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# Development of Magnetometer based Portable Self-Respiratory Training System for Enhancing the Efficiency of Radiation Therapy

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**As the demand for radiation therapy increases, an appropriate breathing training has been becoming a vital element to improve the accuracy and efficiency of radiation therapy. It is important for patients to maintain the constant respiratory cycle due to difficulties of identifying exact treatment site of respiratory organs, which move with every breath of patients (e.g. part of thorax or abdomen). In order to train the patient's periodic breathing and evaluate patient's respiratory cycle quantitatively, we have developed magnetometer based respiratory training system. Before subject experiment, mechanical simulation was performed to evaluate stability of the developed devices. The correlation between sensor module and subjects' respiratory motion was confirmed in the mechanical simulation, and then the possibility of measuring respiratory cycle of patients by using the magnetometer was verified through subject experiment. So, it is found that the developed device improves efficiency of breath training based on visual bio-feedback, and then general use in clinical practice is expected.**

**Keywords :** respiratory interaction, respiratory motion, radiation therapy, magnetic field, IMU sensor, magnetometer

## 1. Introduction

Radiation therapy has been a general treatment for removing tumors, which uses high energy radiation. Recently, radiotherapy has become an essential principle to treat cancer and some benign tumors, and as its importance increases, the number of hospitals, which equip radiation therapy is increasing also [1]. It is important to identify accurate location of treatment site and limit radiation to regions of interest (ROI), to minimize unnecessary exposure for protecting the normal tissue [2].

However, it is difficult to determine an exact treatment site of respiratory organs, which changes its location with respiration (e.g. part of thoracic region or abdomen region). Therefore, respiratory gating technique is currently used to reduce respiratory motion effects. This is a technique in which radiation is exposed when a patient's breathing pattern is in a specific location [3]. Most patients have an unavoidable irregularity in their respiratory cycle, which decreases the accuracy of the treatment. To perform breathing correction training that gives patient stable respiratory cycle contributes significantly to accuracy of the radiation treatment. Therefore, the need for equipment, which enables the patient to monitor his or her respiratory cycle is becoming a priority.

To meet these needs, Inertial Measurement Unit (IMU) has been used for measuring the acceleration of patient's movement, which is occurred by their respiration activity, and then the sensor acquires respiratory cycle pattern of patient. However, the acceleration sensor has a low spatial resolution and significant noise compared to acquired signal [4]. This suggests the patient's respiratory pattern acquired from the acceleration sensor shows lower signal to noise ratio (SNR). By this difference, it has been a limitation in improving the efficiency of self-radiation therapy.

In order to remove the noise mentioned above and improve accuracy of the acquired signal, Magnetometer


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in IMU has been adopted in this study. Among the various types of sensor which comprise IMU, Magnetometer is a device for measuring the intensity of magnetic field with fine spatial resolution and low noise. In this study, the magnetometer was employed to acquire phase of respiratory training system by measuring the intensity of a magnetic field occurred from magnet, and then tracks accurate location of the sensor [5]. The use of a magnetic sensor based on the magnetic field (magnet source) provides not only a higher spatial resolution but also lower power consumption, enabling a more accurate respiratory training than conventional methods, which used an accelerometer of IMU. It also provides a breathing cycle graph with high accuracy [6, 7]. Therefore, MEMS (Micro Electro Mechanical Systems) magnetic field sensor is employed as novel method to compensate the mentioned problems and obtain more accurate respiratory cycle signals for patient self-respiratory training. It also has developed as portable sized for space saving in clinical environment. Therefore, the cost can be reduced and the convenience of use can be expected. The possibility of patients' respiratory cycle measurement using magnetometer and its' clinical application potential are evaluated through experiments.

## 2. Methods

### 2.1. Position estimation method based on magnetometer

The intensity of the magnetic field detected at the sensor. H (magnetic flux density, Gauss) is reciprocal proportion to distance between sensor and target L (length, cm). Therefore, the intensity of magnetic field decreases as distance increases (Fig. 1). The magnetic field sensor estimates the position of target depending on distance change between sensor and target. The magnetic intensity between sensor and magnets was measured with ruler. Its details are described in Table 1.

