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A Method for Estimating Bicycle Air Pressure Decrease based on Vibration Sensing of Bicycles using Smartphone

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Abstract - Some people experience accidents or near misses while riding because they did not conduct bicycle inspections before riding. There is a need to promote riders to conduct bicycle inspections to reduce the number of people who experience this. In this study, we focus on air pressure inspection and propose a method for estimating bicycle air pressure decrease based on vibration sensing using smartphone. The acceleration in the direction perpendicular to the ground is acquired with a smartphone, and the standard deviation and the amplitude spectrum of each frequency are used as features to estimate the air pressure decrease using random forests and other methods. Evaluation experiments were conducted to classify whether the best timing for tire inflation, to estimate the air pressure value and classify it based on that value, and to evaluate whether the training data from other locations and bicycles can be diverted. The results of the evaluation experiments showed that 96.1% correctly classified when tire inflation was needed, but it was difficult to divert the training data. We developed an application that promotes air pressure inspection using the proposed method.

Keywords: Smartphone, Sensor signal processing, Bicycle, Air pressure

1 INTRODUCTION

There is a need to promote bicycle inspections because only a few people who ride a bicycle do so every time. According to a survey conducted by au Insurance, 86.9% of bicycle riders do not conduct any or few necessary inspections before riding(whether the brakes work, whether the tires are inflated sufficiently, the position, color, and angle of reflective materials, whether they are dirty, whether the handlebars and saddle are not wobbly, whether the chain is loose or rusty, whether the bell and buzzer ring, whether the lights come on) [1]. 89.3% of bicycle riders do not conduct annual bicycle inspections at a bicycle store. According to Bicycle Association, it is recommended that you conduct your bicycle inspections every time you ride your bicycle, and that they conduct bicycle inspections at bicycle stores at least once every six months [2]. 81.8% of bicycle riders experienced bicycle malfunctions without inspections. One in five of them experienced accidents or near misses. There is a need to promote riders to conduct bicycle inspections before riding to reduce the number of malfunctions and accidents or near misses experience.

In this study, we focus on tire air pressure inspection among the inspections that should be conducted before riding, and the purpose of this study is to realize air pressure inspections without introduction / operation costs and time consuming. Existing inspection methods need to use exclusive devices such as air gauges to confirm air pressure. Even with exclusive devices, there is a need to remove the cap from the valve of the tire in order to measure it. This method is time consuming.

In this study, a method for estimating air pressure decrease using smartphone is proposed. There is need for a sensor to estimate air pressure decrease. Smartphones are equipped with many sensors. There is no need to purchase new sensors because smartphones are widely used nowadays. In addition, they can quickly confirm the results of air pressure estimation because they are often carrying their smartphone with them at all times. For these reasons, we considered that air pressure inspections could be promoted using smartphone without introduction / operation costs and time consuming.

The flow of promoting air pressure inspection using smartphone is shown in the Fig. 1. The rider inflates the tire to the maximum proper pressure indicated on the side of the tire. Next, the rider rides bicycle while in possession of a smartphone. The smartphone collects feature values that occur at the best timing for tire inflation using equipped sensors. The smartphone estimates whether the air pressure is the best timing for inflation. The best timing for inflation is when the air pressure is about to decrease below the minimum proper pressure. The minimum proper pressure is the minimum pressure that can make the tire perform effectively. The smartphone promotes the rider to inflate when it estimates the best timing for inflation. In this flow, There is no need to confirm the air pressure frequently or to use exclusive devices to measure it. Therefore,we consider that air pressure inspection can be conducted without installation/operation costs and time consuming.

The outline of this study is as follows. Chapter 2 introduces air pressure related works, and describes their features and problems. Chapter 3 describes a method for estimating air pressure decrease based on vibration sensing of a bicycle using a smartphone in order to solve the problems of existing methods. Chapter 4 evaluates the method proposed in this study, and Chapter 5 considers the results. In conclusion, a summary and future issues are describes.

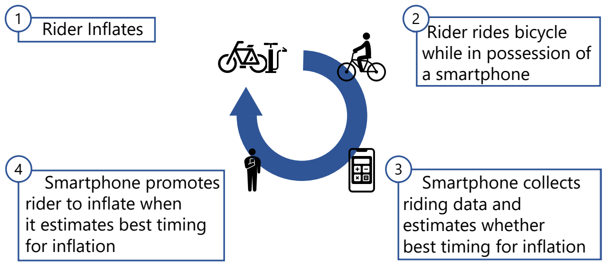


Figure 1: Flow of promoting air pressure inspection using a smartphone

2 RELATED WORK

In this chapter, studies using sensor data for situation estimation, studies using smartphones as a sensing terminal, and existing products related to air pressure inspection, and studies related to air pressure are introduced. The features, advantages, and problems of these studies and existing products are then described.

