An Estimation Method of Calorie Consumption in Activities of Daily Living based on METs Values

Yoshitaka Nakamura†, Yoshiki Matsubayashi‡, Yoh Shiraishi†, and Osamu Takahashi†

†School of Systems Information Science, Future University Hakodate, Japan
‡Graduate school of Systems Information Science, Future University Hakodate, Japan
{y-nakamr, siraisi, osamu}@fun.ac.jp

Abstract - It is important to know the calorie consumption at the time of life activities for prevention of Lifestyle diseases. In this paper, we propose a method of measuring calorie consumption with high precision. Although there are some studies to calculate the calorie consumption by METs values adapting the state estimation method of the person using an accelerometer, it is insufficient to calculate calorie consumption with high precision for the estimation of the states such as road condition and moving speed. The proposed method aims to calculate calorie consumption with high precision during the life activity by estimating road condition and moving speed in addition to the items of conventional estimation using the accelerometer of smartphone. Finally, from the accuracy evaluation of the proposed method, estimation errors were able to be reduced by about 83% from the conventional methods.

Keywords: Provide up to five keywords to be used for future on-line publication searches and indexing.

1 INTRODUCTION

Lifestyle diseases occupy the biggest factor of cause of death in Japan now [1]. For the prevention of these lifestyle diseases, it is important to balance calorie intake and calorie consumption. Recently, the calorie intake comes to be recorded in many food and be easily known, but calorie consumption is difficult to recognize. Therefore the method to easily calculate calorie consumption is required.

The METs values [4] is known as the method to calculate calorie consumption easily from the strength and the duration of the activity depending on the types of life activities. By this method, we can calculate calorie consumption if we can know what kind of activity a person takes and how long the person continued the activity. In various kinds of activities, activities in daily living have a big influence on calorie consumption of the day, because the activities occupy most of one-day activities [2]. Therefore, we can calculate calorie consumption if we can classify the state of daily living activities precisely. But it is necessary to observe the continuous state of activities to classify the state of daily living activities.

On the other hand, with the development of the mobile terminals such as the smartphones, mobile terminals come to equip with many sensors which can measure various phenomena precisely. A kind of sensor such as the acceleration sensor can sense motion of human beings and the various kinds of sensors can record as data sequences. In addition, these terminals are convenient for recording daily living activities, because the terminal tends to be always worn in daily living activities. Using these sensors equipped with by such terminal, there are several methods to estimate daily activities [3] and method to calculate calorie consumptions [5], [6]. However, though calorie consumption greatly varies with moving speed and road conditions such as stairs or level ground, there is few method to calculate calorie consumption precisely by estimating these elements.

In this paper, we propose the method to estimate of daily life activities precisely and to calculate calorie consumption using the acceleration sensor on the smartphone.

2 RELATED WORK

2.1 State Estimation using Acceleration Sensor

There is a method of state estimation of daily activities using acceleration sensor [3]. This method makes multiple parameters from the data obtained from acceleration sensor, and estimates states from the characteristic values in each state. Figure 1 shows the variance of the acceleration, the power spectrum derived from FFT of the acceleration(FFT power spectrum) and the angle of the terminal in each state such as ”Sitting”, ”Standing”, ”Walking” and ”Running”. These values are obtained from the acceleration sensor in the pocket of pants.

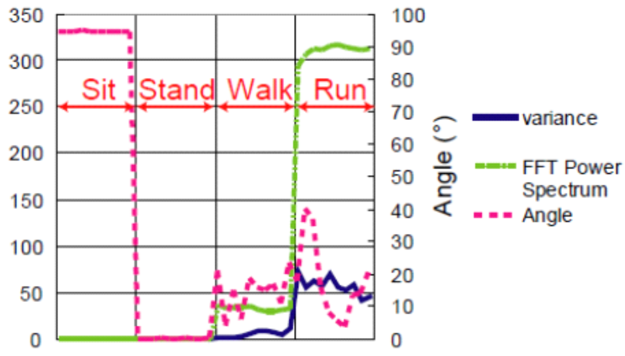

Figure 1: Variation of characteristic values

2.2 Measurement of Calorie Consumption

2.2.1 METs Values

There are many studies to apply the state estimation method to calculate calorie consumption using METs(Metabolic Equivalent of Tasks) values. The METs values [4] is the technique proposed by the American College of Sports Medicine and is expressed in the following expression (1).

$$EE = 1.05 \times METs \times W \times T \quad (1)$$

EE means calorie consumption(kcal), W means the weight of the subject person(kg) and T means the duration of the activity(hours). The METs value means that the strength of activities is equivalent to several times at resting condition. The examples of METs values are the following table 1. For example, we can calculate calorie consumption on the following expression (2) when the subject person weighs 60kg and did normal walk of around 67m/min on level ground for 30 minutes.

