the timing of blood pressure increase using the changepoint method is proposed. If a change in blood pressure can be detected, it is suggested that the method can be applied not only to driver tension, as in this study, but also to other driver conditions. The following two points are the originality and novelty of this paper: the development of a new portable noncontact blood pressure monitoring system, and the validation of this system compared to the traditional contact-type blood pressure monitoring system.

The remainder of this paper is organized as follows. Section 2 introduces the measuring algorithm of the infrared blood pressure monitoring system and an experiment to verify the effect of this system. Section 3 discusses the experimental results. Section 4 summarizes this study.

2. Materials and Methods

2.1. Mechanism of the Infrared Radiation Type Noncontact Blood Pressure Monitoring System

The newly developed infrared radiation type noncontact blood pressure monitoring system of a transmitter and a receiver. The transmitter irradiates infrared rays to a person, and the receiver receives faint reflected infrared rays from the person's skin. When the reflected infrared light hits the receiver, the signal is processed by an amplifier and a filter circuit and is output as a detection signal. This signal varies based on the relative changes in blood flow. The algorithm for estimating blood pressure is based on a previous study [21]. In this previous study [21], a non-invasive monitoring device which can measure blood pressure, pulse rate, respiratory rate, and oxygen saturation continuously with a single sensor using the photoplethysmographic technique, was developed. The accuracy and precision of the device were measured in comparison with conventional monitoring methods used in intensive care units (ICUs). In this study, the detection algorithm for blood pressure measurement in this previous study [21], i.e., the photoelectric sphygmomanometer technique, was used. The method in this previous study [21] uses projected light to capture the displacement of the arterial surface due to the expansion and contraction of blood vessels. This makes it possible to receive photoelectric volumetric pulse waves. Based on this signal, blood pressure is calculated continuously. We have developed a steering-wheel blood pressure to monitor this algorithm [19]. As mentioned above, this system is useful in that it is noncontact and resistant to body motion. However, from a market launch perspective, its design needs to be reconsidered. Therefore, as a new blood pressure measurement system based on this algorithm, we developed a portable, noncontact blood pressure measurement system with infrared irradiation.

The developed infrared radiation type portable noncontact blood pressure monitoring system is shown in Figure 1, and a block diagram of the developed infrared radiation type portable noncontact blood pressure monitoring system is shown in Figure 2. The external dimensions of the portable noncontact blood pressure monitoring system are approximately 10 [cm] $\times$ 5 [cm] $\times$ 2 [cm].

Figure 1. The developed infrared radiation type noncontact blood pressure monitoring system.