2.1 Studies Using Sensor Data for Situation Estimation

There are studies on situation estimation using sensor data to estimate road surface conditions [3], [4]. In these studies, data acquired from accelerometers [3] and cameras [4] are used to estimate the situation. Also, there is a study that uses Wi-Fi to detect changes in the state of indoor doors and windows [5]. This sutdy use data acquired by sensors to estimate the situation of places and objects.

It is time consuming to confirm a situation in multiple places or multiple times by visual confirmation. As an example, describe the case of visual confirmation of road surface condition. If there are multiple places to confirm, there is time consuming to move to a different place. If there are multiple times to confirm, there is a need to go to confirm at a certain time. Using the sensor, data collected at a certain time at the confirmed places can be estimated for the road surface condition. Therefore, road surface conditions can be estimated by the sensors without time consuming. Similarly, we considered that tire air pressure inspection could be conducted by sensors without time consuming.

2.2 Studies Using Smartphones as Sensing Devices

There are studies that use smartphones as sensing devices for congestion sensing [6]. A general smartphone is equipped with various sensors such as acceleration sensor, gyro sensor, magnetic sensor, GPS, barometric sensor, proximity sensor, light sensor, camera, and microphone. Therefore, a single smartphone can acquire multiple sensor data. The smartphone is widely used nowadays, and many people are often carrying their smartphone with them at all times. Therefore, estimation using smartphone is without introduction / operation cost. In some cases, a system is created using multiple exclusive sensors. Using the system, there is a need to use multiple exclusive sensors as well. A system using smartphone as a sensing device can be easily used. If the system is released to the application store, it can be used by many people who have smartphone. Because of these advantages, we considered that we could take advantage of them in this study.

2.3 Existing Products Related to Air Pressure Inspection

There are products that help to confirm air pressure such as air pressure sensor from Kashimura [7] and Tyrewiz from Quarq [8]. The air pressure sensor from Kashimura [7] is attached to four tires of a car. The air pressure information is wirelessly transmitted to a monitor in the automobile. The air pressure is displayed on a monitor in real time. Tyrewiz from Quarq [8] is attached to two tires of a bicycle. The exclusive application is installed on a smartphone. The air pressure information is wirelessly transmitted to a exclusive application. The air pressure is displayed on a exclusive application in real time. The rider can always confirm the air pressure. Therefore, there is no time consuming to confirm the air pressure. However, exclusive sensors are expensive and there is a need to manage batteries. Therefore, installation / operation costs are high. In this study, Smartphone is used as a sensor. There is no introduction and operation cost with this method.

There is a product that helps to inflate such as Smart Air Inflator from KuKiire [9]. When the inflator is attached to the tire, it automatically inflates the tire. The air pressure can be automatically inflated to the preferred pressure at the time of inflation. Therefore, there is no time consuming process to conduct air inflation. However, this product does not always measure air pressure. Therefore, if the rider determines that there is no problem in dangerous condition, the rider will ride in a dangerous condition. In this study, the smart phone estimates the best timing for inflation. Dangerous riding conditions are prevented for this method.

There is product that does not require air pressure such as Air Free Concept from Brigestone [10]. A tire that does not require air is called a punctureless tire. When regular tires are replaced with punctureless tires, there is no need for air pressure inspection without time consuming. However, punctureless tires cost more than regular tires. In addition, the ride quality is different between regular and punctureless tires, and the rider feels uncomfortable. In this study, bicycles used in everyday life will be used. The ride quality is not affected for this method.

2.4 Studies on Air Pressure

There are studies on air pressure such as TPMS. TPMS is a air pressure monitoring system using a barometric sensor. TPMS are broadly classified into direct and indirect methods.

There is a direct method study that proposes a technology to improve the performance of barometric sensors [11]. A barometric sensor is directly attached to the tire and measures the air pressure. Therefore, air pressure can be measured with high accuracy. However, barometric sensors are expensive to produce.

There is a indirect method study that uses a single barometric sensor to estimate the air pressure of four tires [12]. One barometric sensor measures the air pressure of one tire. The air pressure of one tire is used to estimate the air pressure of the other three tires. If the air pressure of four tires is to be measured directly, there are need to use four barometric sensors. However, only one barometric sensor is used to estimate air pressure. Therefore, air pressure estimation can be conducted at low cost. However, a dedicated sensor is used even if only a little. Therefore, it is costly to a certain extent.

In a previous study, we examined air pressure decrease estimation from bicycle riding speed [13]. The force required to pedal decreases as air pressure decreases. Therefore, we considered that the riding speed would decrease as well. An experiment was conducted to estimate air pressure decrease using riding speed. From the results, features that can be estimated for air pressure decrease did not occur. As the reason for this, features that can be changed by the rider's discretion were used. For example, even hen the pedals felt heavy, the rider adjusted the force and drove at the same speed as when there was enough air pressure. Therefore, there is a need to use features that occur with air pressure decreases that the rider cannot change.

