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뇨실금 방지 시스템에서의 뇨량 측정을 위한 초음파 변환기의 개발

(The Development of Ultrasonic Transducer for Measurement of Urine Volume in Incontinence Preventive System)

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요 약

본 연구에서 방광 내벽과 외벽사이의 거리를 측정하여 뇨량을 계산하는 시스템에 적용하기 위한 방광용 초음파 변환기를 설계하고 개발하였다. 뇨량 측정 시스템은 방광에서 오줌을 배출하기 전의 양을 측정함으로써 뇨실금 환자의 치료 과정을 도와주게 된다. 이 실험의 결과로, 뇨량을 더 정확하게 측정할 수 있고 또한 뇨실금 방지 시스템을 개발할 수 있다. 본 연구를 통하여 개발되는 시스템은 뇨실금과 야뇨증 환자를 더 오래 더 건강한 삶을 살 수 있도록 해줄 수 있을 것이다.

Abstract

In this study, we designed and developed an ultrasonic transducer which can measure urine volume based on the estimation of distance between the interior-wall and posterior-wall of bladder.

Measurement of urine volume is a way to help patients with urinary incontinence by detecting the amount of urine before the urine is released from the bladder. With the results of this experiment, we can measure the urine volume more accurately and also develop an incontinence preventive system.

This study can help patients with urinary incontinence and enuresis to live longer, healthier lives.

Keywords : Incontinence, Ultrasonic transducer, Impulse response

I. Introduction

As a person ages, bones become weaker, dementia can set in and urinary incontinence commonly occurs.

Urinary incontinence means that you can't control your bladder. It is a common and problem for old age people and adult women in Korea. 45% of women aged over 30 years, more than 2.5 million people are affected by this condition.

It is hard to tell or check the number of people with urinary incontinence namely because those inflicted find it embarrassing to report their condition. In addition, there is the minimum. number of people attended the current cure.

Deplorably, treatment and research are backward and lacking when compared to the demand for treatment. This can be seen in the fact that only about 15.1% of men and 3.3% of women are treated.

One of the current treatments, with a warning system for enuresis is Tamura T. This system measure a difference of temperature or impedance with an electrode. This system is deficient in that it gives warning after urination.

Treatment with the warning system for a children's enuresis is given by a guardian after

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taking a measurement of a electro-encephalogram. This system is deficient in that it can only be applied to a patient during sleep.

Considering the deficiencies of the current available methods, the important if further researcher and development for an warning system for incontinence (one that warns the patient of an impending bladder movement) is obvious.

The bladder has direction when the bladder swells by the urine gathers. So, the direction which the bladder can swell as back-upper because of there viscera or tissues and bladder don't adhere.

We considered the perineal region as the disposition region. But, most patients view this with mental resistance. For this reason, the disposition region of the transducer is suitable 2cm above the pelvic joint this was confirmed through the experiment.

In the test, under 300cc, there is a high linear-relationship between the urine volume and the distance between the interior-wall and posterior-wall of the bladder. In general, because it is around 200~300cc of urine volume that cause people to want to urinate, ultrasonic echo ranging is, of course, a suitable technique for measuring or detecting such small amounts of urine for an warning system.

The ultrasonic sensor for detection of time of urination should be designed to get the specific character which is different from sensor for general purpose because of a special measurement. Therefore, it is a necessary to develop the compatible ultrasonic sensor for incontinence preventive system.

Ⅱ. Main subject

1. The algorithm to estimate the urine volume

(1) Estimation of distance by using Echo ranging method

Echo ranging method is the determination of distance by measuring the time interval between transmission of a radiant energy signal (sound) and the return of its echo.

An expression for distance between two boundary layers, D, is:

$$D_1 = \frac{C \cdot (T_2 - T_1)}{2} \quad (1)$$

In this equation C is the speed of sound in the medium as determined primarily by the characteristics of the medium. The symbol T is elapsed time.

A known speed of sound in any medium is applied to the Echo ranging method. The ultrasonic wave should be reflected through in a straight line and pass through to the boundary layers directly. In addition, it is possible for an application when the speed of sound is fixed in the medium.

