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# Optimal ROI Determination for Obtaining PPG Signals from a Camera on a Smartphone

**Keonsoo Lee* and Yunyoung Nam†**

**Abstract** – Photoplethysmography (PPG) is a convenient method for monitoring a heart rhythm. In addition to specialized devices, smartphones can be used to obtain PPG signals. However, as smartphones are not intended for this purpose, optimization is required to efficiently obtain PPG signals. Determining the optimal region of interest (ROI) is one such optimization method. There are two significant advantages in employing an optimized ROI. One is that the computing load is decreased by reducing the image size used to extract the PPG signal. The other is that stronger and more reliable PPG signals are obtained by removing noisy regions. In this paper, we propose an optimal ROI determination method by recursively splitting regions to locate the region that produces the strongest PPG signal.

**Keywords**: Photoplethysmography, Region-of-interest, Optimal method, Smartphone.

## 1. Introduction

Photoplethysmography (PPG) is one of the most widely used methods for monitoring a heart rhythm. Alternatively, the electrocardiogram (ECG) can be used to acquire the state of a heart. However, due to the convenience in usage, PPG is often used to monitor daily a heart rhythm, which does not require high accuracy or detail of the heart beats [1, 2]. PPG signals are obtained using a flashlight and a photodetector. While part of the emitted light is absorbed into the tissue and blood, a portion of the light is reflected or transmitted, which can be detected by the photodetector. Depending on the level of arterial oxygen saturation, the amount of absorbed light is changed. By detecting this change, heart beats can be estimated. Instead of using a flashlight and photodiode, a light-emitting diode (LED) and a camera of a smartphone can be used. The LED is used as the flashlight, and the camera as the photodiode. Therefore, people who have their own smartphone, are able to monitor their heart rhythm at anytime and anywhere [3, 4, 5].

However, obtaining PPG signals with a smartphone is computationally complex compared with using specialized devices, which is affected by the gap between the flashlight and the camera lens, motion artifacts while holding a smartphone, limited frame rate, and excessive resolution of the images. Thus, to use a smartphone for obtaining PPG signals requires a method that overcomes these issues. In this paper, we propose an optimal ROI selection method for obtaining reliable PPG signals using a smartphone camera. Instead of using a series of full-size images obtained from the smartphone camera module, a portion of each image is used. By excluding unnecessary parts of the images, the size of the images used to obtain PPG signals is reduced. This downsized image, i.e., the ROI, requires less computational resources and produces more reliable PPG signals [6]. However, optimal selection of the ROIs is necessary to obtain more reliable PPG signals. In [7], researchers compared with five algorithms using the statistical features such as the mean and the maximum spectra power of the PPG signal of each ROI, and heuristic rules such as removing ROIs to select the optimal ROIs.

In this paper, we conducted experiments with various resolutions, and region sizes to determine the optimal ROI for smartphone PPG applications. Related work is provided in Section 2. The semantics of these features and a method of combining reliable features are presented in Section 3. The experimental results are shown in Section 4. Finally, the conclusion is given with discussions in Section 5.

## 2. Related Work

### 2.1 PPG signal acquisition

Numerous researches have been presented for estimating a heart rhythm using PPG signals as PPG signals are cost-effective and easily obtainable compared with ECG signals. NellcorTM's PM10N [8] and LAXTHA's ubpulse T1 [9] are professional devices used to acquire a subject's PPG signals. There are also numerous smartphone applications, including Azumio Inc's Instant Heart Rate [10], Runstastic's Runtastic Heart Rate PRO [11], Bio2Imaging's Heart Beat Rate Pro [12], and more than 120 others that were able to be downloaded for this purpose.

† Corresponding Author: Dept. of Computer Science and Engineering, Soonchunhyang University, Korea. (ynam@sch.ac.kr)
* Dept. of Medical IT Engineering, Soonchunhyang University, Korea. (keonsoo@sch.ac.kr)
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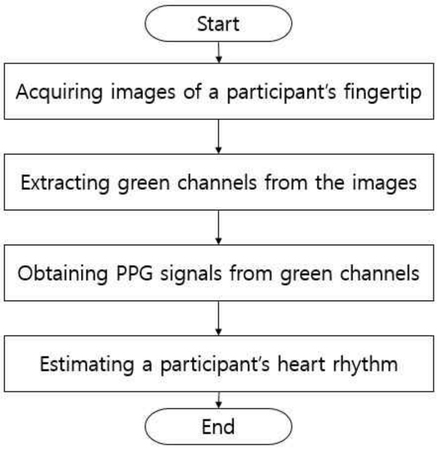