3 METHOD FOR ESTIMATING AIR PRESSURE DECREASE BASED ON VIBRATION SENSING

This chapter describes the proper pressure required for air pressure decrease estimation. Then, the flow of air pressure decrease estimation using vibration is described.

3.1 Proper Pressure

There is a proper pressure for effective tire performance for bicycles. The maximum value of the proper pressure is referred to as the maximum proper pressure. The minimum value of the proper pressure is referred to as the minimum proper pressure. If the pressure is within the proper range, it indicates for effective tire performance. If the rider continues to ride outside of the proper pressure, the tire will suddenly burst, and the tube inside the tire will deteriorate. Therefore, air pressure inspection is important to prevent tire burst and deterioration. There may be a maximum proper pressure indicated on the side of the bicycle tire as shown in the Fig. 2. Also, there may be a maximum and minimum proper pressure indicated on the side of the bicycle tire. For city bicycles, only the maximum proper pressure is often indicated. For road bicycles, the maximum and minimum proper pressure are often both indicated.

When the air pressure is about to decrease below the minimum proper pressure, this is the best timing to inflate. If the air pressure is more than the minimum proper pressure, there is no problem to ride. If the air pressure is less than the minimum proper pressure, it is dangerous to ride. Therefore, there is a need to promote inflation to the rider when the air pressure is about to decrease below the minimum proper pressure.

Figure 2: Maximum proper pressure indicated on the side of the tire

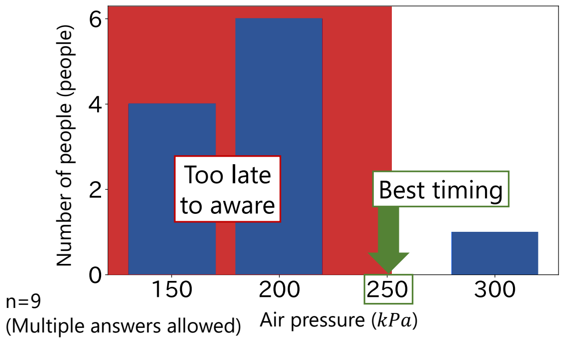


Figure 3: Air pressure that subjects felt should be inflated

3.2 Necessity of Air Pressure Decrease Estimation

Preliminary experiment was conducted to confirm that there is a need for air pressure decrease estimation. Nine male undergraduate and graduate students were asked if they felt they should be inflated. Subjects were asked to ride bicycles at 50 kPa increments from 150 kPa to 300 kPa without informing the air pressure. Subjects were then asked when they felt they should be inflated. Multiple answers were allowed when they felt they should be inflated. The subjects were also divided into two groups. The experiment was conducted by changing the order of air pressure for each of the two groups.

The results of the preliminar experiment are shown in the Fig. 3. Many subjects felt that they should be inflated at 200 kPa and 150 kPa. The minimum proper pressure for the bicycle used in this study is 250 kPa. Therefore, 250 kPa is the best timing for inflation. However, many people do not inflate at the best time and ride in dangerous conditions. From the result, it was found that there is a need to inform the rider of the best timing for inflation.

3.3 Flow of Air Pressure Decrease Estimation Using Vibration

Bicycle vibration was used as a method to estimate the best timing for inflation. Bicycle vibration changes depending on air pressure. A schematic diagram of vibration changes as-

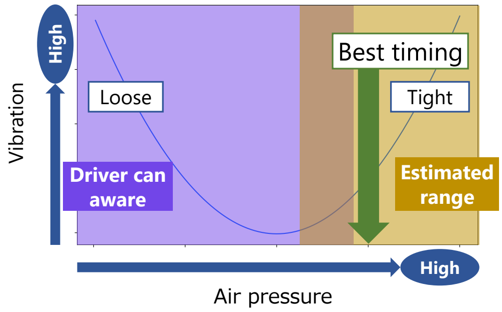


Figure 4: Schematic diagram of vibration changes associated with changes in air pressure

sociated with changes in air pressure is shown in the Fig. 4. If the air pressure is high, vibration is not absorbed very well. If the air pressure decreases to a certain degree, vibration is absorbed by the increased cushioning. If air pressure decreases significantly, vibration is not absorbed by the decreased cushioning. However, the rider can clearly aware that the condition is dangerous. Therefore, we conduct the estimation to the range where the rider does not aware that the condition is dangerous.

The flow of estimating air pressure decrease using vibrations is shown in Fig. 5. The flow consists of preparation and sensing, feature extraction, and air pressure decrease estimation by machine learning.

The rider enters the minimum proper pressure for the bicycle into the smartphone. The minimum proper pressure is necessary to acquire the best timing for inflation.