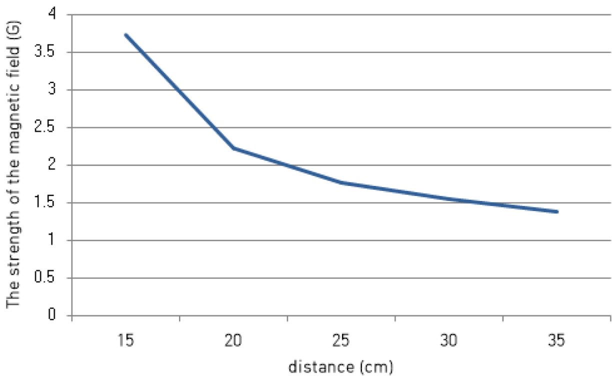


**Fig. 1.** (Color online) The strength of the magnetic field as the distance changes.

**Table 1.** The intensity of the magnetic field as the distance changes.

| Distance (cm) | The strength of the magnetic field (G) |
|---|---|
| 15 | 3.732 |
| 16 | 3.347 |
| 17 | 2.945 |
| 18 | 2.669 |
| 19 | 2.446 |
| 20 | 2.227 |
| 21 | 2.106 |
| 22 | 1.992 |
| 23 | 1.897 |
| 24 | 1.826 |
| 25 | 1.769 |
| 26 | 1.711 |
| 27 | 1.684 |
| 28 | 1.636 |
| 29 | 1.608 |
| 30 | 1.552 |

#### 2.2.1. Performance evaluation of mechanical simulation

The aim of evaluation was to verify the relevant association between the data, which was acquired at the sensor and patients' respiratory activities. Distance between the device and the magnet was discretionally set to 15 cm and measures the maximum value and the minimum value. Position changes detected from the sensor were measured for 3 minutes (Fig. 2, Fig. 3).

#### 2.2.2. Subject experiments

Experiments were proceeded with 5 volunteers. Magnetometer was attached to subject's chest and magnet was attached to subject's back (Fig. 4). The subject asked to lie on bed as a fixed pose, and then height of magnetometer at subject's inhalation, exhaust and normal breathing


**Fig. 2.** (Color online) Device experiment.

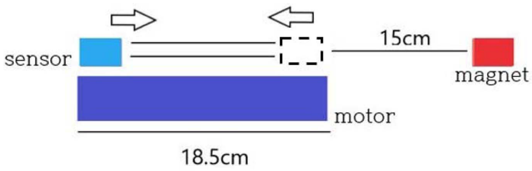


**Fig. 3.** (Color online) Mimetic diagram of machine experiment.

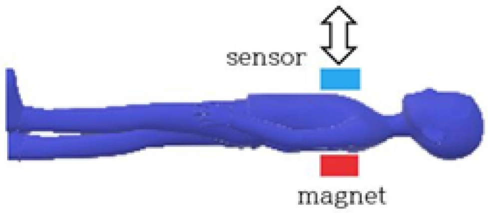


**Fig. 4.** (Color online) Mimetic diagram of subject experiment.

was measured. Two types of experiments were conducted to assess efficiency of the training according to the instructions provided to the patient. With voice instructions of the device, subject breathed for 3 minutes at intervals of 3.5 seconds, and then experiments are performed 2 times. 1st experiment provided only voice instructions and 2nd experiment provided both visual instruction and voice instruction (Fig. 5).