Using this method, we can calculate the capacity of a 3-dimensional fabric, which contains two boundary layers in the medium.

Fig. 2 presents the process for calculation of capacity when a 3-dimensional fabric exists in the medium.

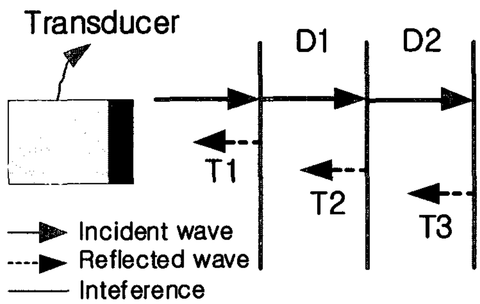


그림 1. 반사파 거리 측정법
Fig. 1. Schematic of Echo Ranging Method.

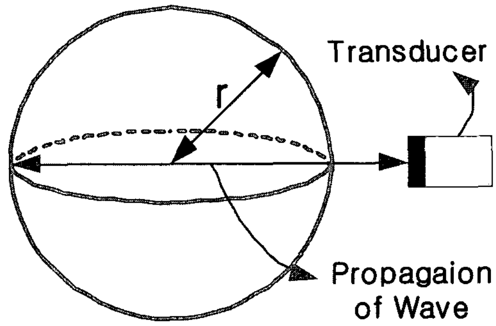


그림 2. 반사파 거리 측정법을 이용한 부피 측정
Fig. 2. Volume estimation using Echo Ranging Method.

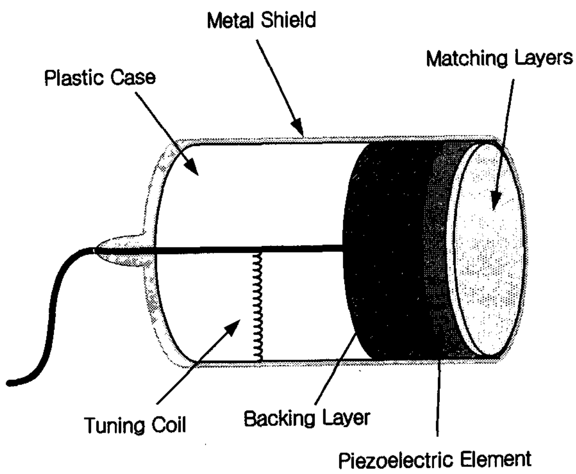


그림 3. 초음파 변환기의 구조
Fig. 3. Schematic of Ultrasonic Transducer.

(2) Structure of Ultrasonic Transducer

Fig. 3 presents the structure of the ultrasonic transducer. The ultrasonic transducer is composed of a piezoelectric element, matching layers and backing material.

The Piezoelectric element is the most important component, in that it determines the characteristic of the transducer, as detectors and transmitters of acoustic signals.

The parameters of the transducer and characteristics of the piezoelectric transducer are the most important factors in determining the characteristic of the material, backing material and matching material.

2. Development and Design of Ultrasonic transducer

(1) Principle of Design of Ultrasonic transducer

The performance and use of the ultrasonic transducer is affected by the section of the piezoelectric transducer, backing material and matching material.

So, for development of the transducer, the design of its parameters should necessarily be highly suitable to facilitate its performance and use.

In the design of the ultrasonic transducer, the selection of the piezoelectric transducer is the most important factor in determining the design for matching and backing material.

The kernel of design for a piezoelectric transducer is a selection of resonance frequency.

Generally, the resonance frequency is determined mainly by the Equivalent Circuit Analysis Method(ECM), Finite Element Method(FEM) and Boundary Element Method(BEM).

ECM is suitable for the characteristic analysis of a simple fabric but does not hold variable conditions of the boundary.

In addition, there is a limit to ECM when analyzing characteristics of 3-dimensional and non-linear of ultrasonic transducer in that errors are made in analysis.