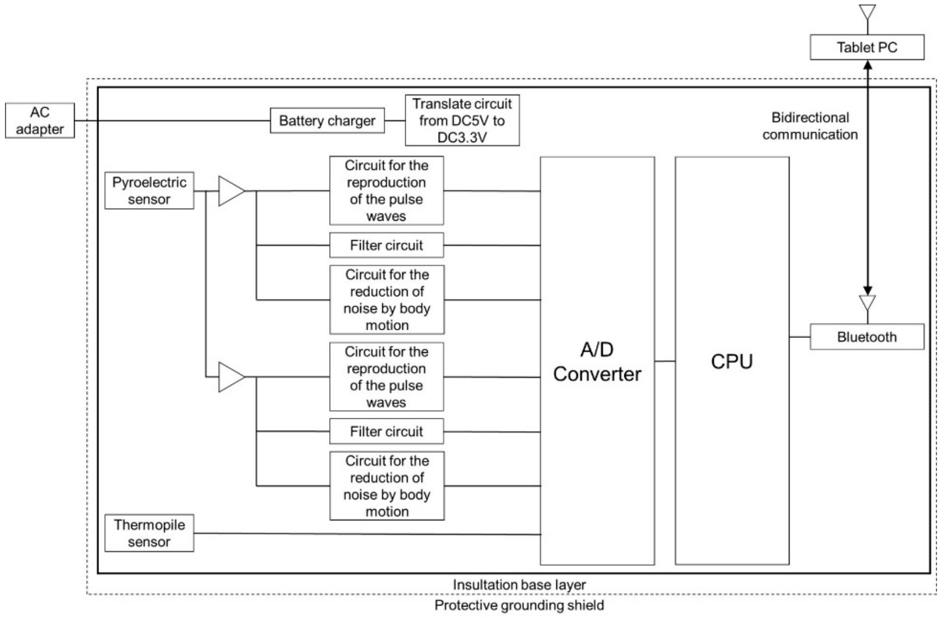

Figure 2. Block diagram of the developed infrared radiation type noncontact blood pressure monitoring system.

2.2. Evaluation of Accuracy

An experiment was conducted in order to compare the measurement accuracy between contact-type blood pressure monitoring systems, which are pharmaceutically approved products in Japan, and the developed infrared radiation type noncontact blood pressure monitoring system. Two male participants and one female participant joined the experiment. Although the number of participants is indeed small, the developed system is based on almost the same principle as in the previous study [20], and its accuracy was originally guaranteed. The number of participants here is small because the experiment is only to check the accuracy of the developed infrared radiation type noncontact blood pressure monitoring system.

The developed infrared radiation type noncontact blood pressure monitoring system was set one meter away from the participants. Each participant was attached to a contact-type blood pressure monitoring system (Radia Press RBP-100, KANDS, Inc.) and asked to sit calmly for 5 min (Figure 3). The blood pressure of each participant was measured by an RBP-100 and the developed infrared radiation type noncontact blood pressure monitoring system. Here, the blood pressure of each participant was measured twice. The result is shown in Figure 4, where (a) is the average systolic blood pressure, (b) is the average diastolic blood pressure, and (c) is the average pulse rate. The average value in each graph is ± 1 SD. In all three graphs in Figure 4, there is no significant difference between the values displayed by the RBP-100 and the infrared radiation type noncontact blood pressure monitoring system. Thus, it is found that there is no obvious difference between the accuracy of the results from the RBP-100 and the tested infrared radiation type noncontact blood pressure monitoring system. In other words, it can be said that the RBP-100 and the tested infrared radiation type noncontact blood pressure monitoring system almost same accuracy.

Figure 3. Set-up of experiment for comparing the accuracy of RBP-100 and developed infrared radiation type noncontact blood pressure monitoring system.