2.2.3. Fourier transformed spectrum analysis

In order to estimate the regularity of subject's respiratory, Fourier transform was employed [8]. A frequency characteristic of data acquired from magneto sensor was calculated by using Fourier transform, and then the time-series signal was decomposed into frequency based signals. In this study, the Fourier transform was applied to the signals of time versus response (Fig. 10~19), and then graph is converted to a frequency versus response graph as shown in Fig. 20~24. For this calculation the Matlab 2015a (MathWorks, USA) was used, especially, 'Spectrogram' function in Matlab was utilized with hamming window for frequency analysis. The window size is 1024 with

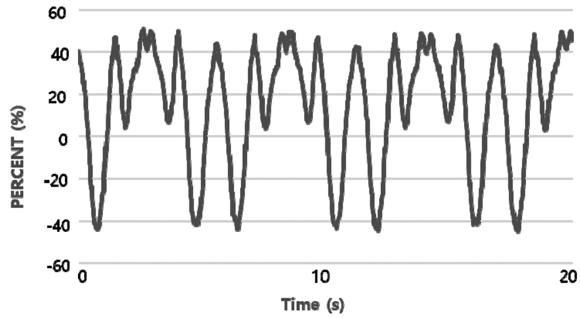


**Fig. 6.** Maximum value 0.959(G), Minimum value –0.489(G).

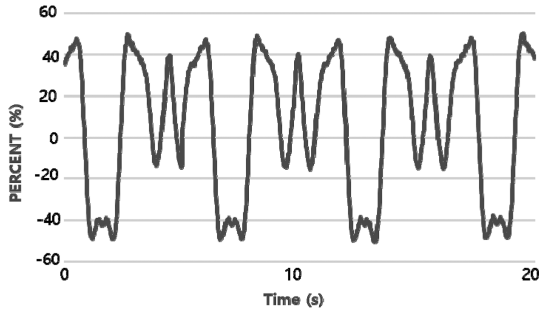


**Fig. 7.** Maximum value 1.008(G), Minimum value –0.335(G).

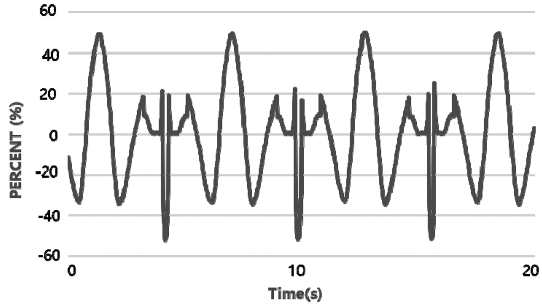


**Fig. 8.** Maximum value 0.55(G), Minimum value –0.266(G).

50 % overlap ratio.

### 2.3. System implementation

The self-respiratory training system is comprised of

**Fig. 5.** (Color online) Subject experiment.

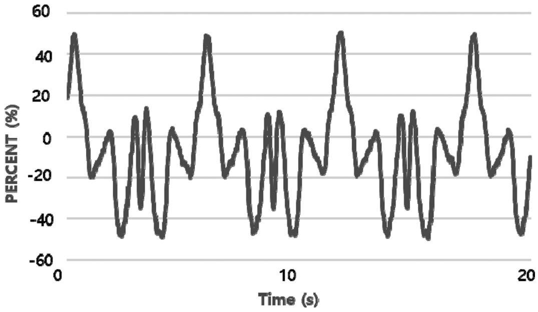


**Fig. 9.** Maximum value 0.61(G), Minimum value 0.001(G).

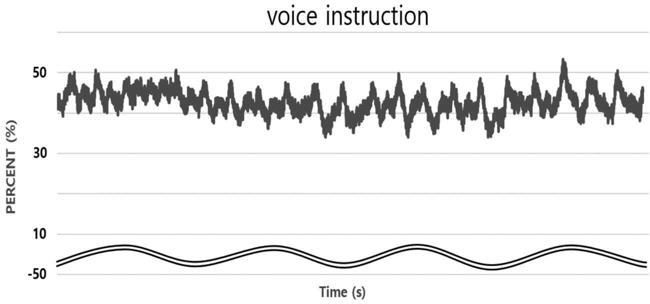


**Fig. 10.** Acquired signal with voice instruction from subject A.

hardware, and software parts. In the hardware parts, IMU sensors (3space, USA) that is composed of magneto sensor, gyro sensor, and accelerator sensor was utilized. In the software part, home-made software that can measure all sensor signal was developed by using Python 3.5 (anaconda python ver3.5, USA) on Windows 10. The software is executable on Windows 10 operating system without any installation (Fig. 2(A)). The bar-graph in Fig. 2(A) shows the height ratio of sensor position : In which the belt is pressured on a subject's breast. Only the height ratio and bar-graph (corresponding to height ration of sensor position) are displayed for visual feedback in real-time during self-respiratory training. In addition, laptop speaker generates an indication sound in real-time for self-respiratory training. All data of height ratio and related information (time and etc.) was saved as an ascii-format on the computer file system for post-analysis.