FEM, BEM is suitable for the characteristic analysis of transducers because it is able to analyze a complex fabric in multi-dimensional aspects. However, it is a complex method and takes a long time to calculate.

FEM and BEM are complex methods and take a long time to calculate in comparison with FCM, but it is in use when the design requires a detailed analysis.

In this study, FEM was used in the variable factor analysis of the design. A numerical value analysis was used for the acoustic pressure distribution of the sound field.

The Rayleigh-Sommerfeld integration method was used for sound field analysis.

(2) Structure Design

In order to examine the suitability of the developed ultrasonic transducer, we use the pulse-echo mode.

Transmitted ultrasonic pulse using this mode should be able to travel long distance and return. So, there is a need to compromise between the depth of transmission and the resolution.

We set a goal of a 1MHz transducer for both transmission and reception.

A thin and circular Piezoelectric ceramic material(PZT) was used as a piezoelectric element.

The center frequency was determined by using the resonance frequency in the thickness mode.

We used 5A in several types of PZT, which has high sensitivity, a high ratio for induced electricity and highly reliable performance even if time goes by.

To resonate using thickness mode, the Piezoelectric ceramic is designed to be 1/2 the wavelength of the ultrasound beam in thickness and should be designed at least five times thicker in diameter but be around ten times thicker for desirability.

The piezoelectric elements were designed to be multiple layers because multiple matching layers provide efficient sound transmission between the piezoelectric element and soft tissue for a range, or spectrum, of ultrasound frequencies. The impedance of each layer is determined by using De silets formula.

We selected materials, which approximates estimated value, as impedance-matching layer. The diameter of each matching layer was determined to be 1/4 the wavelength of the ultrasound beam.

The backing layer was designed to achieve the acoustic impedance which approximates the piezoelectric element. These layers must absorb the energy emitted from the PZT element effectively. Additionally, the thickness of the backing layer was designed to be at least 20mm so that the backing material can absorb the vibrational ultrasonic energy effectively and provide a very efficient use for the ultrasonic energy when the thickness of backing layers becomes thicker.

Table.1 shows the estimated material data of our designed transducer by using the proposed method in the study for ultrasonic transducer design.

표 1. 설계된 변환기의 재료 상수
Table 1. Material data of designed transducer.

	PZT5A	1st M/L	2nd M/L	B/L
Center Frequency	1MHz	-	-	-
Thickness(mm)	2	0.567	0.630	20
Acoustic Impedance(Mrayl)	33.7	10.24	2.975	32
Density(kg/m^2)	7750	4287	1179	1920
Young's Modulus(GPa)	63.11	16.3	5.02	0.5
Poisson's Ratio	0.33	0.33	0.33	0.33

(3) Design Value Analysis

A. Finite Element Analysis

We designed a optimal 1-MHz transducer and simulated its characteristic using a finite element analysis with ANSYS ver. 5.6.1.

The piezoelectric ceramic element is an anisotropic material, therefore we simulated the piezoelectric ceramic element after the setting up material property as an isotropic model since there is little difference in essence when comparing to a isotropic modeling analysis.

Transverse resonance vibration has been generated with the result that we analyzed from the resonance vibration mode of the transducer using a Nodal solution.

Fig. 4 shows the displacement and deformation of a meshed ultrasonic transducer after the transducer modeling was set up at 1MHz resonance frequency.

The displacement and deformation of each unit

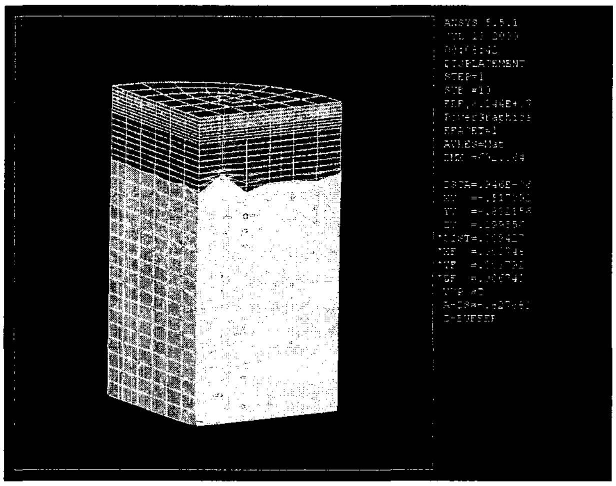


그림 4. 공진 진동 후의 1/4 분할 초음파 변환기의 변위와 변형
Fig. 4. Displacement and deformation of 1/4 meshed ultrasonic transducer after resonance vibration.