**Fig. 1.** General process of estimating a participant's heart rhythm using a smartphone

## 2.2 PPG signal analysis

The general process of obtaining PPG signals using a smartphone is shown in Fig. 1. The first step is to acquire images of a subject's fingertip. A subject places an index or middle fingertip on the camera lens. Light is projected onto the subject's fingertip. The light is absorbed depending on the arterial oxygen saturation in the blood vessels, which is changed by the subject's heartbeat. An image that shows a subject's arterial oxygen saturation level is taken. In the second step, the green channel of the image is extracted because the change in absorbed light is greater in this color channel [13]. The third step is to obtain a PPG signal from the green channel. The intensity of the green channel represents the PPG signal of the image. When the size of the recorded image is too big to calculate the intensity, the image is divided and a sub-image is used instead. A region in close proximity to the flashlight is preferred because the intensity of PPG signals obtained in these regions is stronger [14]. To evade noise such as motion artifacts or respirations, various filters are applied to the obtained PPG signals. Low-pass, high-pass, and band-pass filters are widely used active filters. As the frequency band of heart beats is in the range of 0.5-4.0 Hz, removing other frequency ranges can reduce the noise in PPG signals [15]. The last step is to estimate the heart rhythm of a subject. From the obtained PPG signal, peaks are detected. The number of peaks in a PPG signal is regarded as the number of heart beats during a given temporal interval.

# 3. Method

## 3.1 Data collection

The method of obtaining PPG signals in this paper follows the process of the four steps shown in Fig. 1. In the first step, we record a video of a subject's fingertip. Notably, there is a quality difference in recorded videos using android smartphones. Recording videos using android smartphones can be carried out with one of these methods. The first method is to use the MediaRecorder class. With the QUALITY_HIGH_SPEED_LOW property of the CamcorderProfile class, a video with over 100 frames per second (fps) can be recorded; however, it is not possible to analyze the acquired video in real time at this rate, which introduces a temporal delay. The other way is to use the preview method of the camera class. With this method, it is almost impossible to achieve over 30 fps. However, analyzing images in real time is possible. In this research, the MediaRecorder class was used to record a 14-s video of a subject's fingertip. In the second step, the recorded video was analyzed using MATLAB, the green channel was extracted, and a PPG signal was obtained. A band-pass filter (range: 0.5-4.0 Hz) was applied. The heart rate was estimated by detecting peaks in the last phase.

In the study, we recruited 12 participants, aged 21 to 27 years old, with even gender distribution. None of the participants had cardiac disorders. A LG G3 (LG Electronics, Seoul, Korea) was used for recording each participant's fingertip video. The video was recorded at 120 fps with 1280 × 720 resolution. The frame rate of PPG signals used in specialized devices such as BIOPAC systems' PPG 100C is over 100 Hz [16]. To be comparable with these signals, the PPG signals were acquired at a rate of 100 fps. 10 records for each participant are collected in the study.

## 3.2 Data analysis

The objective of using a ROI is to reduce the computing load and obtain more reliable PPG signals. The reliability of a PPG signal is defined as the strength of the signal, given below:

$$Strength = \frac{\sum_{i=1}^{n} (Peak_i - Valley_i)}{n} \tag{1}$$

To reduce the computational load, the size of the ROI needs to be minimized. However, the smallest ROI may not be the optimal ROI. Depending on the motion artifacts during the PPG signal acquisition phase, the position where the strongest signal is obtained changes. To be robust against noise, the ROI needs to be sufficiently large.

To determine the optimal ROI, we propose a method which reduces the size of the ROI recursively. Fig. 2 shows the process of the proposed method. In the first step, the entire region is divided into four subregions. The size of each subregion and the aspect ratio of the subregion are consistent with the parent region. In the second step, the strength of obtained PPG signals from each subregion is calculated using Eq. (1). Then in the third step, the subregion with the strongest PPG signal is selected.

