Gaming control using a wearable and wireless EEG-based brain-computer interface device with novel dry foam-based sensors.

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Background

- Wireless BCI systems

Emotiv EPOC neuro-headset

Neurosky Mindset

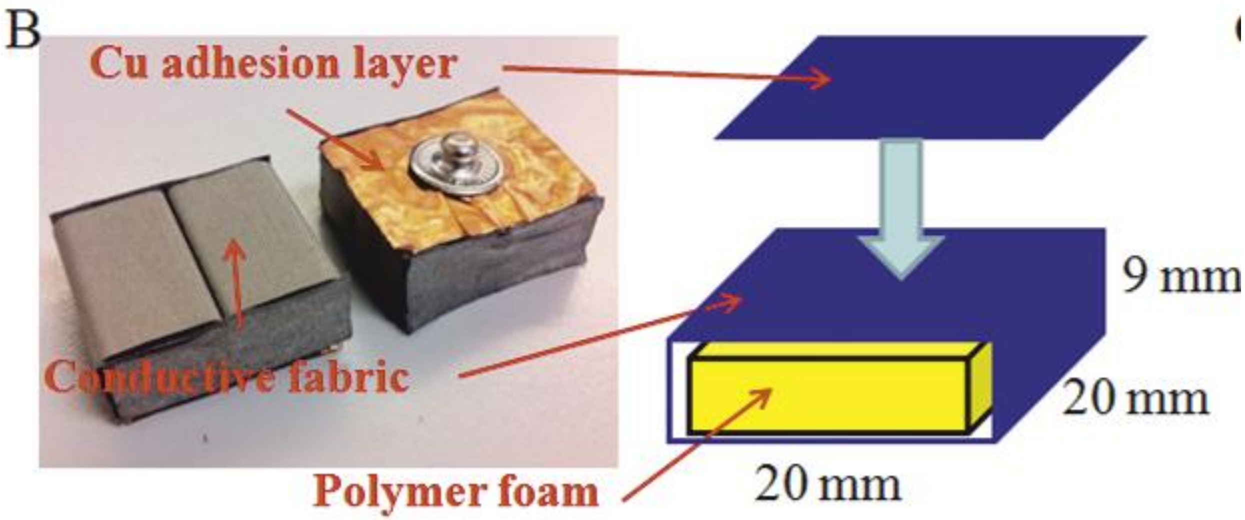
Introduction & Motivation

- Limitations of wet- and MEMS-type EEG sensors
  - Skin abrasion
  - The required used of conductive gel
  - Time-consuming, uncomfortable, and often painful
  - Degraded signal quality due to skin regeneration and drying of the conductive gel
- Goals
  - They developed a wearable, EEG-based BCI device with a novel dry foam-based sensor for gaming control.
  - A real-time focusing detection algorithm was implemented in their device to detect the real-time cognitive state of the user.

System Design

- Dry EEG sensors

- Dry electrodes are designed by using conductive polymer foam made of a urethane material.
- Conductive foam was covered with a 0.2mm thick taffeta material.
- This was made from an electrically conductive polymer fabric and was coated with Ni/Cu on all of its surfaces.
- A 0.2-mm layer of Cu was used as an adhesion layer that was then connected to the wireless EEG acquisition module.



System Design

- Wireless EEG acquisition module

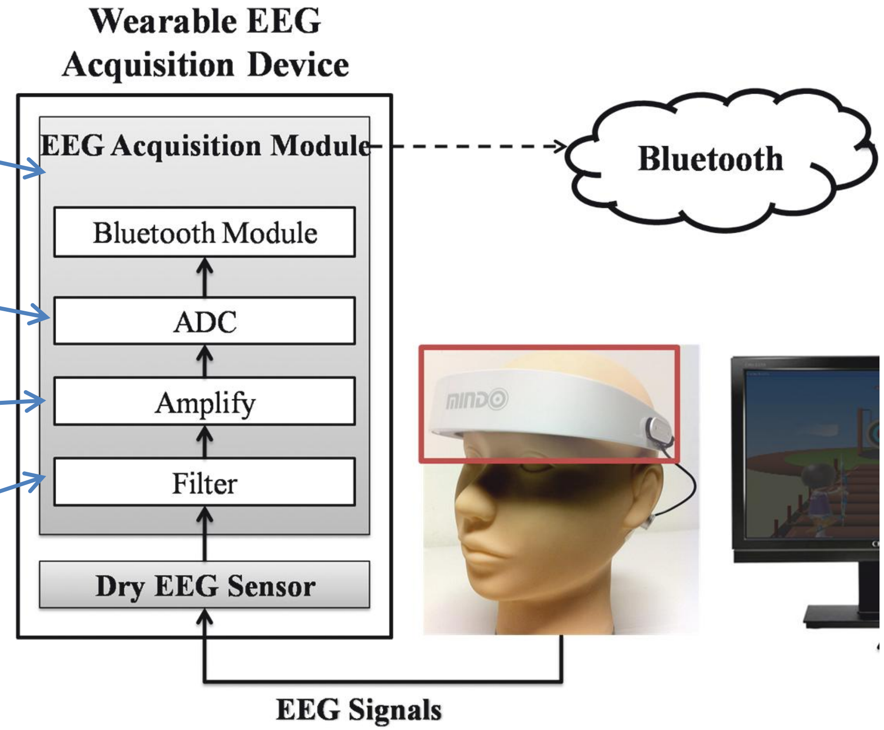
- This module was designed for acquiring EEG signals from the dry EEG sensors.
- Included components : INA2126(Texas Instruments opamp), AD8609(Analog Device opamp), MSP430(Texas Instruments microprocessor), BM0403(Unigrand Ltd., Bluetooth module)