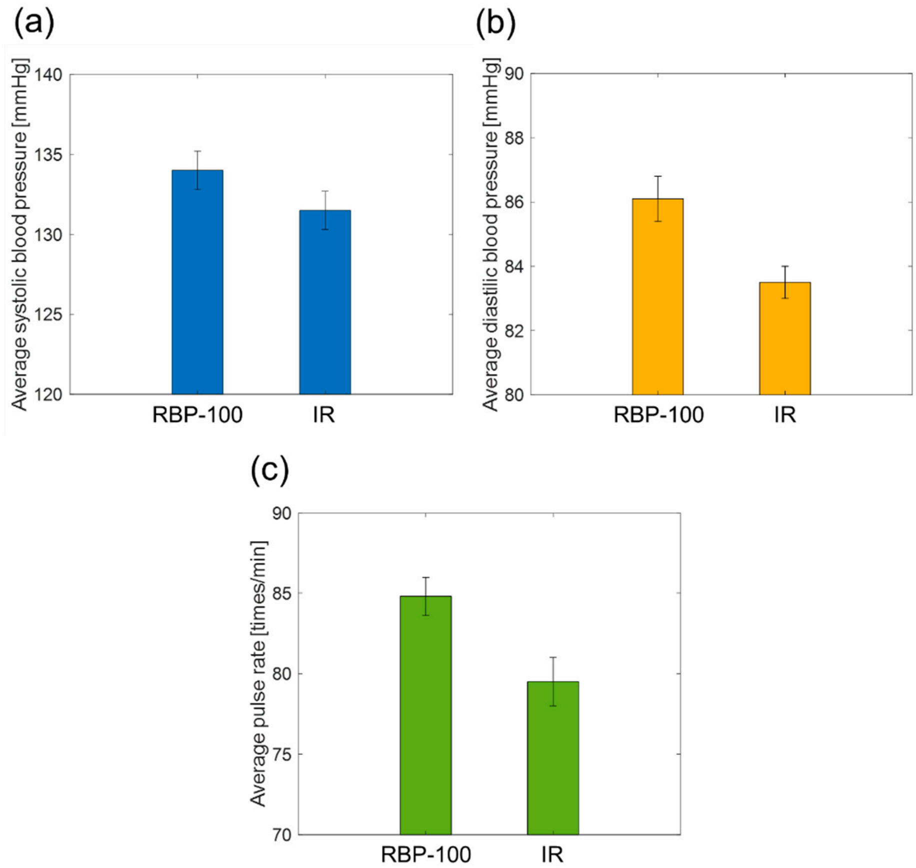

Figure 4. Graphs of (**a**): average systolic blood pressure, (**b**): average diastolic blood pressure, and (**c**): average pulse rate. Here, IR means the developed infrared radiation type noncontact blood pressure monitoring system.

2.3. Evaluation of Time Lag for Detection

The accuracy of the continuous blood pressure measurement system has been evaluated in Section 2.2. However, when using the developed infrared radiation type noncontact blood pressure monitoring system, it is necessary to consider the time lag until the blood pressure is detected due to the distance between the system and the user. Here, we conducted an experiment to evaluate the effect of the time lag when the infrared radiation type noncontact blood pressure monitoring system is attached in a vehicle. A driving simulator called DS-nano- (Advanced Solutions Technology Japan) was used for this experiment. This driving simulator has the exterior and interior of a real vehicle to make the driver feel as if he/she were driving a real vehicle; the developed blood pressure monitoring system introduced in Sections 2.1 and 2.2 was mounted on a small shield above the instruments of the driving simulator. Thirteen males, ranging in age from 21 to 50 years, participated in this experiment. Indeed, it is not a good experiment if the participants are limited to men. The reason why only males participated in this experiment was because there were few females in the environment of the authors, and it was not possible to gather female participants. All participants were briefed on the experiment and informed consent was obtained from all.

In all experiments, the participants were asked to drive in a simulated urban-like environment with many intersections with poor visibility. They were asked to drive at about 50 km/h for about 4 min. After about 3 min of driving, a vehicle ran out onto the road from a blind corner (Figure 5). Here, the direction from which the vehicle ran (from the left or right) and the time the vehicle appeared to run from the blind corner were random. The participants' blood pressure and driving behavior (speed, steering angle, brake pressure) were also measured. To evaluate the time lag, a contact-type continuous blood pressure monitor (μBP-mp, KANDS, Inc.) was attached to the participants and blood pressure was measured. In addition, sweating sensors were attached to the left and right thumbs to detect sweating caused by the sudden appearance of additional vehicles. The details of the experiment are shown in Figure 5. Figure 6 shows the setup and configuration of the infrared radiation type noncontact blood pressure monitoring system.

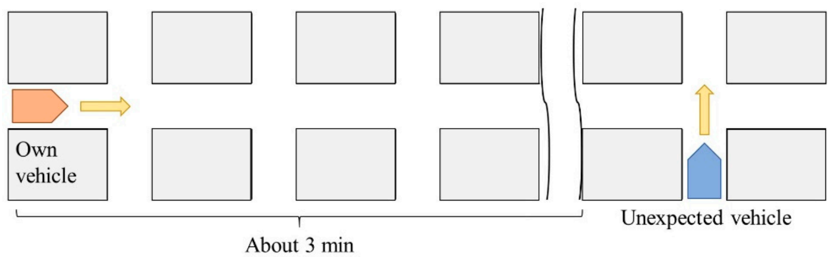

Figure 5. The position of the vehicle and the other vehicle (an unexpected vehicle) during driving. After driving for approximately 3 min, the other vehicle runs out.