## 3. Results

### 3.1. Mechanical simulation result

During whole mechanical simulation experiments, the magneto-values were measured to estimate a sensor's precision and stability. Using a maximum and the minimum values o f magnetic flux, Percentage variables that could represent a phase of subjects' respiratory were calculated. Although amplitudes and patterns have differences at

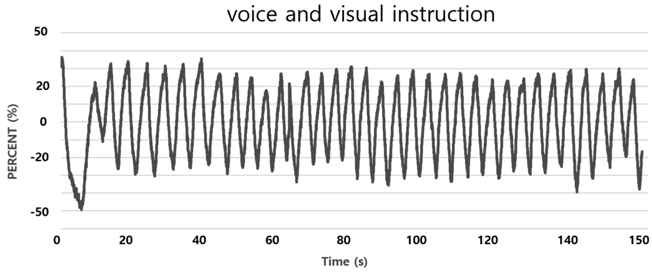


**Fig. 11.** Acquired signal with voice instruction and visual instruction from subject A.

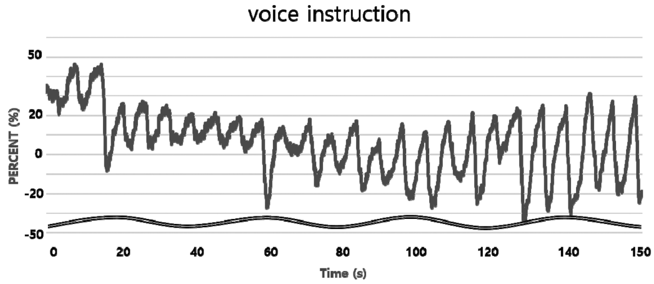


**Fig. 12.** Acquired signal with voice instruction from subject B.

each magnetometer, it has regularity and repeatability also as shown in Fig. 6~9. The regularity of magnetometer can show the precision and stability of sensor.

### 3.2. Subject experiment result

Irregular signals were measured from subjects, who were provided only voice instructions as shown in Fig. 10, 12, 14, 16 and 18. These irregularities were caused by differences in subjects' breathing condition and movement during the experiment, thereby increasing unnecessary exposure for patients. When both voice and visual instructions was provided to subject, irregularities on the graph decreased and regular signals were observed as shown in Fig. 11, 13, 15, 17 and 19. Thus, efficiency of respiratory training could be improved by providing both visual and voice instructions.