Table 1: Examples of METs values

METs	Activiteis
1.0	Sitting quietly and watching television
1.2	Standing quietly
1.3	Sitting and reading books
1.4	Sitting and talking, eating
1.8	Standing and talking
3.0	Walking(67m/min, Level ground)
3.3	Walking(81m/min, Level ground)
3.8	Fast walking(94m/min, Level ground)
10.0	Running(161m/min, Level ground), Swimming
15.0	Running up the stairs

$$1.05 \times 3.0 \times 60 \times 0.5 = 94.5(kcal) \quad (2)$$

2.2.2 Measurement of Calorie Consumption using State Estimation

The method considering the moving states [5] can estimate the moving state such as ”Stopping” or ”Walking” or ”Running” or ”Bicycle” or ”Train, Car, Bus” using mobile terminals. Furthermore, in the ”Walking” state this method distinguishes ”Level ground”, ”Up the stairs” and ”Down the stairs”, and calculates calorie consumption from estimated state and METs. The state estimation of this method uses only the FFT power spectrum of the acceleration as the characteristic value. The measured power spectrums are converted into symbols decided beforehand. And each state is estimated from these plural symbols

The method considering daily life activities [6] can estimate the basic four states of daily life activities such as ”Sitting” or ”Standing” or ”Walking” or ”Running” using sensors on the market. The state estimation of this method uses the values of variance, dominant frequency, the FFT power spectrum of the acceleration and the angle of the terminal as the characteristic value.

2.2.3 Problems

Table 2 shows that the METs values are greatly different in the difference of speed and the road condition. This has a big influence on the calculated value of calorie consumption.

Table 2: Difference in METs between ”Walking” and ”Running”

METs	Activiteis
2.5	Walking(54m/min)
5.0	Walking(107m/min)
8.0	Walking down the stairs Running(134m/min)
10.0	Running(161m/min, Level ground)
15.0	Running up the stairs

Though the method of Ref. [5] considers only moving state, the estimation of ”Bicycle” or ”Train, Car, Bus” is unnecessary if we calculate calorie consumption only in daily life activities. This method does not consider moving speed. As for the method of Ref. [6], the road condition where the subject person ”runs” or ”walks” such as ”up and down the stairs”, is not estimated. For more accurate calcuration of calorie consumption, it is necessary to be able to estimate these speeds and conditions.

3 PROPOSED METHOD

We propose the method to calculate calorie consumption in daily life activities. This method consists of two processes such as the process of state estimation and the process of calcuration of calorie consumption. The process of state estimation uses the acceleration sensor of smartphone, and the process of calorie calcuration uses METs values. And the basic daily life activities shall be classified into four state such as ”Sitting”, ”Standing”, ”Walking” and ”Running”.

When the acceleration value is measured using smartphone, there is a problem that the acceleration values change by the wearing place of smartphone. In the proposed method, smartphone is attached to the pocket of pants(Fig.2). In this way, it becomes easy to distinguish the change of state by the angle of foots at the time of ”Sitting” and ”Standing”. And at the time of ”Walking” and ”Running”, it becomes easy to catch the change of the acceleration.

Figure 2: Wearing place of smartphone

The frequencies of "Walking" and "Running" are usually delivered to 0-10Hz. Therefore the sampling rate of the acceleration sensor sets it to 20Hz. The state estimation process uses the variance of the acceleration, the basic frequency derived from FFT of the acceleration and the angle of the smartphone. The variance and the frequency of the acceleration are calculated from 64 latest acceleration data.

3.1 Process of State Estimation

The proposed method estimates the states of "Walking up the stairs", "Walking down the stairs" and "Running up the stairs" in addition to "Sitting", "Standing", "Walking" and "Running" states of the conventional method. And the method calculates the velocity of moving at the time of "Walking" and "Running". Figure 3 shows the overview of the proposed method.