Moving average filter (60Hz notch filter,)

12bits resolution ADC, 256Hz Sampling rate

Gain = 5500

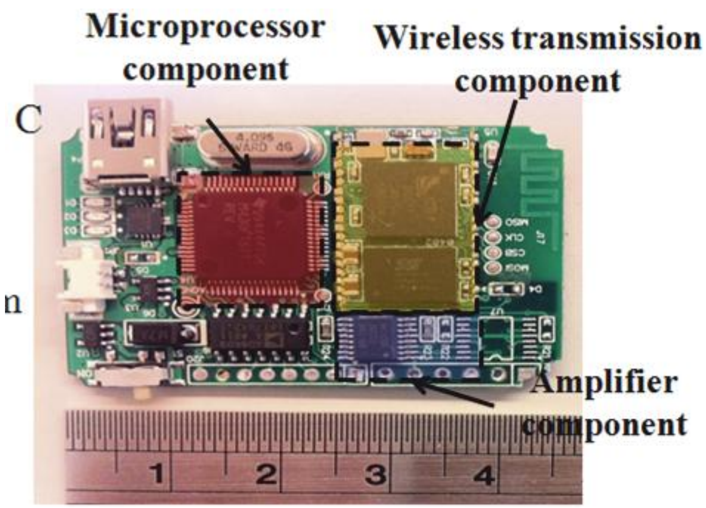
Preamplifier + Bandpass filter (0.5 ~ 50Hz)

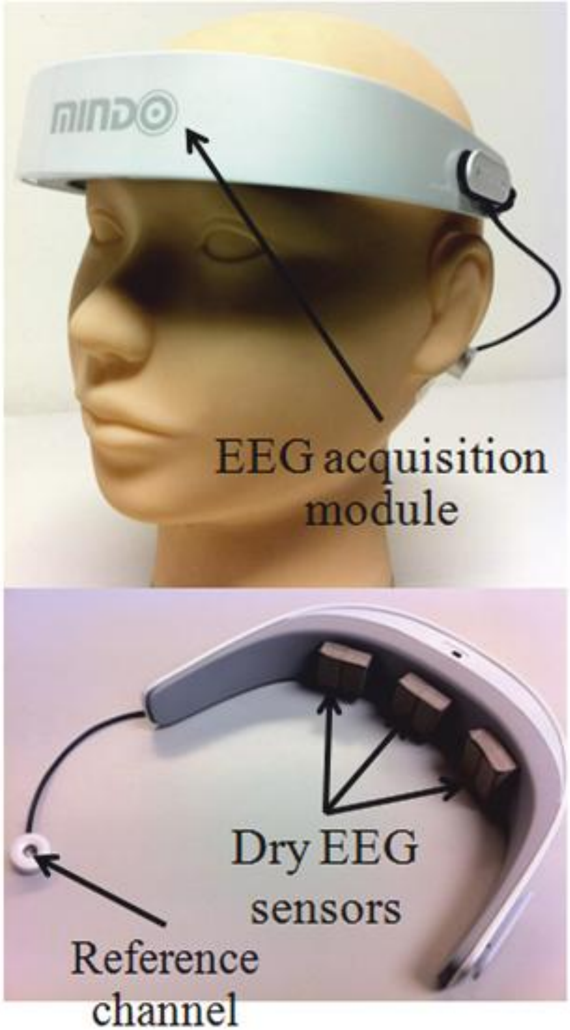


System Design

- Wireless EEG acquisition module

- Size : 4.5 x 3 x 0.6cm3
- Power consumption : 31.58mA with a 3.7V DC power supply
- Battery life : 23 hours using a commercial 750mAh Li-ion battery.