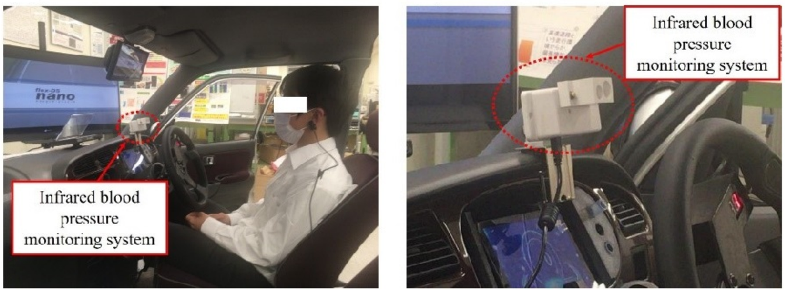

Figure 6. Attachment situation of the developed infrared radiation type noncontact blood pressure monitoring system.

The changepoint method was applied in order to detect the first change point from the unexpected vehicle's first appearance in blood pressure time-series data. Change points are abrupt variations in time series data. Such abrupt changes may represent transitions that occur between states. Detection of change points is useful in the modelling and prediction of time series and is found in application areas such as medical condition monitoring, climate change detection, speech and image analysis, and human analysis [22]. The changepoint method is a method for detecting such abrupt changes. The changepoint method considers the number of change points as vector which consists of some change points. Now, consider $\tau = (\tau_1, \tau_2, \ldots, \tau_{k+1})$, $l(\cdot)$ as log likelihood and λ as penalty. Here, likelihood ratio is considered as follows:

$$\min_{k,\tau}\left(\sum_{i=1}^{k+1}\left[-l\left(z_{\tau_j-1:\tau_j}\right)\right]+\lambda k\right)$$

where z_t means time-series data of which average value is change in time, so,

$$z_t|\theta_t \sim N(\theta_t, 1)$$

Change point can be detected according to value of λ. Many change points are detected when value of λ is small, and vice versa. In this study, changepoint package of R 3.6.0 was used to detect change points [23]. Figure 7 shows that an example of detecting change points of a participant's average blood pressure time-series data. In Figure 7, red vertical lines mean detected change points.

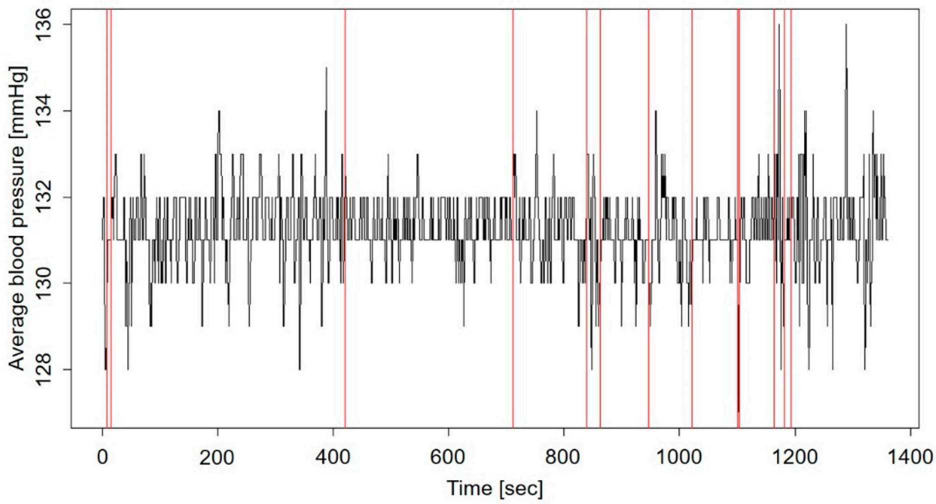

Figure 7. An example of detecting change points by the changepoint method (λ = 12). Blue vertical lines mean detected change points.

In this study, the change point, after the unexpected appearance of a vehicle, is selected through the following algorithm:

(1) The time when the unexpected vehicle appeared (t_1) is first determined; this is achieved by inspecting data logged by the driving simulator.