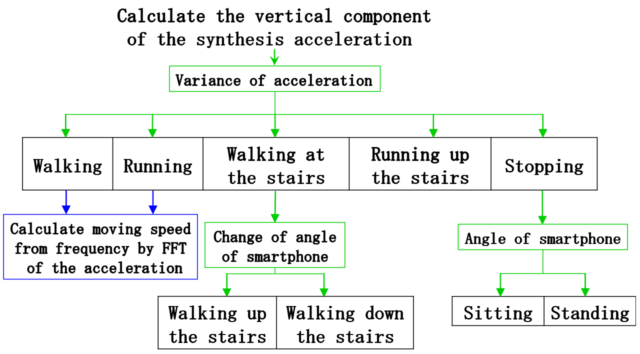

Figure 3: Overview of state estimation

Reference [3] shows that four states "Walking", "Running" and "Stopping" can be classified by the variance of the synthesis acceleration. Furthermore, the proposed method estimates the states "Walking on the stairs" or "Running at the stairs" in addition to the states "Walking" and "Running". However, we cannot distinguish the states "Walking on the stairs" and "Running at the stairs" from the states "Walking" and "Running" by the variance of the synthetic acceleration as shown in Fig. 4. The vertical movement of "Walking on

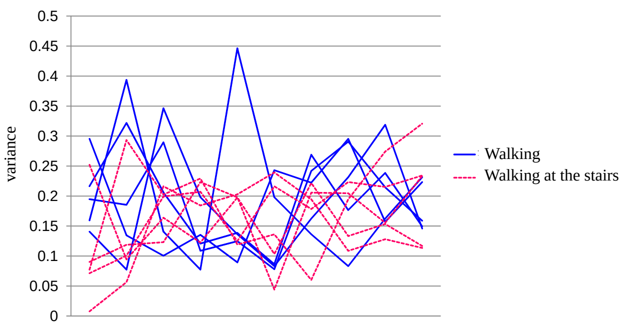

Figure 4: Variance of the synthesis acceleration

stairs" is stronger than normal "Walking". Therefore I verified whether we could detect the characteristic by the vertical component of the variance of the synthesis acceleration. Figure 5 shows the result. There are great difference of the

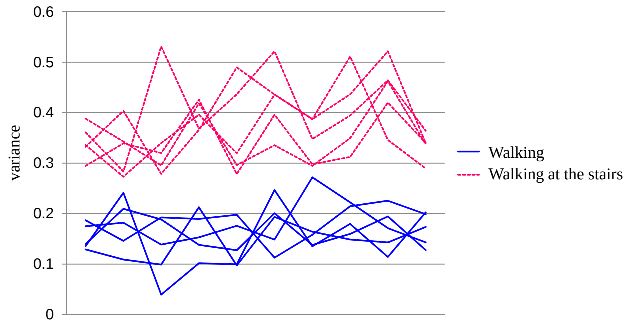

Figure 5: Variance of the vertical component of the synthesis acceleration

vertical component of variance of the acceleration, whether the subject person walks on the stairs, In this way we can estimate the states "Walking", "Running" "Walking on the stairs", "Running at the stairs" and "Stopping" only using the value of variance.

The calculation procedures of the vertical component of the synthesis acceleration are as follows.

1. About x-axis and y-axis and z-axis, the gravity component of the acceleration is removed from the acceleration of the x-axis and y-axis and z-axis.

2. The acceleration is composed from x, y, z component of acceleration that removed gravity component, according to the following expression.

$$Acc = \sqrt{x^2 + y^2 + z^2} \tag{3}$$

3. The angle θ is calculated from the inner product between the synthesis acceleration and the gravitational acceleration.

$$\theta = \cos^{-1}\left(\frac{\vec{a} \cdot \vec{b}}{|\vec{a}||\vec{b}|}\right) \tag{4}$$

4. The vertical component of acceleration is calculated from the angle θ.

$$Acc_v = Acc \times \sin\theta \tag{5}$$

Acc means synthetic value of the acceleration. x, y and z mean x-axis(y-axis, z-axis) component of the acceleration that removed a gravity component respectively. θ means the angle between synthesis acceleration and the gravitational acceleration, $\vec{a}$ means the acceleration that removed the gravity component, $\vec{g}$ means the gravity component of the acceleration. Acc_v means the acceleration of the vertical direction.

3.1.1 State Estimation

Each state is estimated using each threshold found experimentally about the variance, the angle and the variation of the angle(differences between 64 latest maximums and minimum of the angle data) of measured acceleration. The setting of the threshold is described in section 3.1.3.

At first, basic state such as "Stopping", "Walking", "Walking on the stairs", "Running" and "Running up the stairs" are estimated using the variance of the acceleration of the vertical direction. Table 3 shows the threshold. The state is decided where of the threshold range the variance va of measured acceleration is included in.