can be foreseen using this analysis. Fig. 4 shows the displacement and deformation has been generated at the center of the designed sensor.

B. Numerical Analysis of Sound Field

In this test, we simulated and estimated the designed ultrasonic transducer and set up a table of values with MATLAB ver. 6. 0.

The test was estimated by an analysis of its impulse response and the sound field of the designed transducer.

Fig. 5 shows the impulse response characteristic and frequency response characteristic for a given pulse.

The frequency response characteristic for the given pulse is presented by a fewer number of cycles, a short-duration pulse and a large frequency bandwidth of 1MHz resonance frequency. (Fig. 5)

In the next test, we performed a sound field

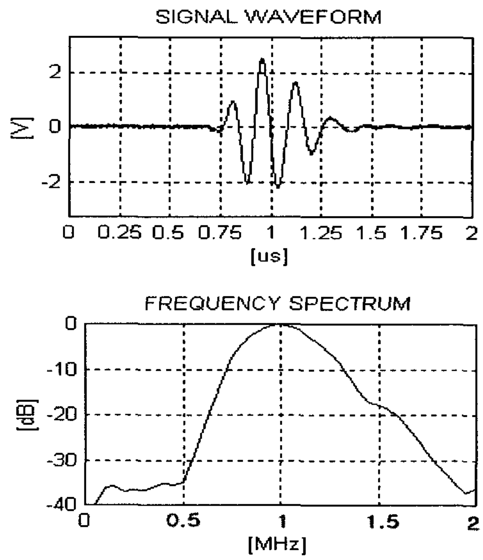


그림 5. 임펄스 응답특성과 주파수 응답특성

Fig. 5. Impulse response characteristic and frequency response characteristic for a given pulse.

표 2 임펄스 응답의 시뮬레이션 결과

Table 2. Results of impulse response simulation.

Center frequency (MHz)	1.05	Sensitivity (V_{P-P})	4.21
Pulse Width (μs)	2.67	Band width (%)	53.26