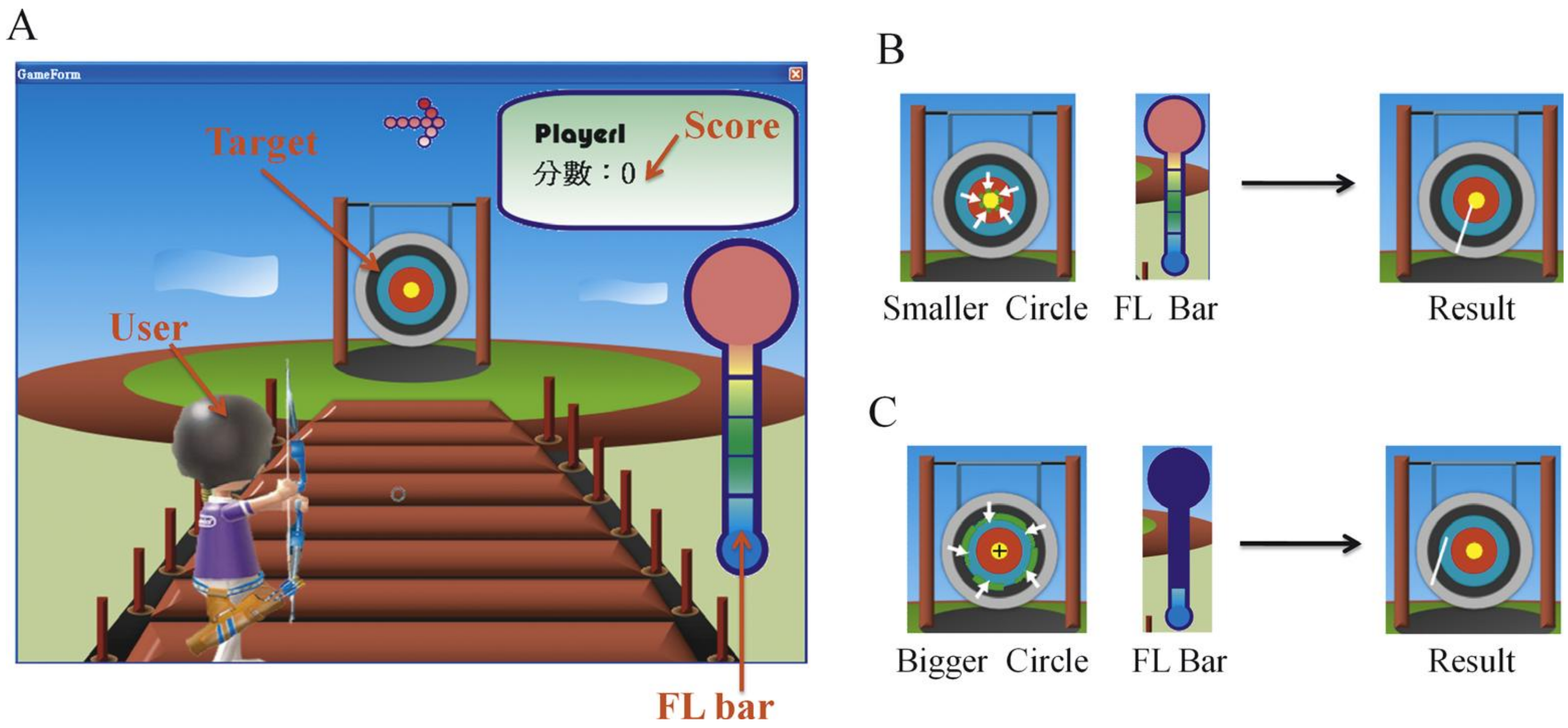
Application Design

- Archery game design

- They designed the archery game controlled by users via mental focusing feature.
- To measure the mental focusing level, they utilized the principle that the power of the alpha rhythm has a negative relationship with the mental focusing level.
- Using the focusing level(FL), they control the aiming of allows.
  - High FL : the shot was close to the center of the target – high score
  - Low FL : the shot was far from the center of the target – low score
- Game design
  - Total ten trials
  - Each trial persisted for ten seconds
  - The FL was initialized to zero for every shot.
  - The FL values were calculated every 2s.