Table 3: Threshold of basic states

State	Threshold
Stopping	$v < 0.07$
Walking	$0.07 \leq v < 0.33$
Walking on the stairs	$0.33 \leq v < 0.53$
Running	$0.53 \leq v < 1.35$
Running up the stairs	$1.35 \leq v$

Then, when it is in the state of ”Walking on the stairs”, the states of ”Walking up the stairs” and ”Walking down the stairs” are estimated using the variation of the angle measured at smartphone. Table 4 shows the threshold. The state is decided where of the threshold range the variation of the angle a_v is included in.

Table 4: Threshold of ”Walking on the stairs”

State	Threshold
Walking up the stairs	$0.67 < a_v$
Walking down the stairs	$a_v \leq 0.67$

Finally, when it is in the state of ”Stopping”, the states of ”Sitting” and ”Standing” are estimated using the angle data measured at smartphone. Table 5 shows the threshold. The state is decided where of the threshold range the angle data a. is included in.

Table 5: Threshold of ”Stopping”

State	Threshold
Sitting	$1.1 \leq a < 2.0$
Standing	$a < 1.1, 2.0 \leq a$

3.1.2 Calculation of the Velocity

The step is defined in Ref. [7], and calculates using the following expressions. S_w means stride in walking, S_r means the stride in running and H means the height of the subject person.

$$S_w(m) = H(m) \times 0.45 \quad (6)$$

$$S_r(m) = H(m) \times 0.5 \quad (7)$$

The velocity of the subject person v can be calculated on the following expression. S means the stride and P means the pace of walking/running.

$$v(m/min) = S(m/steps) \times P(steps/min) \quad (8)$$

The pace at the time of ”Walking” or ”Running” is calculated by FFT of the acceleration data.

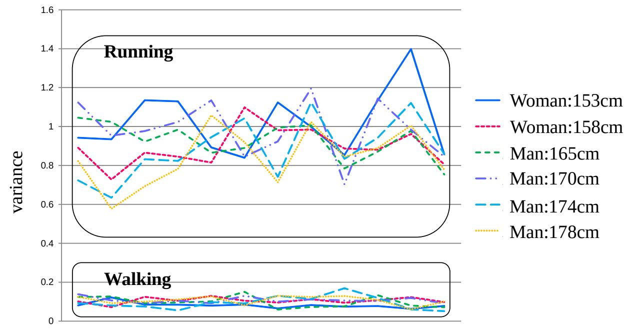

Figure 6: Variance of the acceleration at the time of ”Walking” or ”Running”

3.1.3 Setting of the Threshold

These thresholds are set using decision tree and the result of preliminary experiment. As a preliminary experiment, six subject people including man and woman continued each state for about 300 seconds. The threshold is set by the variance, the angle and the variation of the angle provided from this experiment using decision tree. Figure 6 shows the value of variance in each subject person at the time of ”Walking” and ”Running”. Though the variance tends to become small if the subject person is short, the ranges of the variance are divided clearly at the time of ”Walking” and ”Running”, and it is possible to distinct by the threshold.

3.2 Measurement of Calorie Consumption

The METs values corresponding to the state in the proposed method is set by table 6. At the time of ”Walking” and ”Running”, METs values depend on the speed v and calculate on the following expressions by Ref. [3].

Table 6: METs values of each states

METs	Activities
1.5	Sitting
1.8	Standing
Expression(9)	Walking
Expression(10)	Running
3.0	Walking down the stairs
8.0	Walking up the stairs
15.0	Running up the stairs

$$Walking : METs = 0.0272(m) \times v + 1.2 \quad (9)$$

$$Running : METs = 0.0930(m) \times v - 4.7 \quad (10)$$

4 EXPERIMENTAL EVALUATIONS

In this experiment, the proposed method is implemented on iPhone4. And the precision evaluation is divided into two evaluations. First one is the precision evaluation of the calcuration of calorie consumption. Second one is the precision evaluation of the state estimation.

4.1 Precision Evaluation of the Measurement of Calorie Consumption

As an experiment scenario, six subjects move along the original route and measure the state of activities. The estimated precision is evaluated by comparison between the correct value and measured value by the proposed method and the measured value by the conventional method. The correct values are calculated from real activities and the METs values. The scenario is set as follows.