Fig. 3 shows the resulted signals from these three steps. In preparation for the proposed method, a video of a subject's fingertip was recorded using a smartphone. The recorded video was then transferred to a desktop computer and analyzed. From the video, the green channel was extracted. Because the video was recorded in YUV color space, the video was converted from the YUV to the RGB color space.

Fig. 3(a) shows the change in values extracted from the green channel. To exclude noise, a band-pass filter was used. Fig. 3(b) shows the result of applying a band-pass filter. The peaks and valleys detected from the signals corresponds to the number of heart beats within the time interval. Fig. 3(c) shows the detected peaks and valleys.

In the fourth step, the selected region was evaluated to determine whether or not it was optimal, based on the region size and minimal computational load. The threshold for the criteria was determined from the experiment described in Section 4. If the region selected in the fourth step fulfilled the optimal criteria, it was selected as the optimal ROI and the recursion was terminated. If the region failed to fulfill the criteria, the recursion continued until an optimal ROI was selected.

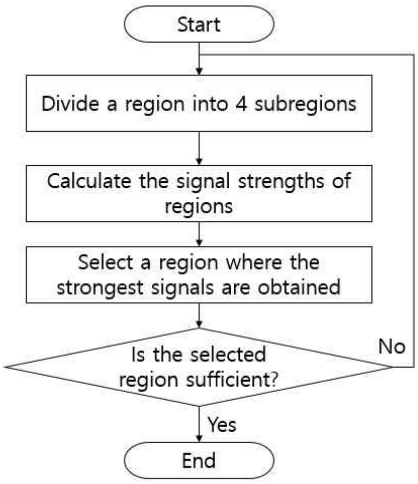
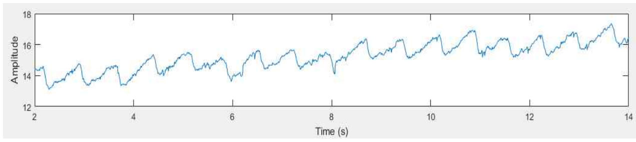


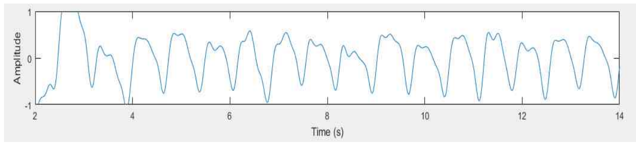

**Fig. 2.** Proposed method for determining the optimal ROI

## 4. Results and Evaluation

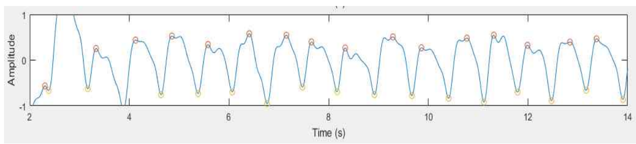
In the first cycle, the size of the sub region was 640 × 360; the distribution of the selected region is shown in Fig.