Application Design

- Game interface



Application Design

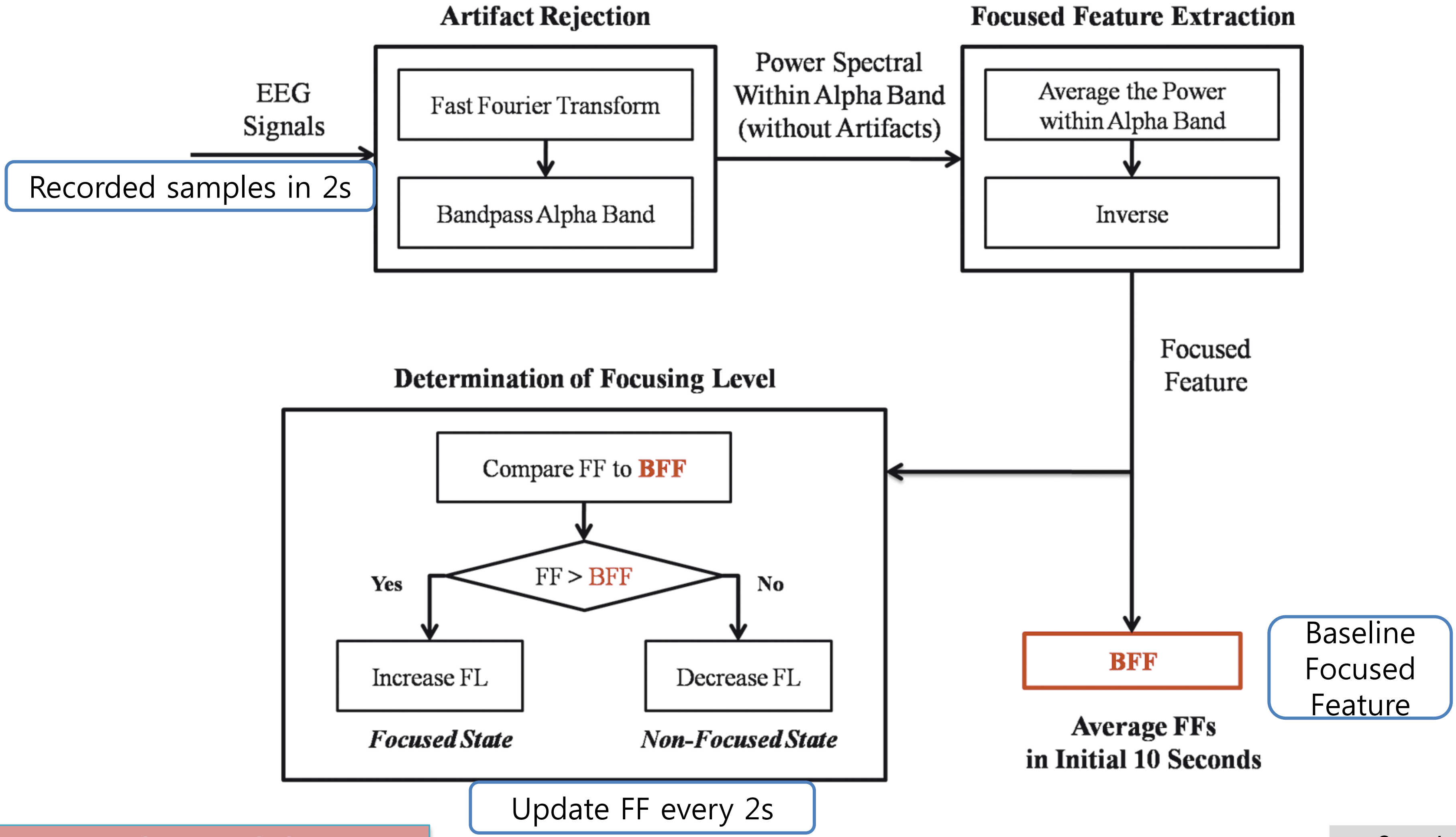
- Focusing level detection algorithm

$$X = [X_1 \quad X_2 \quad \cdots \quad X_{512}]$$