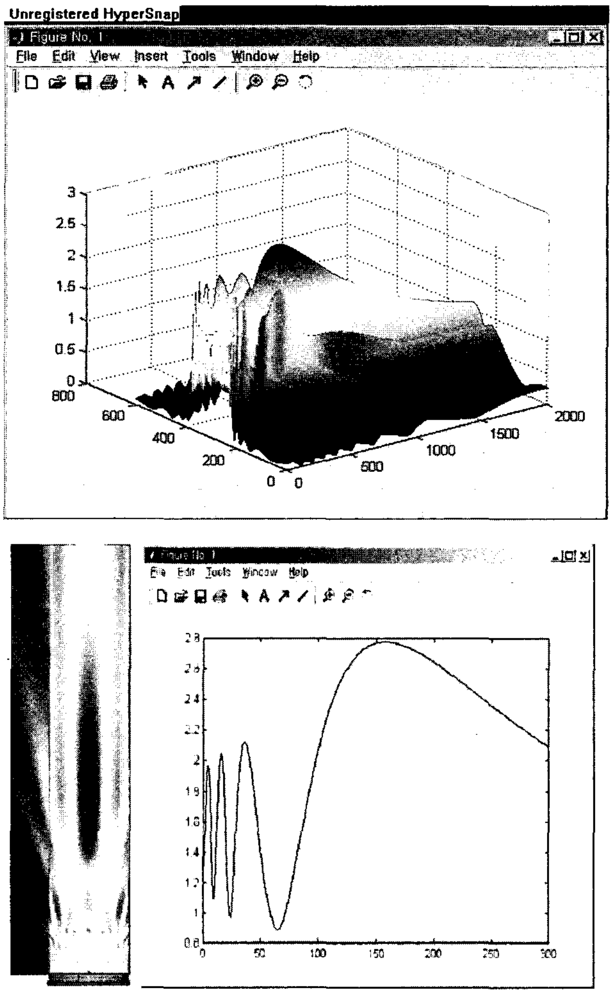


그림 6. 설계된 변환기의 빔 방사패턴과 축방향 음압 특성

Fig. 6. Beam emission pattern and Axial pressure profile of designed transducer.

analysis for the designed transducer. The simulation for the sound field which spread out in a longitudinal pattern with a single-element using Rayleigh-Sommerfeld integration resulted in the sound field analysis.

Fig. 6 shows the results of 2 and 3-D sound field analyses for the designed transducer.

In this chapter, we simulated a transducer beam characteristic on the assumption that the maximum distance of the inner-wall of bladder is 150mm.

Fig. 6 shows that the sound field of the designed transducer has a maximum sound pressure between 130mm and 160mm. When we considered that a distance from the surface of body to the inner-wall of bladder is 7~8cm, this design proved to be suited to its purpose since the designed transducer can transmit the ultrasound beam efficiently to the body.

(4) Fabrication of transducer and characterization

We fabricated the ultrasonic transducer using the estimated values from experiments with Case-molding method.

Transmitted pulse response characteristic and frequency response characteristic were tested for the characterization of the fabricated transducer. To drive on ultrasonic transducer, we fabricated the circuit which used a 200-Volt pulse.

TDS 360(Tecktronic corps.) was used as a measurement system.

Fig. 8 and Fig. 9 shows the response characteristic and frequency characteristic for the transmitting pulse.

Table. 3 shows the result of the test. There is little difference compared to the result of a test using FEM however, a different sensitivities could be compared to each other due to the magnitude of the transmitting pulse was different from the value of the simulation.

However, in the result of a clinical demonstration, we can gather acceptable data about the developed transducer and we can confirmed a possibility of operation.

Fig. 10 shows a waveform as a result of the measurement of the distance between the interior-wall and the posterior-wall of the bladder using an ultrasonic operating circuit.

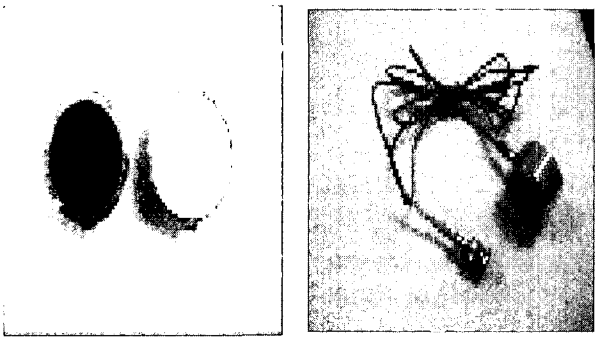


그림 7. 제작된 변환기

Fig. 7. The figure of fabricated transducer.

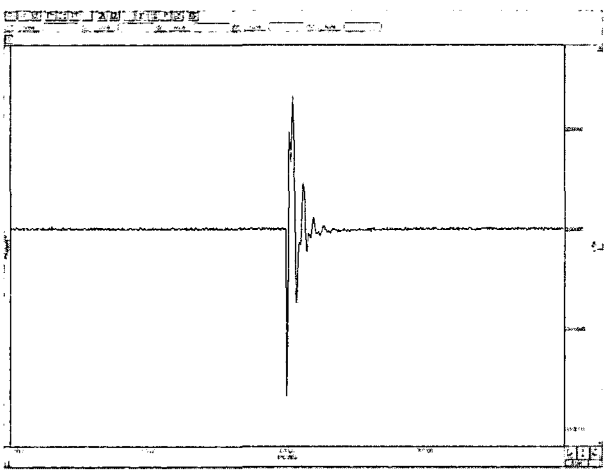


그림 8. 주파수 응답특성

Fig. 8. Characteristic of frequency response.