(a) Green channel extraction from a video




(b) Band-passed PPG signal




(c) Peak and valley detection for estimating heart rhythm

**Fig. 3.** The result of each steps of the proposed method

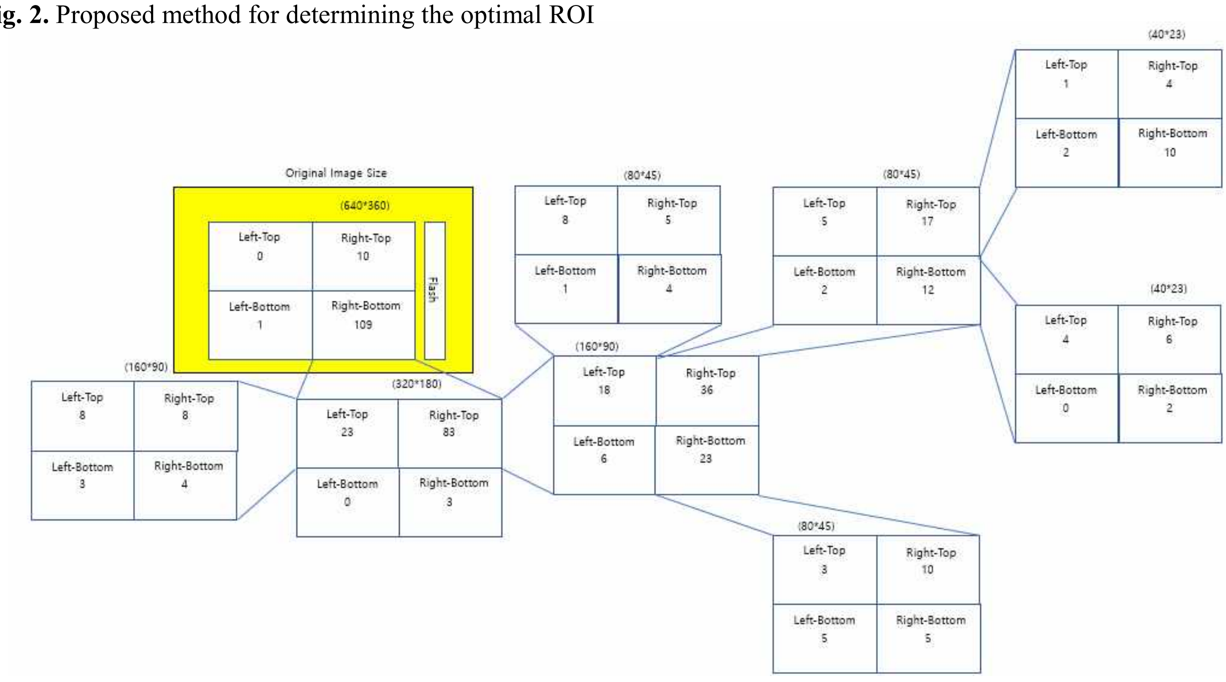



**Fig. 4.** Strength of the ROI in the divided region; The smaller the ROI size, the stronger the PPG signal obtained

4. Ninety-eight percent of the selected regions were in the Right-Top and Right-Bottom. Because the LG G3 has a flashlight on its right side, stronger PPG signals were obtained in the regions closer to the flashlight. The flashlight in the LG G3 consists of two LEDs; Right-Top showed stronger PPG signals than Right-Bottom. In the second cycle, the subregion's size was 320 × 180. Right-Top was the most common location where the strongest PPG signals were obtained.

With a probability of 19%, the ROI belonged to the Left-Top. Therefore, in the third cycle, Right-Top and Left-Top were divided. The chance of having a ROI in the divided region was below 10%. The Right-Top region in the second cycle had a 69% chance of including the ROI. In the third cycle, this region was divided into four subregions. The Left-Top region had a 15% chance, the Right-Top region a 30% chance, and the Right-Bottom region a 19% chance of including the ROI. Those regions whose chance of including the ROI was higher than 10% were divided. The smallest region with the highest chance of including the ROI was a region in the index (32, 18). The index was defined by dividing the original image with a grid of 32 × 32. The cell marked in red is the smallest region with the highest possibility of generating the strongest PPG signal. The size of this region is 0.1% of the original image, and the possibility of having the strongest signal was 8%. If the region in red is combined with the region in (32, 19), the combined region's probability of having the strongest signals becomes 13%. This is a trade-off problem in which a decision is made as to whether doubling the computing load is an acceptable compromise given that the probability will increase from 8% to 13%. Fig. 5 shows the amount of time required to estimate heart rhythm with different region sizes. The sizes of the regions in the first through sixth cycles were 640 × 360, 320 × 180, 160 × 90, 80 × 45, 40 × 23, and 20 × 12, respectively. As shown in Fig. 5, when the size of the region was smaller than 40 × 23, the advantage of reducing the region size disappeared. In the process of estimating a heart rhythm as shown in Fig. 1, the computing load affected by the ROI size is restricted to the second and third steps. Thus, it is meaningless to reduce the size of the ROI to less than 920 pixels.

The difference of computation times between a region of size 80 × 45 and a region of size 40 × 23 was 0.17 seconds. The combination of regions with a size of 40 × 90 and a probability of 13% to produce the strongest PPG signal, requires 0.06 seconds. The consumed time is dependent on the machine's computing power. The 0.06-s calculation was performed on a desktop with a Pentium G4400 processor. Because the computation time required is dependent on the machine, it is difficult to conclude the appropriate tradeoff between time and size for optimal results. However, there is a threshold in which the computing load is not reduced by further reducing the ROI size. In this experiment, the threshold of the ROI size was 40 × 23. The important factor is not the aspect ratio but the number of pixels in the ROI. Considering the complexity of extracting pixels of different ROI shapes, using the shape of a rectangle requires less computation than that for a circle, oval, or triangle.