$$Y = FFT(X) = [Y_1 \quad Y_2 \quad \cdots \quad Y_{256}]$$

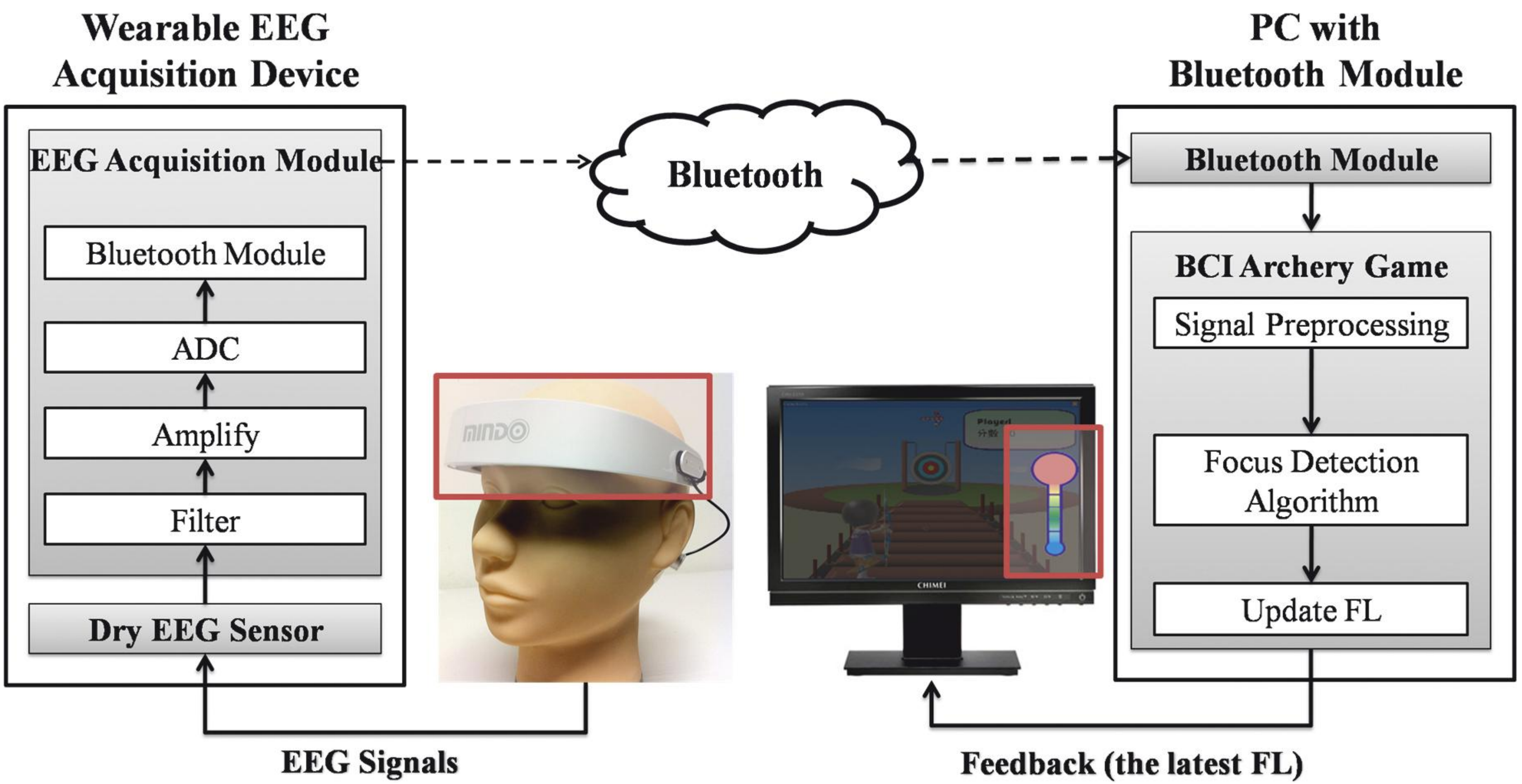
$$P_\alpha = \frac{1}{5}\sum_{n=8}^{12} Y_n$$ (Feature extraction & Averaging)