(2) The variable t_2 denotes the time at which the unexpected vehicle appears, plus 30 sec. The reason for selecting an interval of 30 s is based on previous research [24]; about 10 to 15 seconds must elapse before taking a reading of the maximum blood pressure, after drivers are surprised at the appearance of the unexpected vehicle.

(3) The variable t_3 is the time when mean blood pressure is at a minimum, between t_1 and t_2.

(4) Change points are detected by the changepoint method. λ, the penalty value is set to 1 because as many change points should be detected as possible. Here, the number of detected change points is defined as N, and the time of detection for a change point i is defined as T_i; the set of times is thus defined as $\boldsymbol{T} = \{T_1, T_2, \ldots, T_N\}$.

(5) Next, the minimum value of the difference between $\{T_1, T_2, \ldots, T_N\}$ and t_3 is calculated; a set $\boldsymbol{T}_{diff} = \{T_1 - t_3, T_2 - t_3, \ldots, T_N - t_3\}$ is created.

(6) $\underset{T_i}{\operatorname{argmin}}\{T_1 - t_3, T_2 - t_3, \ldots, T_N - t_3\}$ is calculated. The time as calculated by $\underset{T_i}{\operatorname{argmin}}\{T_1 - t_3, T_2 - t_3, \ldots, T_N - t_3\}$ is defined as T_{cp}.

(7) $T_{cp} - T_1$ is calculated. This is considered the duration over which blood pressure increases after the unexpected appearance of the vehicle.

The R-like pseudo source code of this algorithm is shown in the following:

Library (changepoint)

$t_2 \leftarrow t_1 + 30$

$t_3 \leftarrow$ which.min (data $ mean_bloodpressure [t_1:t_2])

$\boldsymbol{T} \leftarrow$ cpt.var (data $ mean_bloodpressure, pen.value = 1)

$\boldsymbol{T}_{diff} \leftarrow \boldsymbol{T} - t_3$

$\boldsymbol{T}_{cp} \leftarrow$ which.min ($\boldsymbol{T}_{diff}$)

Here, "data" in the above source code means a variable which contains each participant blood pressure data, therefore "data $ mean_bloodpressure" means the mean blood pressure of each participant.

It is true that the algorithm introduced above may not be adequate. However, the main purpose of this paper is to verify the difference in timing of detection between contact type continuous blood pressure monitoring systems and infrared radiation type noncontact blood pressure monitoring systems. In addition, the criterion of judging what an "increase in blood pressure" is did not previously exist; there also exists no previous research explaining blood pressure increases resulting from a person's surprised state, such as the state arising from the unexpected appearance of a vehicle. Thus, in this study, the timing of blood pressure increase was determined according to the above algorithm and analyzed.

3. Consideration

First, it was verified whether participants were really surprised at the appearance of the unexpected vehicle and whether their blood pressure increased. It is known that perspiration shows a person's tension, thus the timing of perspiration from the unexpected vehicle shows whether participants were really surprised at the appearance of another vehicle. Figure 8 shows the average time ± 1 SD of all participants to increase the perspiration value from the point of the appearance of the vehicle based on the algorithm introduced above; however only λ, the penalty value, was changed to 15 because the change points seemed to be earlier than the timing of blood pressure increase. In Figure 8, left means time to increase the perspiration value of the left thumb, right means the time to increase the perspiration value of the right thumb, and min (L, R) means the minimum time of "left" and "right". Eleven out of thirteen participants had a perspiration response, and from Figure 8, the time from the appearance of the unexpected vehicle to triggering a perspiration response in the left or right thumb seems to be approximately nine sec.

The timing of the increase in mean blood pressure from the time the unexpected vehicle appeared was calculated based on the algorithm presented above. To detect this timing, the changepoint method was applied. From the results of the calculations by the changepoint method, the average increasing time of ± 1 SD of all participants is shown in Figure 9. Here, in Figure 9, "μBP-mp" means the timing based on the blood pressure measured by the contact type blood pressure monitoring system (μBP-mp) and "IR" means the timing based on the blood pressure measured with infrared radiation type noncontact blood pressure monitoring system.