The strength of the PPG signal is an important consideration in determining the ROI. Depending on the ROI size, the strength of the PPG signal is increased. The increment of the strength is expected because in every recursion, the region with the strongest PPG signal is selected, as shown in Fig. 2. However, the rate of the signal

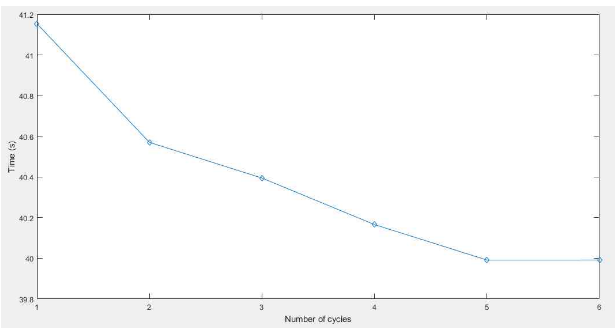



**Fig. 5.** Time required to estimate a heart rhythm depending on the size of the region; As the cycle increases, the size of a region is reduced in the process in Fig. 2

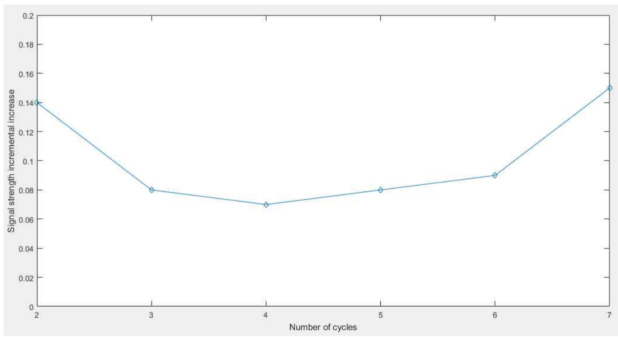



**Fig. 6.** Signal strength increment depending on the number of cycles; The X-axis starts from the second cycle because the rate is compared to the previous cycle

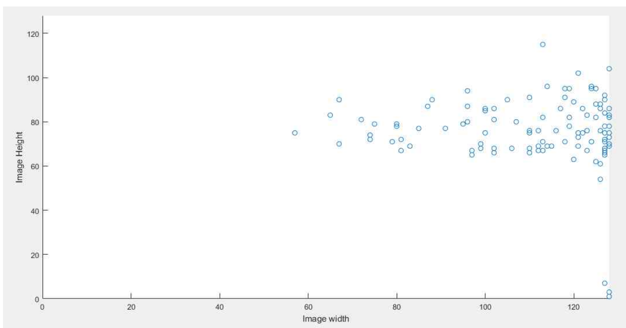



**Fig. 7.** After the seventh cycle, regions where the strongest PPG signals are obtained are widespread; In this case, the ROI is easily affected by noise such as motion artifacts

strength increment depends on the size of the ROI. Fig. 6 shows the trend of the strength increment. For the second cycle where the size of a region changes from 640×360 to 320×180, the strength increased 14% on average. Between 320×180 and 160×90, the strength increased 8% on average. Until the sixth cycle where the size of ROI was 20 ×12, the rate of signal strength increment was averagely 8%.

For the seventh cycle, the rate of signal strength increment was 15% on average. However, the size of the region in the seventh cycle was 10×6, which is too small to be robust against noise. Fig. 7 shows the distribution of regions after the seventh cycle; regions where the strongest PPG signals were obtained were widespread. Therefore, in the region where noise such as motion artifacts are made, the ROI is easily changed. Thus, recursion of the ROI selection process is not recommended to exceed six times.