Table 7: The scenario of experiment

Order	Activiteis	Time
1	Walking	30sec
2	Walking up the stairs	30sec
3	Walking	30sec
4	Walking down the stairs	30sec
5	Standing	60sec
6	Running	15sec
7	Running up the stairs	30sec
8	Sitting	60sec

Figure 7 shows the result of the evaluation. As a result, the proposed method can calculate calorie consumption closer to the correct value than the conventional method.

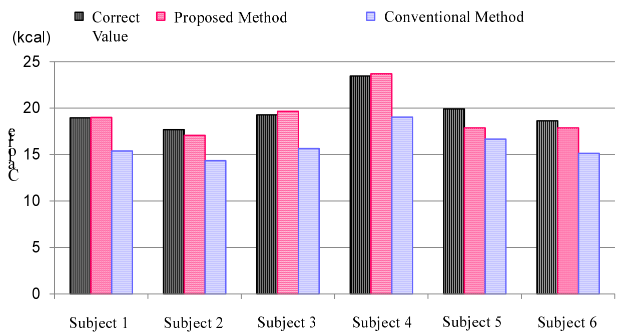

Figure 7: Result of evaluation of the calcuration of calorie consumption

4.2 Precision Evaluation of the State Estimation

The correct answer rate of the state estimation process is calculated according to the following expressions and evaluates the precision of estimation. C means the correct answer rate, N_c means the number of states estimated correctly and N_e means the number of states estimated.

$$C(\%) = \frac{N_c}{N_e} \times 100 \tag{11}$$

The proposed method aims for highly precise calcuration of calorie consumption at the time of the daily life activity by improving the precision of individual state estimation. Therefore it is desirable for the individual state estimation has around 90% of the correct answer rate.

Table 8 shows the result of the precision evaluation of the state estimation process. In this table, "W u s" means "Walking up the stairs", "W d s" means " Walking down the stairs" and "R u s" means "Running down the stairs". The vertical line expresses the real state and the horizontal line expresses the estimated result.

The precision of the state "Sitting" and "Standing" reached 100%, and "Walking" achieves 95.4%. On the other hand, The precision of the state "Walking up the stairs" achieves 70.7%, "Running" achieves 84.4% and "Running up the stairs" achieves 74.2%. The precision of the state "Walking down the stairs" turned out low about 44%.

4.3 Discussion

4.3.1 Discussion about Precision of the Measurement of Calorie Consumption

We consider about the proposed method's precision of the calcuration of calorie consumption. From the result of Fig.7, the measured value of the our method is almost the correct value than the measured value of the conventional method. Therefore, our method can calcurate calorie consumption precisely at the time of daily life activity than the conventional method. And the error average of the measured value of the proposed method and the correct value is about 0.69 kcal. On the other hand, the error average of the conventional method is about 3.6 kcal. These errors are errors per 4 minutes 30 seconds. If exchanging this for 18 hours that are the mean activity time of the person of the day, the error of the proposed method becomes equivalent to about 165 kcal. The error of the conventional method becomes equivalent to about 860 kcal. Therefore, the proposed method could reduce 86% of errors than the conventional method. 860 kcal which is the error of the conventional method is equivalent to 3-4 cups of rice bowls because one cup of rice bowl(140g) is 235 kcal [8]. 165 kcal which is the error of the proposed method does not reach one cup of rice bowl. However, this value is an error when exchanging the experiment scenario for 18 hours. Actually "Sitting" or "Standing" or "Walking" which can be estimated precisely by the proposed method is the major state of daily life activities. Therefore it is expected that the error becomes less than 165 kcal when the proposed method in daily life.

4.3.2 Discussion about Precision of the State Estimation

We consider about the proposed method's precision of the state estimation. From the result of table 8, "Sitting" and "Standing" and "Walking" can achieve more than 95% of high precision. In contrast, the estimated rate of "Walking down the stairs" is low with 44The "Walking down the stairs" causes many false estimates with the "Walking up the stairs" state. The reasons of increase of false estimations is the problem about the effectiveness of the thresholding. Figure 8 shows the change of the angle of smartphone at the time of "Walking down the stairs" and "Walking up the stairs". From the result, there are the parts which have a large difference of the change of the angle and the parts which have a small difference of the change of the angle. This depends on the individual difference in the way of going up stairs and going down stairs. In