The rider attaches the smartphone as shown in the Fig. 6 and rides on a paved road. The smartphone is attached to the bicycle so that it is perpendicular to the ground using a smartphone holder. The smartphone must not obstruct the driving. Therefore, the smartphone conducts sensing without displaying the screen. Vibration changes depending on the ground type ridden on. Therefore, the estimation is conducted on paved roads that are generally used. Also, the vibration changes during a stop at a signal and with bumps. When stopped, the vibration is not changed by the air pressure. Vibration changes from different bumps. Therefore, data from such situations are excluded, and sensing is performed in situations where it is easy to estimate.

Acceleration in the y-axis direction during riding can be used as the vibration generated by the contact between the ground and the tires when the smartphone is attached as shown in the Fig. 6. However, the gravity acceleration is also included in the acceleration in the y-axis direction. Therefore, the acceleration in the y-axis direction without the gravity acceleration, is used.

Features of air pressure decrease are extracted from the acceleration data acquired during riding when the rider arrives at the destination. The standard deviation of acceleration in the y-axis direction and the amplitude spectrum for each frequency are used as the feature values. The acceleration standard deviation in the y-axis direction is considered to indicate the strength of the bicycle vibration. Also, the amplitude spectrum of each frequency in the y-axis direction is con-

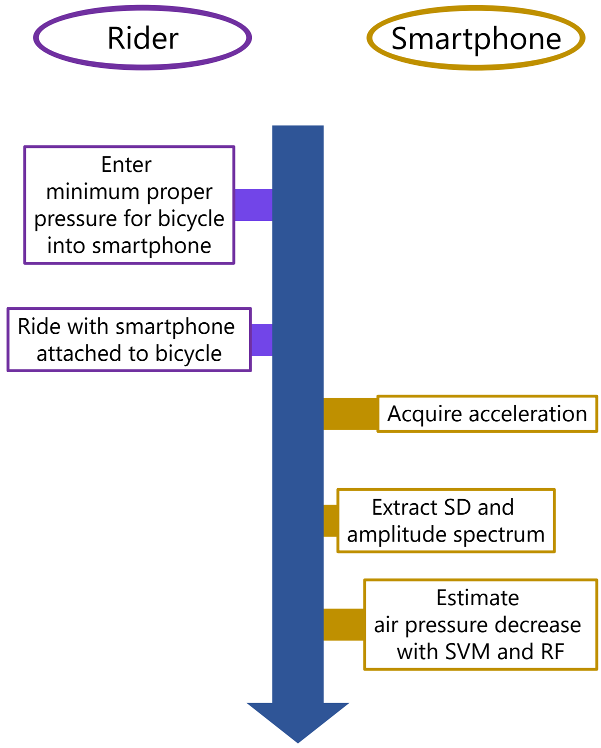


Figure 5: The flow of estimating air pressure decrease using vibrations

sidered to be a distribution of frequencies of the vibration occurred in the riding. Air pressure decreases as tire cushioning increases within the estimated range. Therefore, it is considered that the vibration of the bicycle is decreased and the acceleration standard deviation is decreased. In addition, it is considered that the vibration at higher frequencies is absorbed and the higher frequency amplitude spectrum is decreased. Therefore, we considered that the acceleration standard deviation in the y-axis direction and the amplitude spectrum for each frequency could be used as features for air pressure decrease estimation.

Preliminary experiment was conducted to confirm whether the standard deviation of acceleration in the y-axis and the amplitude spectrum of each frequency can be used as fea-

Figure 6: Smartphone attached and acceleration axis

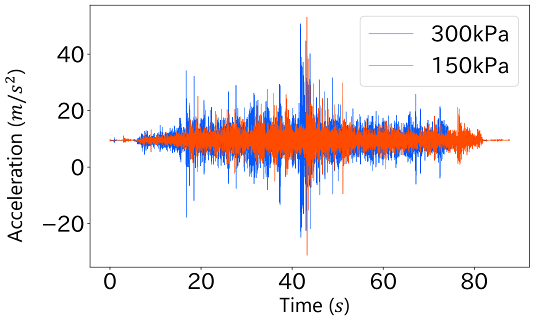


Figure 7: Acceleration in y-axis direction for each air pressure

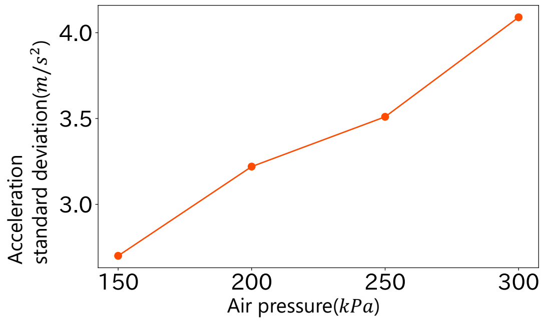


Figure 8: Variation of mean acceleration standard deviation in y-axis direction for each air pressure