The same results were obtained from the datasets acquired with resolutions of 1280×720, 1920×1080, and 3840×2160. The frame rate of the videos at each resolution was set to 30 fps, as 30 fps was the highest frame rate for the maximum resolution. Fig. 8 shows the time required for each resolution. Compared with the results shown in Fig. 5, 25% of the time was consumed for 1208×720 resolution because the frame rate was reduced from 120 fps to 30 fps. Fig. 9 shows

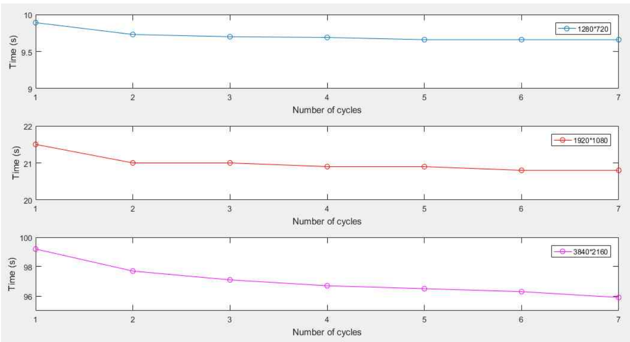



**Fig. 8.** Time required to estimate a heart rhythm depending on the size of the regions for three resolutions: 1280 × 720, 1920×1080, and 3840×2160

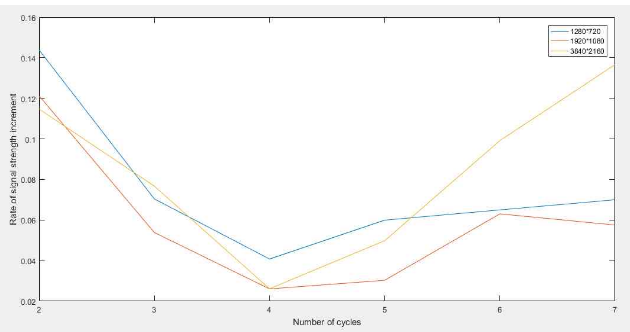



**Fig. 9.** Rate of signal strength increment depending on the region size for three different resolutions: 1280× 720, 1920×1080, and 3840×2160; The X-axis starts from the second cycle because the rate is compared to the previous cycle

the rate of signal strength increment for each resolution. Compared to the data shown in Fig. 6, the fourth cycle shows a rebounding pattern. As such, five recursions are recommended for the process described in Fig. 2. The region obtained after five recursions covers 0.1% of the original image and its position is near the smartphone's flashlight.

## 5. Conclusion

In this paper, we have presented the method for determining optimal ROIs by recursively splitting and selecting the most suitable region with the strongest PPG signals. The recursion is terminated when the selected regions are qualified as optimal ROIs. The criteria for determining the optimal ROIs are the stability of the estimating time for a heart rhythm and the signal strength increment. The experiments were conducted on 12 participants using an android phone to acquire videos of the participants' fingertips.

Our results showed that the estimation time for a heart rhythm becomes stable after the fifth recursion, and the signal strength increment becomes stable after the third recursion. The highest density of a region was achieved by the fifth cycle. Therefore, we believe that the optimal number of a recursions is five. For images of 1280×720 resolution, the size of the ROI in the fifth cycle was 40×23. The coordinate of ROI was (32, 18) when the original image was divided into a grid of 32 × 32.

For future work, the proposed method will be applied using various smartphones, given that the computing power [17] camera modules vary considerably among models. To determine the optimal ROI independent of the smartphone, an autonomous configuration will be researched.

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**Keonsoo Lee** He received the M.S. and Ph.D. degrees in computer engineering from Ajou University, Korea, in 2004 and 2013, respectively. He is currently an Research Professor at the Medical Information Communication Technology, Soonchunhyang University, Asan, Korea. His research area includes artificial intelligence, knowledge representation, and multi-agent system.

**Yunyoung Nam** He received the B.S., M.S., and Ph.D. degrees in computer engineering from Ajou University, Korea in 2001, 2003, and 2007 respectively. He was a senior researcher in the Center of Excellence in Ubiquitous System (CUS) from 2007 to 2010. He was a research professor in Ajou University from 2010 to 2011. He also spent time as a postdoctoral researcher at Center of Excellence for Wireless & Information Technology (CEWIT), Stony Brook University, New York from 2009 to 2013. He was a postdoctoral fellow at Worcester Polytechnic Institute, Massachusetts from 2013 to 2014. He is a director at ICT Convergence Rehabilitation Engineering Research Center at Soonchunhyang University from 2017. He is currently an assistant professor in the Department of Computer Science and Engineering at Soonchunhyang University. His research interests include multimedia database, ubiquitous computing, image processing, pattern recognition, context-awareness, conflict resolution, wearable computing, intelligent video surveillance, cloud computing, biomedical signal processing, rehabilitation, and healthcare system.