Because this infrared noncontact blood pressure monitoring system is noncontact, the timing of the developed blood pressure increase may be significantly longer than that of a contact-type. The detection time by the developed system was found to be approximately 2.5 s shorter than that of the contact type continuous blood pressure measurement system; however, there is no significant difference about the detection time between these blood pressure monitoring systems. For in-vehicle applications, a delay in the detection timing of blood pressure changes could lead to a serious accident because a system cannot detect driver's state and warn him/her immediately. Therefore, changes in blood pressure must be detected immediately to ensure driver safety; in other words, the timing of blood pressure change detection must not be delayed compared to the conventional contact type blood pressure monitoring system, and it is necessary to show statistically that there is no difference in the detection timing between the two, i.e., μBP-mp and IR. The result of this experiment states that the developed noncontact blood pressure monitoring system is as good as the conventional system, statistically. This means that there is statistically no difference in detection delay between the noncontact and contact blood pressure monitoring systems. Therefore, the developed system can be useful for detecting a driver's psychological state change immediately, such as surprised state as shown in this experiment.

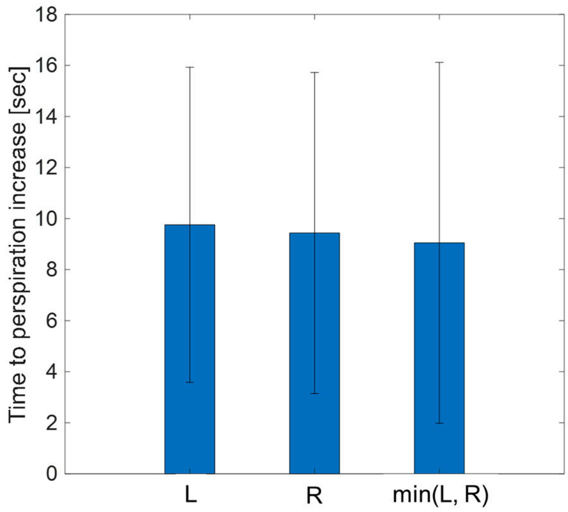

Figure 8. Average time ±1 SD of all participants to increase the perspiration value from the point of appearing unexpected vehicle.

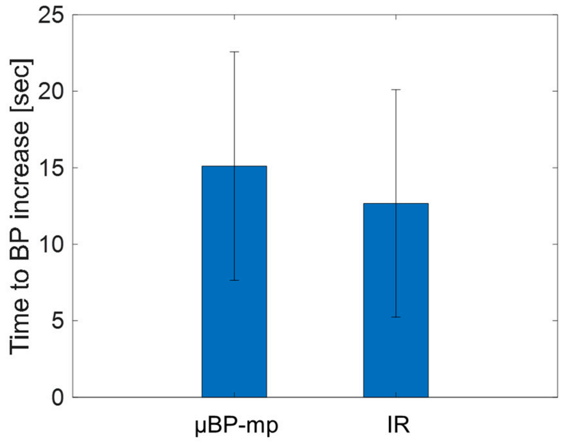

Figure 9. Average blood pressure increasing time ±1 SD of all participants.

As far as we know, there exists no previous published work discussing the relationship between the times when perspiration occurs and when blood pressure increases, as they pertain to a driver's state of surprise. However, consideration of the results suggest that the timing of increased blood pressure follows that at which perspiration occurs; this knowledge may be used to help conceive the mechanism of bio-mechanism or nervous system.

Considering the results reported in this study, we would like to propose a human–machine interface (HMI) for advanced driver-assistance systems (ADAS). Our previous research shows that driver blood pressure increases when a vehicle appears unexpectedly [24]; this could result in a situation that is beyond a driver's ability to cope with successfully [25], perhaps due to being surprised and feeling upset. From a standpoint of safe driving, it is important to be able to detect a driver's state immediately and manage the mental stress of drivers when they face sudden and unexpected events. We think the developed system, introduced in this study, might be a good example for HMI for detecting a driver's state, as explained above.