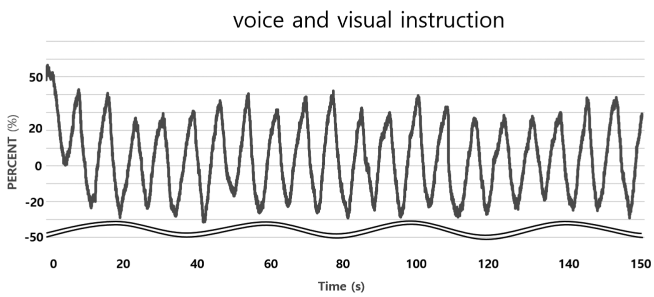


**Fig. 13.** Acquired signal with voice instruction and visual instruction from subject B.

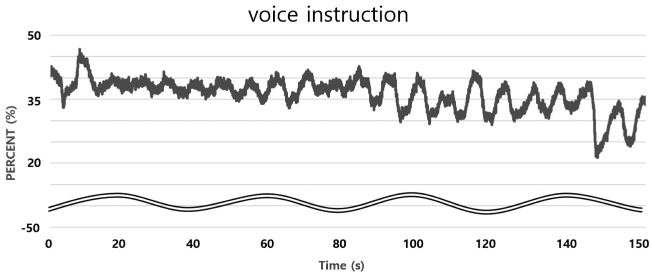


**Fig. 14.** Acquired signal with voice instruction from subject C.

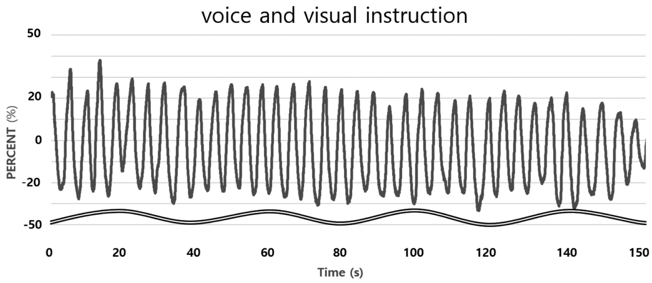


**Fig. 15.** Acquired signal with voice instruction and visual instruction from subject C.

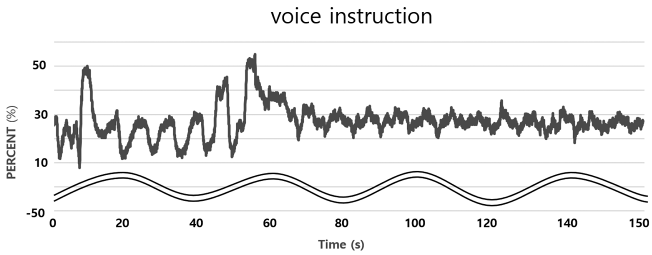


**Fig. 16.** Acquired signal with voice instruction from subject D.

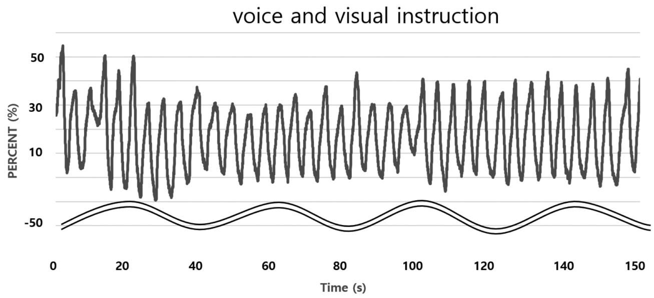


**Fig. 17.** Acquired signal with voice instruction and visual instruction from subject D.

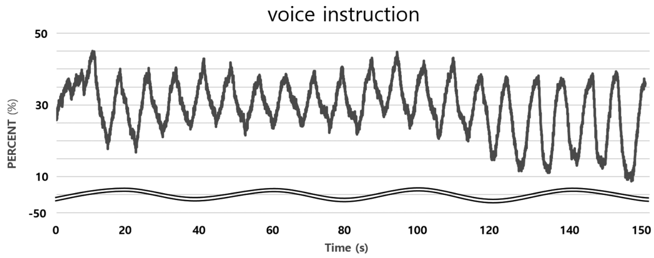


**Fig. 18.** Acquired signal with voice instruction from subject E.

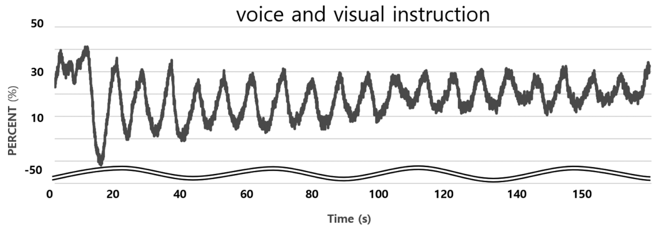


**Fig. 19.** Acquired signal with voice instruction and visual instruction from subject E.

### 3.3. Results of frequency spectrum analysis

Spectrum analysis graph shows the stability of respiratory pattern by displaying frequency characteristics of measured time-series data from subjects. Also, stable respiratory patterns show a peak in the results of spectrum analysis, on the other hands, un-stable respiratory pattern show several peaks in the results of spectrum analysis by including mixed un-regular respiratory activity of subjects. Contrastively, the training signals which include visual feedback show regular and stable single frequency peak.