$$FF = 1/P_\alpha$$ (Inverse)



Method

- Total system schematic



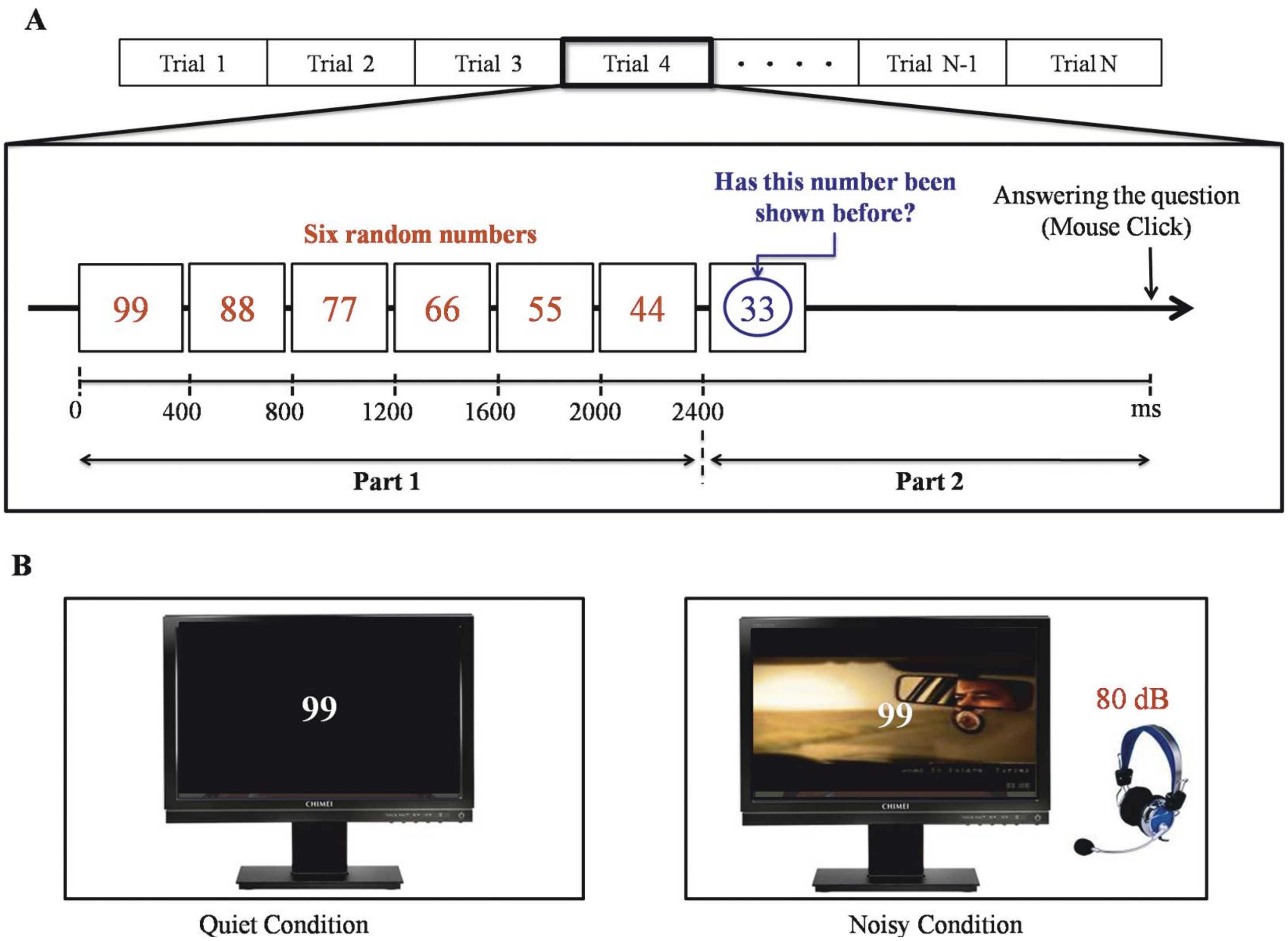
Method

- Verification of the FL algorithm

- Do the FL algorithm indicated the user's focusing level well?
- Short-term memory test
  - The user watches a rapid series of pictures over a few seconds
  - A picture is shown and the user indicate whether of not this picture had been shown before
  - Accuracy high(focused) – test in silence
  - Accuracy low(unfocused) – test under noise
- Experiment procedures
  - Six numbers were presented sequentially, each number lasts for 400ms
  - A number was presented and the user had to indicate whether or not the number had been shown before by using a mouse click
  - Trial was repeated and total 3 min
  - Quite condition vs. noisy condition
  - Average accuracy are used as an indicator to determine the user's focus level.