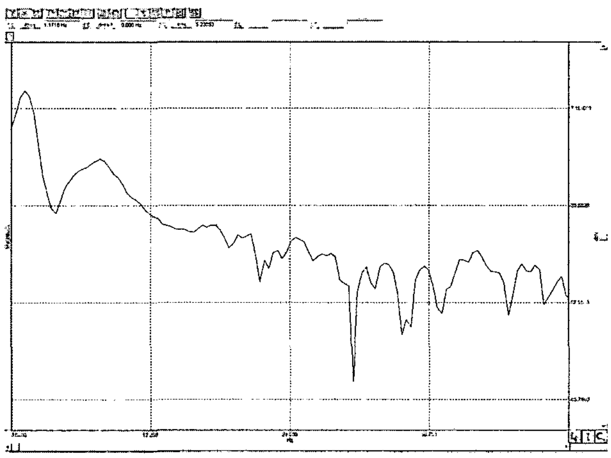


그림 9. 임펄스 응답특성

Fig. 9. Characteristic of impulse response.

표 3 테스트 결과

Table 3. Results of test.

Center frequency (MHz)	1.15	Sensitivity (V_{P-P})	12.0
Pulse Width (μs)	2.4	Band width (%)	54.3

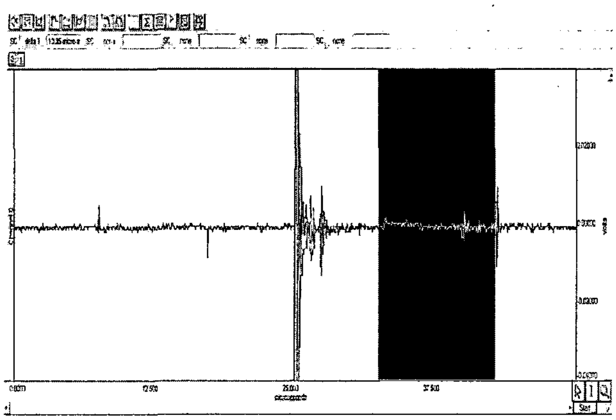


그림 10. 개발된 변환기의 감도 테스트

Fig. 10. Sensitivity test of developed transducer.

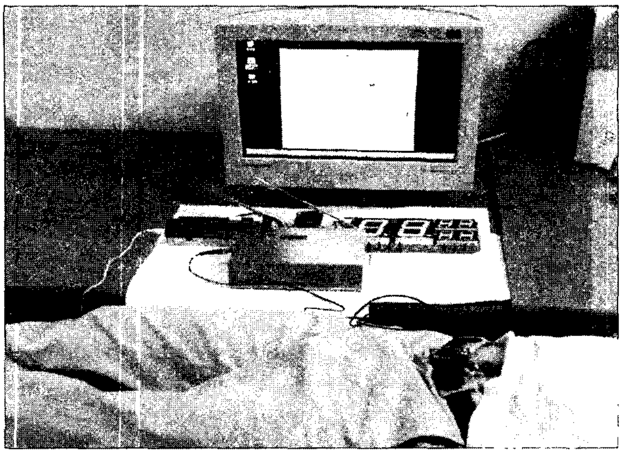


그림 11. 개발된 변환기의 임상 테스트
Fig. 11. Clinical test of developed transducer.

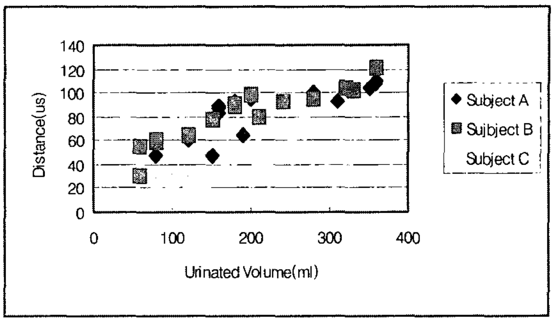
A waveform in the part shown by the dotted line is a signal reflecting from the interior-wall of the bladder and a waveform in the part shown in the square line is a the signal reflecting from the posterior-wall.