Table 8: Result of evaluation of the state estimation

	Sitting	Standing	Walking	W u s	W d s	Running	R u s
Sitting	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Standing	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Walking	0.0%	0.0%	95.4%	0.0%	4.6%	0.0%	0.0%
W u s	0.0%	0.0%	19.5%	70.7%	0.0%	9.8%	0.0%
W d s	0.0%	0.0%	12.0%	32.0%	44.0%	12.0%	0.0%
Running	0.0%	0.0%	0.0%	0.0%	0.0%	84.4%	15.6%
R u s	0.0%	0.0%	0.0%	0.0%	3.2%	22.6%	74.2%

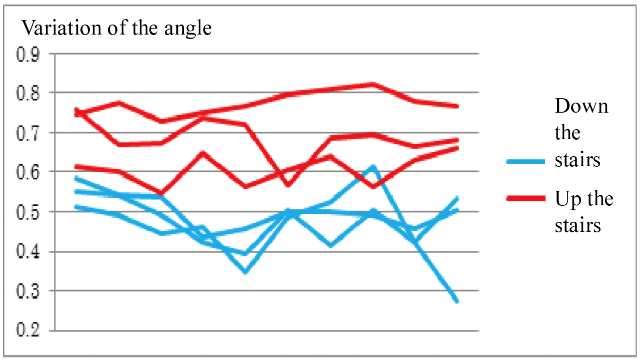

Figure 8: Variation of the angle

particular, at the time of ”Walking up the stairs”, the change of the angle grows larger at going up the stairs lifting foots up highly. Therefore, the correct answer rate of estimation can be improved by changing the threshold on individual basis dynamically. Figure 9 is one of the examples. Because the threshold is not suitable in the middle, the wrong state is estimated. By adjusting the threshold according to the personal characteristic, correct estimation is enabled as in the below graph of Fig. 9.

5 CONCLUSION

In this paper, we proposed the method to calcurate calorie consumption precisely considering daily life activities. Our proposed method achieved precise calcuration of calorie consumption by considering the road condition and movement speed.

We evaluated the precision of the proposed method by the comparison experiments between the conventional method and the proposed method. As a result, it was shown that the proposed method could calcurate calorie consumption precisely in comparison with the conventional method. However, there is the room for improvement because the precision of the proposed method is low in ”the case to walk down the stairs”.

For future work, we need the improvement of the estimation accuracy of activities by applying plural learning models. In addition, it is necessary to evaluate the calculation of calorie consumption in the daily unit because the experiments of this paper depend on the original scenario.

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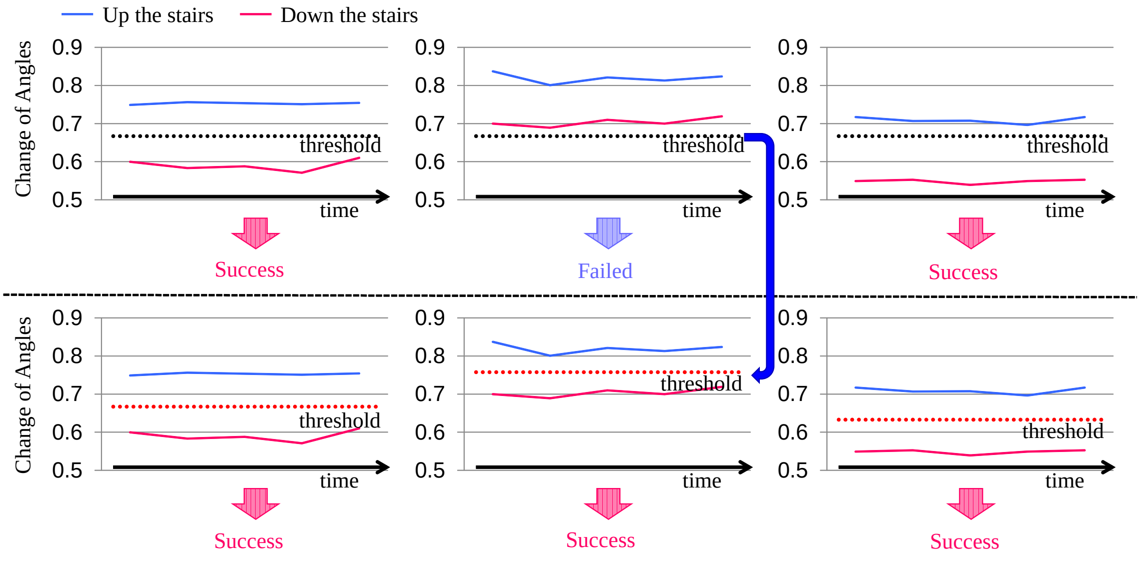

Figure 9: Change of the dynamic threshold

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