## 4. Discussion

Subjects who were provided with only voice instruction could not exclude their usual breathing habits during the experiment, showing low training efficiency (Fig. 10, 12, 14, 16 and 18). Since there is no visual indicator of the respiratory cycle, in that condition, subject's reaction time latency to voice instructions occurs, and then causes irregular breathing patterns. However, the visual instructions were provided also, the subject could recognize the visual

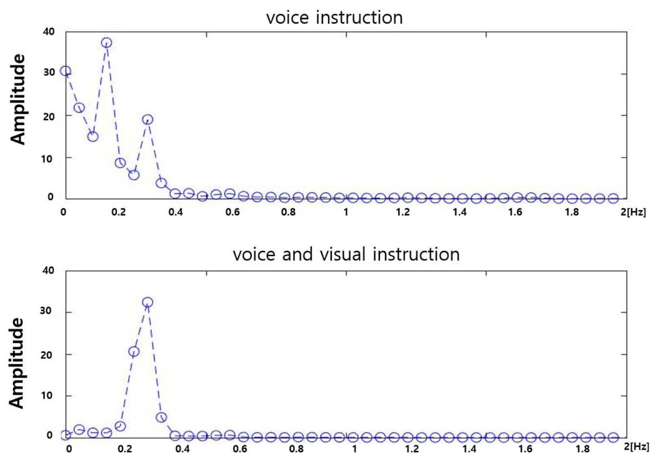


**Fig. 20.** (Color online) Fourier transformed signal of subject A.

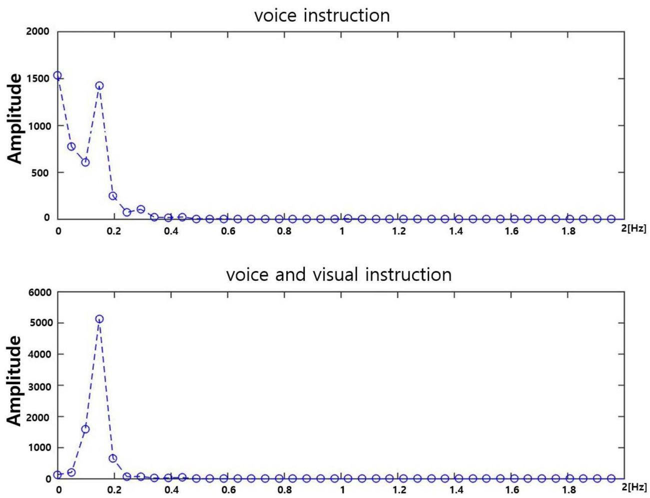


**Fig. 21.** (Color online) Fourier transformed signal of subject B.

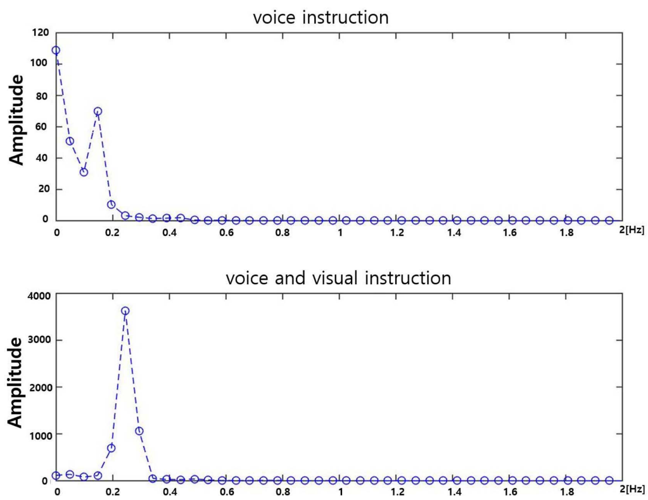


**Fig. 22.** (Color online) Fourier transformed signal of subject C.

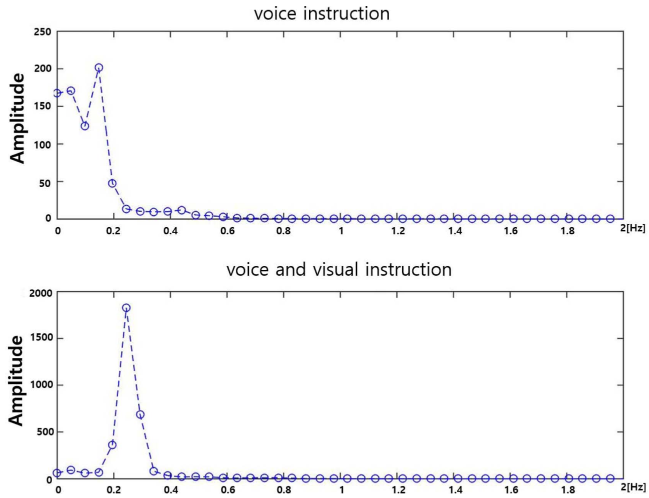


**Fig. 23.** (Color online) Fourier transformed signal of subject D.

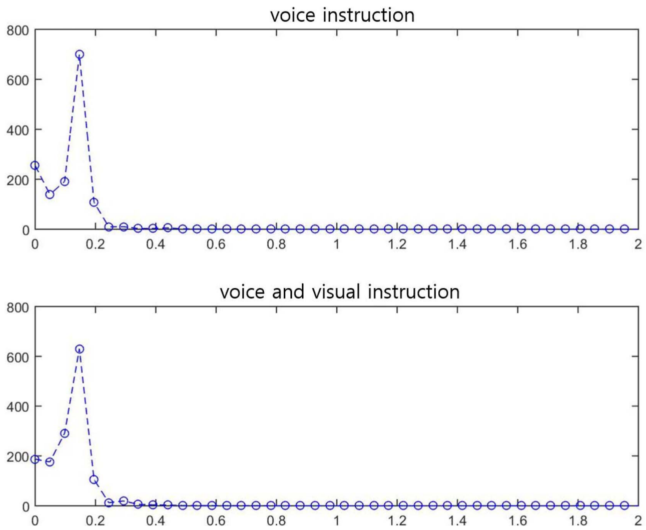


**Fig. 24.** (Color online) Fourier transformed signal of subject E.

breathing pattern, so that the breathing cycle becomes more regular than providing voice instruction only (Fig. 11, 13, 15, 17 and 19). In Fig. 20~24, the results of spectrum analysis were applied to estimate the frequency characteristics of measure training signals. From enhanced results (by applying visual and voice feedback), it can be confirmed that visual and voice feedback condition enhance the efficiency of respiratory training. From the results, the study verifies possibility of measuring the respiratory cycle of a subject using IMU-magnetometer. It is expected that developed device and system will be applied to improve efficiency of respiratory training for radiation therapy.

Five subjects participated to evaluate the performance of developed novel technology for the portable self-respiratory training system. Although only five subjects attended in this study, the possibility of the system for self-respiratory training is significantly demonstrated by two experiments. For the further study, more patients from clinic sites should be participated to enhance their efficiency radiation therapy. In addition, the improved computational algorithm with IMU will be developed to estimate a more accurate position for portable self-respiratory training system.

## 5. Conclusion

To improve the efficiency of patient respiratory training implemented before radiotherapy, magnetometer based portable respiratory training system has been developed. By respiratory training for patient with developed device, regularity of breathing pattern of the patient can be improved. This can reduce unnecessary dose exposed to organs moving with patient's irregular breathing. In order to improve accuracy and efficiency of breathing correction training, the subjects were provided with visual and voice instructions. As a result, it is possible to improve regularity of respiratory pattern of the subjects by providing visual and voice instructions. In particular, it has been confirmed that efficiency of training protocol using visual bio-feedback is higher than condition without it. So, it is expected to be widely applied in clinical practice in foreseeable future.

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