Ⅲ. Experiment

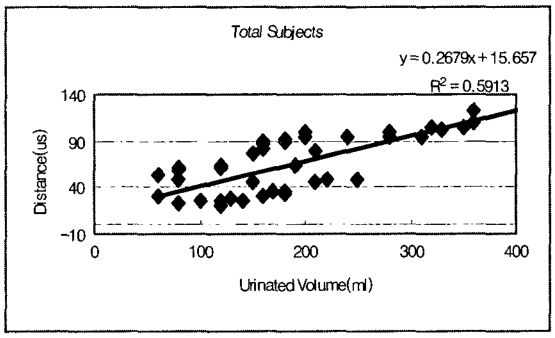
1. Clinical Test With Developed System

To verify the usefulness of developed urine volume sensor and urine alarm system, we performed additional clinical test for three healthy men. Using developed urine volume estimating algorithm collected data was analyzed to make correlation. In additional purpose, it was performedto verify the usefulness of measurement in 2cm upper from pelvic joint, and the correlation between urine volume and distance of bladder's anterior/posterior wall. In test, incident angle was perpendicular to skin and urine volume was measured by beaker.

Fig. 12-(a) shows correlation between urinated volume and bladder's inter-wall distance of each subject. Fig. 12-(b) shows correlation of total data from three subjects. X-axis is urinated volume and Y-axis is distance between bladder's inter-walls. In this paper, real volume is measured by breaker after urination, and measured volume is estimated volume by developed system. According to Fig. 12-(b), we could find the correlations.



(a)



(b)

그림 12. 소변량과 방광의 직경과의 관계
Fig. 12. Urinated volume vs. Distance (us).

표 4. 소변량과 방광 벽간거리 사이의 상관성
Table 4. Correlations between inter-walls distance and urinated volume.

	Correlation	R^2
Subject A	y = 0.2037x + 40.645	0.7369
Subject B	y = 0.2163x + 39.876	0.8497
Subject C	y = 0.1733x + 5.4789	0.877
Subject A+B+C	y = 0.2679x + 15.657	0.5913

2. Discussion

A transducer for measuring urine volume must have a shorter pulse duration, the wider the frequency bandwidth. The ultrasonic transducer with a 1MHz piezoelectric element was designed to get a satisfactory depth of penetration and good resolutions. Double matching layers and a backing layer were added to improve the resolutions.

We were sure that the transducer, for measurement of the distance between the interior-wall and the posterior-wall of the bladder, is able to be fabricated by using FEM, characterization of impulse response and sound field analysis.

There were few errors when we made a comparison between the test and the simulation, but we came to the conclusion that the errors came from differences in the properties between the used materials.

Ⅳ. Conclusion

In this study, we designed and fabricated an ultrasonic transducer using a pulse-echo ultrasound (the range equation) for measurement of urine volume in the bladder, based on the calculation of distance between the interior-wall and the posterior-wall.

We had a thoroughgrasp of the characteristics of the transducer before fabrication using several analysis. The Fabricated transducer is composed of double matching layers, a piezoelectric ceramic element and a backing layer.

We used 5A in several types of PZT which has highly sensitive, a high ratio for induced electricity and highly reliable performance even if time goes by.

The resonance frequency was fixed to 1MHz to allow for a satisfactory depth of penetration, attenuation and resolutions.

There were some errors, but we acquired satisfactory results comparatively and we are confident of its developmental value.

As a result of this study, we can measure the amount of urine volume and estimate the urination time.

This study aims to develop the treatment of urinary incontinence. A warning system will contribute in truly helping patients with this problem by returning their basic ability to tent to themselves, and so gain a sense of independence in this area. The research and work we have done has truly beneficial implications for health care and seniors.

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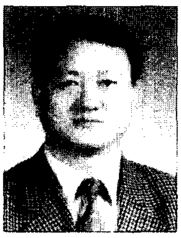
저 자 소 개



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