tures for air pressure decrease estimation. The experiment was conducted with nine male undergraduate or graduate students. A smartphone was attached to the bicycle as shown in the Fig. 6. Subjects were asked to ride bicycle at 50 kPa increments from 150 kPa to 300 kPa for pressure and the acceleration in the y-axis direction was acquired. The acceleration in the y-axis direction was acquired as shown in the Fig. 7. The standard deviation was acquired from the acquired acceleration in the y-axis direction without the gravity acceleration. The acceleration standard deviations of the nine persons were averaged, and the variation of the values for each air pressure is shown in the Fig. 8. The standard deviation of acceleration in the y-axis direction decreases as the air pressure decreases, and a trend similar to that within the estimated range shown in the Fig. 4 occurs. FFT (Fast Fourier Transform) was conducted on the acceleration in the y-axis direction in order to analyze the frequency components in the y-axis direction. The amplitude spectrum for each frequency in the y-axis direction is shown in the Fig. 9. A trend that the amplitude spectrum with higher frequencies decreases as air pressure decreases occurred. Therefore, the standard deviation of acceleration in the y-axis direction and the amplitude spectrum for each frequency were used to estimate the air pressure decrease.

Machine learning is conducted using the features to estimate whether the air pressure is about to decrease below the minimum proper pressure. The data set format of the features is shown in the Table 1. Explanatory variable is the standard deviation of acceleration in the y-axis direction and the amplitude spectrum for each frequency. The objective variable is air pressure. Amplitude spectrum for each frequency uses the

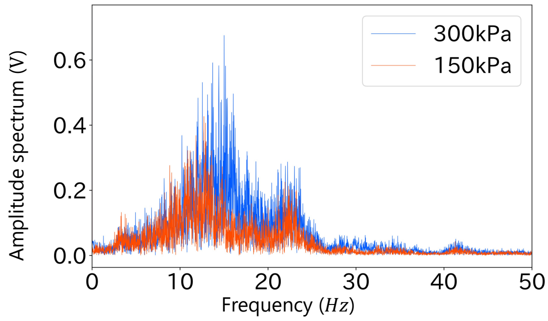


Figure 9: Amplitude spectrum for each frequency generated by bicycle riding

Table 1: Dataset of air pressure decrease features

Explanatory variable		Objective variable
Acceleration standard deviation in y-axis direction (m/s^2)	Amplitude spectrum in y-axis direction (V)	Air pressure of tire (kPa)

average of 0.5 Hz intervals of the frequency. Areas where no significant change occurred when air pressure decreased were not used as features. From the Fig. 9, little change in frequency was occurred after 40Hz. Therefore, the amplitude spectrum in the range of 0.0Hz to 40.0Hz was used. The reason for this narrowing of the range is that a larger amount of data would be burdensome to process on a smartphone. A model trained on this data set is used to classify whether the air pressure is below the minimum proper pressure. There are methods of direct classification using SVM and other methods. Another method is to conduct a regression to estimate air pressure as a numerical value using a random forest or other methods and then classify the air pressure.

4 EVALUATION EXPERIMENT

Experiments were conducted to evaluate the method proposed in this study and air pressure decrease estimation at other locations and on bicycles. The evaluation experiment of the proposed method is designated as Evaluation Experiment 1. The evaluation experiment of air pressure decrease estimation at other locations and on bicycles is designated as Evaluation Experiment 2.

4.1 Evaluation of Air Pressure Decrease Estimation Using Vibration

We conducted Evaluation Experiment 1. The purpose is to evaluate the accuracy of the results estimated by machine learning classification and regression using the standard deviation of acceleration in the y-axis direction and the amplitude spectrum for each frequency.

The experimental setting is shown in Table 2. The subjects were nine male undergraduate or graduate students. The sensing terminal was Galaxy Note 9. The smartphone application phyphox was used to acquire sensor data. The sampling frequency of acceleration is 400 Hz. The location used for the experiment is shown in the Fig. 10. The location is defined as location A. The experiment was conducted on an all paved road so that changes in the road surface would not affect the vibration. In addition, the experiment was conducted on single road without congestion so that the rider did not have to stop. The bicycle used for the experiment is shown in the Fig. 11. The bicycle is defined as bicycle X. In this study, the target is people who use bicycles only for transportation purposes and have little interest in bicycles. People who have little interest in bicycles often use city bicycles which can be purchased inexpensively. Therefore, city bicycle was used in the experiment. The air pressure used for the experiment is 50 kPa increments from 150 kPa to 300 kPa. When the air pressure is 150 kPa, the rider is aware that the air pressure is low. 300 kPa is the maximum proper pressure for the bicycle. The bicycle valve used in the experiment is shown in Fig. 12. The valve shown in the ^^c2^^a0Fig. 12a is called English valve. It is difficult to measure air pressure correctly with English valve. Therefore, English valve was converted to American valve. American valve is shown in the Fig . 12b. It is possible to measure air pressure correctly with american valve. The bicycle used in the experiment was not indicated with the minimum proper pressure. When the weight percentage of the front and rear wheels is the same and the road is paved, the minimum proper air pressure is obtained by the Formula (1)[1]. The bicycle information shown in the Table 3. The weight is defined as 65 kg which is the average weight of a male in his 20s. From the Formula (1)[1], the minimum proper pressure was 250 kPa. Nine subjects rode back and forth along a single road at four different air pressures. A total of 72 data were collected. SVM and Random Forest were used for classification. Random Forest was used for regression. The evaluation was conducted using leave-one-out in which one person's data was the test data from the entire data. The correct rate is the probability that the actual pressure and the estimated result could be classified in the same way. Recall rate is the probability that the estimated result could be classified as not proper when the actual air pressure is out of proper. The correct rate and the recall rate were used to evaluate the results. The accuracy of estimating whether a situation is dangerous or not is important. Therefore, the evaluation was based on the accuracy of the judgment, not on the accuracy of the numerical values obtained in the regression.