4. Conclusions

In this study, the developed infrared cuffless and portable noncontact blood pressure monitoring system was introduced, and the performance evaluation was discussed. It was observed that the detection time using the developed systems is approximately 2.5 s shorter (not a significant difference) than that for contact-based continuous blood pressure measurement systems. Therefore, it is suggested that the infrared cuffless and noncontact blood pressure monitoring system appears to be an adequate device for detecting an increase in the in-vehicle-driver blood pressure.

In addition, the system using a driving simulator was evaluated. However, to be aware of the market launch of this system, it must be evaluated on a real car. Therefore, in the future, we plan to evaluate the system on a real car to demonstrate the effectiveness of the system. The system also needs to be redesigned to be a reasonable size and cost for installation in a real vehicle. In addition, the number of participants in this experiment was less. To ensure the reliability of the system, we would like to conduct the next experiment with more participants to evaluate the system more appropriately.

Author Contributions: T.A. conceived and designed the experiments; T.A. and N.S. performed the experiments; T.A., N.S. and S.K. analyzed the data; N.S. and S.K. contributed developing blood pressure monitoring system.; T.A. wrote the paper. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: All experimental procedures were approved by the Research Ethics Committee (#30-3) of Aichi University of Technology, where the first author was affiliated at the time the experiment was conducted.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The dataset generated during the current study are not publicly available but are available from the corresponding author on reasonable request.

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Conflicts of Interest: The author declares no conflict of interest associated with this paper.

References

1. Stamler, J.; Dyer, A.R.; Shekelle, R.B.; Neaton, J.; Stamler, R. Relationship of baseline major risk factors to coronary and all-cause mortality, and to longevity: Findings from long-term follow-up of Chicago cohorts. *Cardiology* **1993**, *82*, 191–222. [CrossRef] [PubMed]
2. Centers for Disease Control and Prevention. About Underlying Cause of Death. Available online: http://wonder.cdc.gov/ucd-icd10.html (accessed on 11 March 2022).
3. Kario, K. Management of Hypertension in the Digital Era: Small Wearable Monitoring Devices for Remote Blood Pressure Monitoring. *Hypertension* **2020**, *76*, 640–650. [CrossRef] [PubMed]
4. William, J.E. The economic impact of hypertension. *J. Clin. Hypertens.* **2003**, *5*, 3–13.
5. Arakawa, T. Recent Research and Developing Trends of Wearable Sensors for Detecting Blood Pressure. *Sensors* **2018**, *18*, 2772. [CrossRef] [PubMed]
6. International Brotherhood of Teamsters. Revised Blood Pressure Guidelines for Commercial Drivers. Available online: https://teamster.org/revised-blood-pressure-guidelines-commercial-drivers/ (accessed on 11 March 2022).
7. Miao, Q.; Zhang, Y.L.; Miao, Q.F.; Yang, X.A.; Zhang, F.; Yu, Y.G.; Li, D.R. Sudden Death from Ischemic Heart Disease While Driving: Cardial Pathology, Clinical Characteristics, and Countermeasures. *Med. Sci. Monit.* **2021**, *27*, e929212-1–e929212-6. [CrossRef] [PubMed]
8. Abc News. Driver Suffers 'Sudden Cardiac Death' before Mississippi School Bus Crash That Injured Students. Available online: https://abcnews.go.com/US/driver-suffers-sudden-cardiac-death-mississippi-school-bus/story?id=65520740/ (accessed on 11 March 2022).