Method

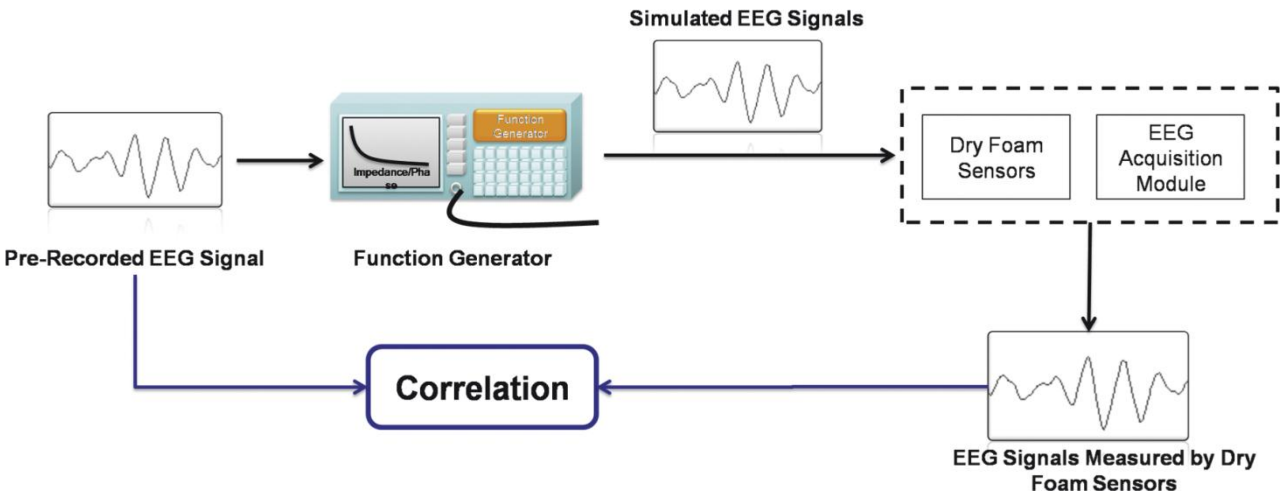
- Verification of the FL algorithm



Results

- Verification of the signal quality of the proposed dry sensor

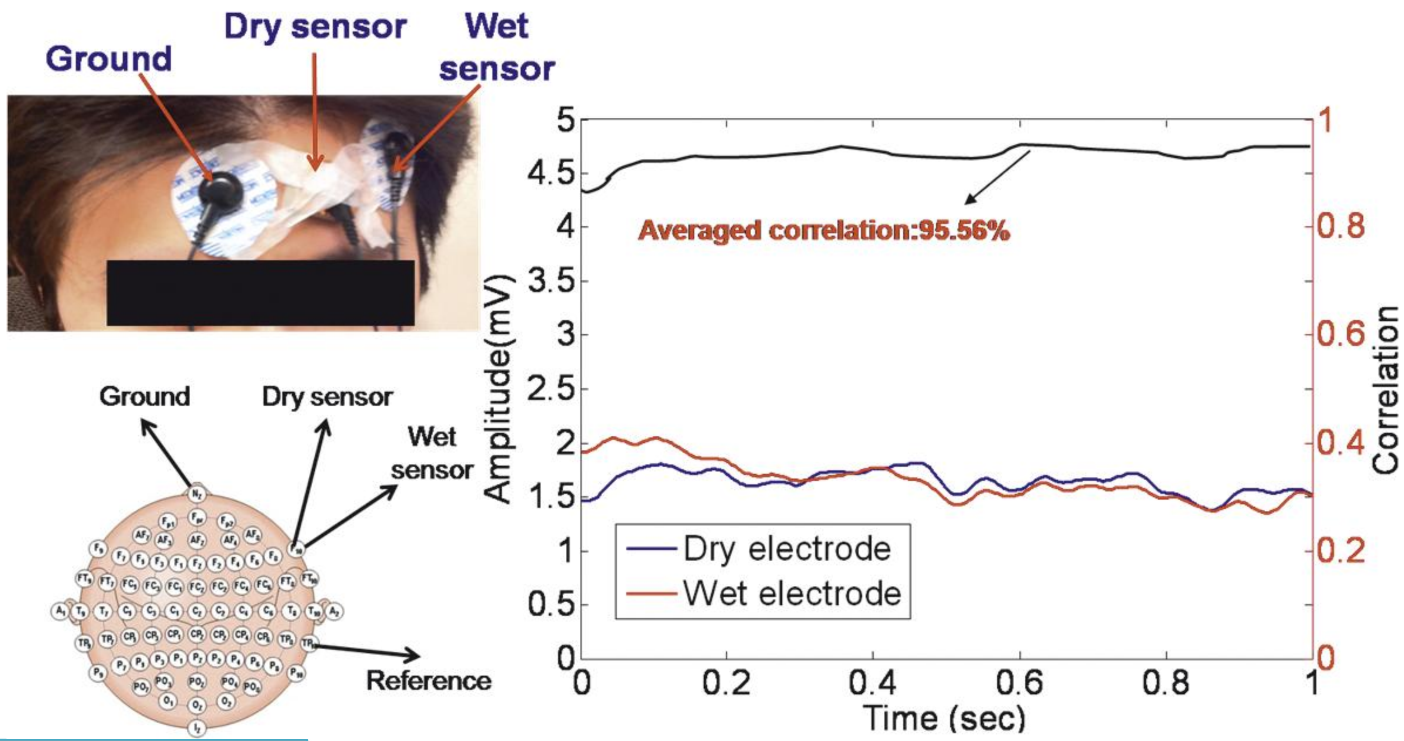
- Experiment procedure
  - The EEG data were prerecorded using standard EEG sensors with conductive gel and were stored in a computer.
  - the EEG data were fed into a programmable function generator and were passed through a voltage divider to generate simulated human EEG signals.
  - Compare the pre-recorded EEG data and the measured EEG data using dry sensor.
- Correlation level : 97.68%



Results

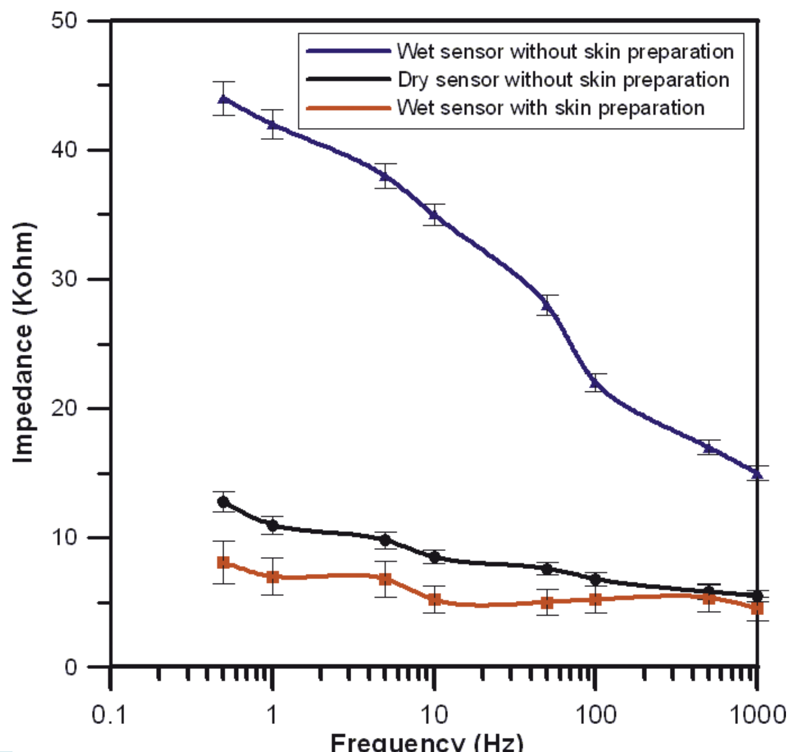
- The correlation between the conventional wet EEG sensor and the dry EEG sensor