The results were shown in the Table 4,5,6,7. The ○ marks indicate the training score when the feature is used. The evaluation results showed higher scores when only the amplitude spectrum of each frequency was used and when both the acceleration standard deviation and the amplitude spectrum of each frequency were used as features. In classification, the correct response rate was 88.9% and the recall rate was 91.1%. In regression, the correct response rate was 79.2% and the recall rate was 96.1%.

[1]Bicycle Exploration!
https://jitetan.com/tire_air_pressure.html

Table 2: Setting of Evaluation Experiment 1

Number of subjects	9
Sensing terminal	Galaxy Note 9
Sampling frequency	400 Hz
Location	Paved road without congestion
Type of bicycle	City bicycle
Air pressure	150 kPa to 300 kPa
Number of data	72
Evaluation method	Leave-one-out
Evaluation index	Correct and recall

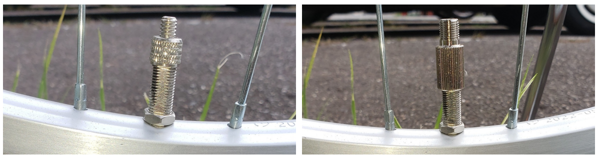
Figure 10: Location of Evaluation Experiment 1

4.2 Evaluation of Air Pressure Decrease Estimation at Other Locations and Bicycles

We conducted Evaluation Experiment 2. The purpose is to confirm whether air pressure decrease estimation can be conducted using data from other locations or bicycles.

The experimental setting is shown in Table 8. This subject was the first author of this study. The same location A as in Evaluation Experiment 1 was ridden by another bicycle, another location was ridden by the same bicycle X as in Evaluation Experiment 1, and another location and bicycle were ridden at the same location as in Evaluation Experiment 1. The locations used as different locations from Evaluation Experiment 1 are shown in the Fig. 14. The left location is defined as location B and the right location is defined as location C. A flatter road was chosen as a difference from the location of Evaluation Experiment 1. The bicycles used as different bicycles from Evaluation Experiment 1 are shown in the Fig.

Figure 11: Bicycle X of Evaluation Experiment 1



(a) English valve **(b)** American valve

Figure 12: Valve style of bicycle tire

Table 3: Information on the bicycle used in the Evaluation Experiment 1

Bicycles	Weight	Tire width	Minimum proper pressure
X	20.5kg	35mm	250kPa

15. The top bicycle is defined as bicycle Y and the bottom bicycle is defined as bicycle Z. As in Evaluation Experiment 1, The bicycles used in the experiment were not indicated with the minimum proper pressure. The bicycle information shown in the Table 9. From the Formula (1)[1], the minimum proper pressure of bicycle Y is 240 kPa and that of bicycle Z is 230 kPa. The subject rode twice back and forth on a single road at three different locations, on three different bicycles at four different air pressures. A total of 48 data were collected. From the results of Experiment 1, some degree of accuracy was confirmed in the regression. Therefore. Random Forest was used for regression. The regression can acquire numerical results of the estimation. Numerical values provide more evidence for inflation. The sensing terminal and air pressure range are the same settings as in the Evaluation Experiment 1.

The results are shown in the table 10. The figure shows the correct and recall rates for each location and bicycle using the data trained on location A and bicycle X used in the Evaluation Experiment 1. The second row from the top shows the correct and recall rates for the same conditions as the training data. Both the correct rate and the recall rate were low for a different location from the training data and for a different bicycle. Both the correct rate and the recall rate were low for the same location as the training data and for a different bicycle. In the case of the same bicycle, at a different location, the recall rate was higher, but the correct rate was lower.