9. Response. Route Bus Driver Suddenly Dies While Driving. Available online: https://response.jp/article/2009/03/24/122108.html (accessed on 11 March 2022). (In Japanese)
10. Kwon, S.; Jung, C.; Choi, T.; Oh, Y.; You, B. Autonomous emergency stop system. In Proceedings of the 2014 IEEE Intelligent Vehicles Symposium Proceedings, Dearborn, MI, USA, 8–11 June 2014; pp. 444–449. [CrossRef]
11. Takano, M.; Morimoto, K.; Takagi, M.; Oda, T.; Nishimura, N. Development of an Emergency Stop Assistant System. *SAE Tech. Pap.* **2019**, *1025*, 1. [CrossRef]
12. B to B Platform. Developed the World's first Commercial Vehicle Emergency Driving Stop System (EDSS)—Scheduled to Be Installed in Hino Selega This Summer. Available online: https://b2b-ch.infomart.co.jp/news/detail.page?IMNEWS1=998247 (accessed on 11 March 2022). (In Japanese).
13. Li, G.; Chung, W.Y. Detection of driver drowsiness using wavelet analysis of heart rate variability and a support vector machine classifier. *Sensors* **2013**, *13*, 16494–16511. [CrossRef]
14. Patel, M.; Lai, S.K.L.; Kavanagh, D.; Rossiter, P. Applying neural network analysis on heart rate variability data to assess driver fatigue. *Expert Syst. Appl.* **2011**, *38*, 7235–7242. [CrossRef]
15. Friedrichs, F.; Yang, B. Camera-based drowsiness reference for driver state classification under real driving conditions. In Proceedings of the 2010 IEEE Intelligent Vehicles Symposium, La Jolla, CA, USA, 21–24 June 2010; pp. 101–106. [CrossRef]
16. Rongben, W.; Lie, G.; Bingliang, T.; Lisheng, J. Monitoring mouth movement for driver fatigue or distraction with one camera. In Proceedings of the IEEE Conference on Intelligent Transportation Systems (IEEE Cat. No. 04TH8749), Washington, WA, USA, 3–6 October 2004; pp. 314–319. [CrossRef]
17. Futatsuyama, K.; Kawachi, T.; Nakagawa, T. Cuffless blood pressure monitoring using steering wheel sensor system. *Trans. Jpn. Soc. Med. Biol. Eng.* **2014**, *1*, OS-67–OS-68. [CrossRef]
18. Futatsuyama, K.; Mitsumoto, N.; Kawachi, T.; Nakagawa, T. Noise robust optical sensor for driver's vital signs. *SAE Tech. Pap.* **2011**. [CrossRef]
19. Arakawa, T.; Sakakibara, N.; Kondo, S. Development of non-invasive steering-type blood pressure sensor for driver state detection. *Int. J. Innov. Comput. Inf. Control* **2018**, *14*, 1301–1310.
20. Arakawa, T.; Kaminaga, K.; Sakakibara, N.; Kondo, S. Development and evaluation steering-type blood pressure measuring monitor based on plethysmography. In Proceedings of the IIAE Annual Conference 2016, Kyoto, Japan, 11 September 2016; pp. 3–4. (In Japanese)
21. Tomita, K.; Nakada, T.; Oshima, T.; Oami, T.; Aizimu, T.; Oda, S. Non-invasive monitoring using photoplethysmography technology. *J. Clin. Monit. Comput.* **2019**, *33*, 637–645. [CrossRef] [PubMed]
22. Aminikhanghahi, S.; Cook, D.J. A Survey of Methods for Time Series Change Point Detection. *Knowl. Inf. Syst.* **2017**, *51*, 339–367. [CrossRef] [PubMed]
23. Killck, R.; Haynes, K.; Eckley, I.; Fearnhead, P.; Lee, J. Package 'Changepoint'. Available online: https://cran.r-project.org/web/packages/changepoint/changepoint.pdf (accessed on 11 March 2022).
24. Arakawa, T.; Tanaka, M.; Obayashi, F.; Kondo, S.; Kozuka, K. Detection of Driver's Surprised State Based on Blood Pressure. *ICIC Express Lett. Part B Appl.* **2015**, *6*, 2353–2360.
25. Lazarus, R.S.; Folkman, S. *Stress, Appraisal and Coping*; Springer: New York, NY, USA, 1984.