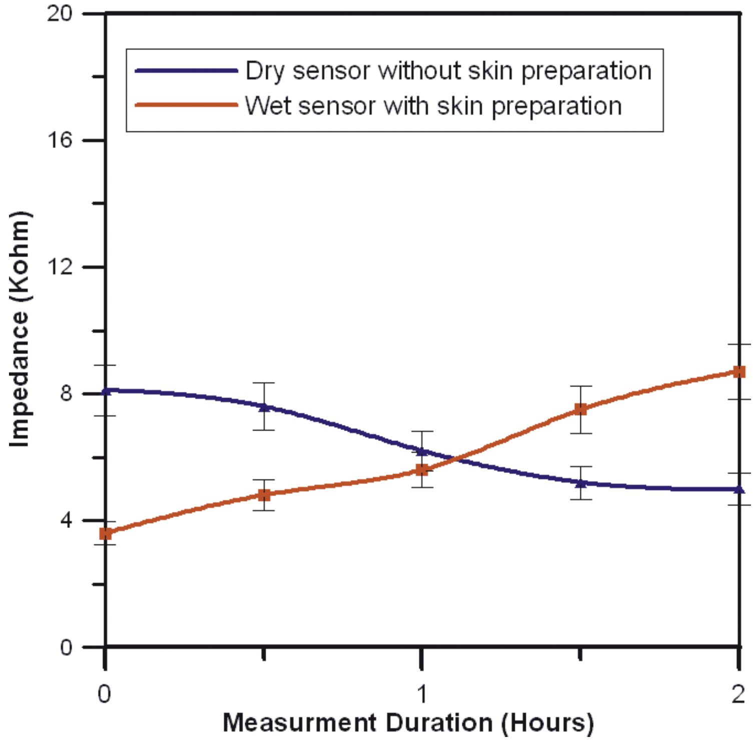
- Correlation level : typically in excess of 95.56%
- The performance of the EEG signal measurement using the dry foam-based EEG sensor was identical to that of the conventional wet EEG sensors.



Results

- Comparison of the impedance at the sensor-skin contact interfaces
  - The impedance levels between the dry EEG sensors without skin preparation and conventional wet EEG sensors with skin preparation is similar.
- Comparison of the long-term impedance variation
  - The dry sensor is more stable than wet sensor because the conductive gels are easy to dry during long-term monitoring





Results

- Relationships between short-term memory testing, FF values and gaming scores under quiet and noisy conditions

- The average accuracy of short-term memory test under two different conditions : 69.0% and 59.8%

Table 1 Results of the short-term memory experiment under quiet and noisy conditions.

	Quiet Condition			Noisy Condition			
	Total	Correct	Accuracy	Total	Correct	Accuracy	*p*-value*
Subject 1	32	24	0.750	22	14	0.636	
Subject 2	44	34	0.773	42	28	0.667	
Subject 3	41	25	0.610	47	27	0.574	
Subject 4	36	24	0.667	38	21	0.553	
Subject 5	58	35	0.603	55	32	0.582	
Subject 6	53	38	0.717	51	25	0.490	
Subject 7	53	36	0.679	54	31	0.574	
Subject 8	54	35	0.648	55	29	0.527	
Subject 9	48	35	0.729	46	31	0.674	
Subject 10	50	36	0.720	47	33	0.702	
			0.690			0.598	0.001

* Paired *t*-test.

Results

- Relationships between short-term memory testing, FF values and gaming scores under quiet and noisy conditions

- The average FF values under two different conditions : 6.94 vs. 4.64
- The users maintained a lower FF under noisy conditions than under quiet conditions because of the presence of distractions.

- Correlation test 1

- The measured FF values were significantly positively correlated to the results of the short-term memory experiment.
  - The measured FF values truly represented the user's mental focusing level.

Table 2 Results of the FF values and gaming scores under quiet and noisy conditions.

	FF			Game Score		
	Quiet	Noisy	*p*-value*	Quiet	Noisy	*p*-value*
Subject 1	8.0	4.9		9.6	7.4	
Subject 2	8.7	4.5		8.4	7.0	
Subject 3	5.4	4.4		9.2	7.6	
Subject 4	6.1	4.2		9.0	8.2	
Subject 5	4.5	3.5		9.0	7.6	
Subject 6	8.9	4.1		9.1	6.9	
Subject 7	7.1	3.9		9.1	6.1	
Subject 8	5.9	4.6		9.1	8.1	
Subject 9	8.0	6.6		8.7	7.9	
Subject 10	6.8	5.6		9.1	7.1	
	6.940	4.642	0.0005	9.013	7.393	0.00004

* Paired *t*-test.

Results

- Correlation test 2

- The game scores are positively correlated to the measured FF values.
  - the game scores are lower if the user performs the test under two different conditions.
- The FF values are an indicator of the focused state and the FL algorithm is a reliable method for measuring the user's focusing level.

Conclusion

- They proposed a wearable EEG-based BCI device with dry EEG sensors for cognitive state monitoring and demonstrated its use during EEG-based gaming control.
- Using their wearable EEG-based BCI device without conductive gel will allow users to monitor their EEG states more comfortably during daily life.
- This wearable EEG-based BCI device and the focusing level detection algorithm can be reliably used to control outside-world applications for general users or researchers.

Thank you