5 DEVELOPMENT OF APPLICATION USING PROPOSED METHOD

We developed an application to promote air pressure inspection in order to make it possible to realize air pressure inspections without introduction / operation costs and time consuming. Using the proposed method, we estimated the air pressure and determined whether it was dangerous or not.

$$mpp = 10 \times \text{round}\left(0.5 \times 10 \times \frac{0.9}{tw - 11.2} \times (bow + biw + 46)\right) \quad (1)$$

Symbol	Description
mpp	Minimum Proper Pressure $[kPa]$
tw	Tire Width $[mm]$
bow	Body Weight $[kg]$
biw	Bicycle Weight $[kg]$
round(x)	Rounding off x

Table 4: Correct rate of each feature in the classification

Used feature values		Correct rate(%)	
Acceleration standard deviation	Amplitude spectrum for each frequency	SVM	RF
○	○	88.9	83.3
○		72.2	68.1
	○	86.1	84.7

An application that promotes air pressure inspection using the proposed method is shown in the Fig. 16. There is a training state and an estimation state.

It begins with a training state in which data is collected to estimate air pressure decrease 16a. The rider enters the minimum proper pressure into the application. If the minimum proper pressure is not indicated, from the Formula (1)[1], enter the weight, bicycle weight, and tire width to calculate the minimum proper pressure. There is a need to measure on a paved road, the same road every time. In addition, the rider does not stop from the start of the measurement to the end. When the measurement start button is pressed, the application starts acquiring data. In this application, the sampling frequency for acceleration and gravity acceleration is 40 Hz. The sampling frequency for Sampling location and barometric pressure is 1 Hz. When the bicycle riding is finished, the rider presses the measurement end button. Enter the current air pressure. The application calculates the riding speed from the location information. The feature values are acquired in the interval from the time when the riding speed first reaches 5 km/h or more to the time when the riding speed last reaches 5 km/h or less. The standard deviation of acceleration on the y-axis and the amplitude spectrum for each frequency are acquired as the feature values. Gravity acceleration and barometric pressure will be used to determine the location of feature extraction.

When a certain amount of data is collected, the application becomes in an estimation state where it estimates the air pressure and judges whether it is in a dangerous condition 16b. When the number of feature data above the minimum proper pressure reaches 10 and the number of feature data below the

Table 5: Correct rate of each feature in the regression

Used feature values		Correct rate(%)
acceleration standard deviation	amplitude spectrum for each frequency	RF
○	○	77.8
○		69.4
	○	79.2

Table 6: Recall rate of each feature in the classification

Used feature values		Recall rate(%)	
Acceleration standard deviation	Amplitude spectrum for each frequency	SVM	RF
○	○	91.1	83.6
○		69.9	62.4
	○	86.5	83.6

Table 7: Recall rate of each feature in the regression

Used feature values		Recall rate(%)
Acceleration standard deviation	Amplitude spectrum for each frequency	RF
○	○	96.1
○		79.4
	○	96.1

minimum proper pressure reaches 10, the state changes to an estimation state in which air pressure decrease is estimated. When the measurement is finished in the estimation state, the estimated air pressure is displayed. In addition, if the estimated air pressure is less than the minimum proper pressure, the display prompts the rider for inflation. The estimated air pressure is estimated from three sets of data. The application displays the average of the estimated air pressure.

In the future of the application, there are several issues such as bicycle riding estimation, extraction of suitable riding locations for measurement, and operation verification. The application should be able to estimate whether the rider is riding a bicycle and can automatically measure it. Currently, the measurement is started by pressing the measurement start button and finished after pressing the measurement end button. The rider can start and finish the measurement without opening the application screen. In addition, the application should be able to automatically extract suitable locations for measurement. Currently, the rider decides on a location that can be paved and does not have to stop midway. The application should be able to automatically extract suitable locations for estimation from driving data. Finally, there is a need to encourage other people to use the bicycles.

Table 8: Setting of Evaluation Experiment 2

Number of subjects	1
Sensing terminal	Galaxy Note 9
Sampling frequency	400 Hz
Number of locations	3
Number of bicycles	3
Air pressure	150 kPa to 300 kPa
Number of data	48
Evaluation index	Correct and recall

(a) Location B

(b) Location C

Figure 13: Location used for Evaluation Experiment 2

(a) Bicycle Y

(b) Bicycle Z

Figure 14: Bicycle used in Evaluation Experiment 2

6 CONSIDERATION OF EVALUATION EXPERIMENT

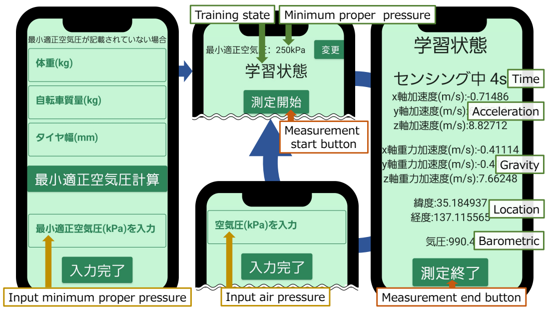
From the results of Evaluation Experiment 1, it was confirmed that the standard deviation of acceleration in the y-axis direction and the amplitude spectrum for each frequency could be used to estimate whether the air pressure was below the minimum proper pressure with a certain degree of accuracy by classification and regression. The regression was as accurate as the classification. The regression can acquire numerical results of the estimation. Numerical values provide more evidence for inflation. Therefore, regres-

Table 9: Information on the bicycles used in the Evaluation Experiment 2

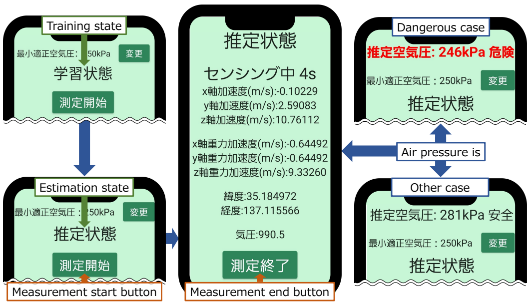
Bicycles	Weight	Tire width	Minimum proper pressure
Y	24.6kg	37mm	240kPa
Z	19.6kg	37mm	230kPa

Table 10: Scores for each location and bicycle when training data is diverted at Location A, Bicycle X

Location	Bicycle	Correct rate (%)	Recall rate (%)
A	X	77.8	96.1
A	Z	75.0	50.0
B	X	62.5	100.0
C	Y	62.5	50.0
C	Z	50.0	25.0



(a) Training state



(b) Estimation state

Figure 15: Flow of application screen using the proposed method

sion using Random Forest is used for air pressure decrease estimation. The accuracy was higher when only the amplitude spectrum of each frequency was used and when both the acceleration standard deviation and the amplitude spectrum of each frequency were used as features. As shown in the Fig. 8,9, each of the feature values changes depending on the air pressure decrease. The acceleration standard deviation is affected by large bumps. The amplitude spectrum shows how much amplitude is present at each frequency. There are bumps and flat places while riding. Basically, there are many flat places. The amplitude of frequencies occurring on flat places is higher and is less affected by bumps. Therefore, two features are used for air pressure decrease estimation. The estimation could be conducted with a certain degree of accuracy even when data from different riders were used for training. Therefore, it was confirmed that the air pressure estimation was possible for the same and locationthe same bicycle.

From the results of the Evaluation Experiment 2, the recall was high in the case of a different location from the training data and the same bicycle, but in other conditions, the correctness and recall were lower than those of the same location as the training data and the same bicycle. Therefore, it was not possible to estimate air pressure decrease with high accuracy. The reason for both the correct and recall rates of Evaluation Experiment 2 may be the different structure of the bicycles. It is considered that different bicycle structures transmit vibration differently, and that the characteristics of the vibration obtained in Evaluation Experiment 1 differed from those obtained in Evaluation Experiment 2. The recall of the training data and the case of another location and the same bicycle was high, so it was found that the bicycles could be judged out of proper at the proper time, but they could be safe to travel in a safe condition. There are places that are frequently used by users and bicycles that need to be learned in advance if the current estimation method is to be implemented as an application. However, if learning is required prior to use, it is time consuming and contrary to the purpose. Therefore, there is a need to come up with learning methods without time consuming.

7 CONCLUSION

In this study, we focus on air pressure inspection and propose a method for estimating bicycle air pressure decrease based on vibration sensing using smartphone. The acceleration in the direction perpendicular to the ground is acquired with a smartphone, and the standard deviation and the amplitude spectrum of each frequency are used as features to estimate the air pressure decrease using random forests and other methods. Evaluation experiments were conducted to classify whether the best timing for tire inflation, to estimate the air pressure value and classify it based on that value, and to evaluate whether the training data from other locations and bicycles can be diverted. The results of the evaluation experiments showed that 96.1% correctly classified when tire inflation was needed, but it was difficult to divert the training data. We developed an application that promotes air pressure inspection using the proposed method.

In the future of air pressure decrease estimation, there is a need to consider a estimation method without time consuming. In this estimation method, there is a need to have riders train in advance at locations and bicycles that they frequently use. Therefore, there is a need to consider methods that do not need to be trained in advance. The machine learning algorithm used in this study required supervised data. However, there are machine learning algorithms that do not use supervised data. If the machine learning algorithms that do not need supervised data are used, there is no time consuming to train it. Therefore, we consider an unsupervised algorithm for estimating air pressure decrease. There is a need to develop and evaluate an application that can estimate air pressure decrease.

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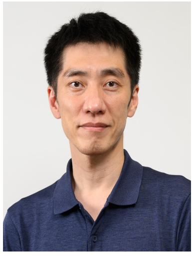

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