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A Study on a Flux Switching Motor Drive for Fan Application

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Abstract

A new class of electronically commutated brushless motors, the flux-switching motor (FSM), is gradually emerging for use in power tools and household appliances especially fan and pump application thanks to green policies. This motor offers such advantages as high-power density and relatively high efficiency compare to induction motors, and low cost and simple motor structure compare to the BLDC motor. This paper presents the principle of the FSM and design of the 12/6 pole FSM drive system for fan application. Test results of the prototype motor are provided to verify the validity of the fan application with a TMS320F2812 DSP and inverter.

Key Words : Flux Switching Motor, Reluctance Motor, Motor Drive, Fan Application

1. Introduction

Fans and pumps account for a great portion of application in the motor market. Specifically, induction motors and brushless DC motors dominate the application market. For the 1kW or greater application market, inverter-driven three-phase induction motors are widely used. For the less than 1kW application systems, on the contrary, single-phase induction motors have been most typical [1].

Because of recent green and high efficiency-oriented governmental policy, permanent magnet-based brushless DC motors or permanent magnet synchronous motors have drawn great attention instead of induction motors that have poor efficiency. In terms of price competitiveness, close watch has been on permanent magnet-less, simple-structured switched reluctance motors. The motor drives for fan and drive applications is a low-priced system that does not require precise speed control. Therefore, brushless DC motors or switched reluctance motors have been closely watched.

To improve efficiency, single-phase brushless DC motors have often been found in 50[W] or smaller systems. In systems that require substantial power, on the other hand, the brushless DC motor drives use permanent magnets. Because configuring these drives is expensive, many studies have been conducted on substitutes. In terms of price competitiveness, switched

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reluctance motors are low-priced with a simple structure. The problem of noise has, however, been a big obstacle in commercialization [2].

Compared to brushless DC motors, flux switching motors use a relatively small number of switches. In addition, they are more efficient than switched reluctance motors in terms of noise reduction, speed and torque control [2]. Fig. 1 illustrates the drive configuration of flux switching motors. For drive configuration, two switch elements, a position sensor such as a hall sensor or shutter and a processor are used.

This paper introduces flux switching motors that are more efficient than induction motors or switched reluctance motors and cheaper than brushless motors in terms of drive configuration, are to easy to produce based on a structure that is similar to switched reluctance motors and require very simple control algorithms [3][4]. In Chapter 2, the principle of the flux switching motor and the related numerical formulas are reviewed. Chapter 3 describes system configuration. In Chapter 4, a drive was configured using TMS320 F2812 and FET (DSP by TI) to determine the feasibility of the flux switching motors for fan application, and test results have been investigated.

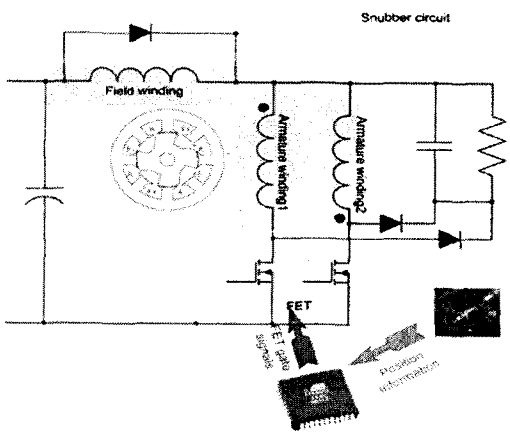


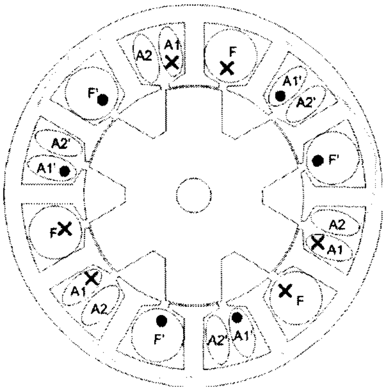
Fig. 1. The drive configuration of flux switching motor

2. Flux switching motor

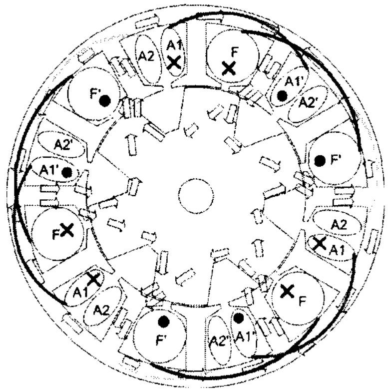
Flux switching motors are driven by the reluctance torque which is created by the interaction of magnetic flux. The magnetic flux that is created by field and armature winding currents flows through stator and rotor as shown in Fig. 2 and Fig. 3.

Fig. 2(a) shows the rotor at its initial position (=0). If current is applied to field (F) and armature (A1) windings as shown in Fig. 2(e), flux linkage is occured as illustrated in Fig. 2(b), 2(c) and 2(d). The rotor is then aligned. Once stator and rotor are aligned as shown in Fig. 2(d), current is applied to field (F) and armature (A2) windings as shown in Fig. 3(e). Again, flux occurs as illustrated in Fig. 3(b), 3(c) and 3(d), and the rotor is aligned. As shown in Fig. 2 and Fig. 3, the flux vector that is created by field winding always occurs in a constant direction. Meanwhile, the flux vector created by armature winding is shifted to a 90 degrees electrical angle.

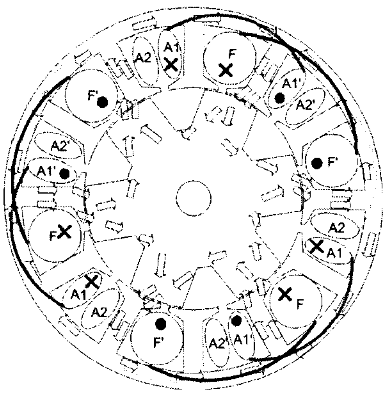
Fig. 4 shows the inductance profiles created by idealized field (F) and armature (A1, A2) windings and the field and armature winding current and winding back EMF waveforms. Even though self inductance can change slightly depending on the shape of the rotor or stator pole, Fig. 4 assumes that the self inductance of field and armature windings is constant, and reluctance torque is created by the mutual inductance between field and armature windings. In sum, in a flux switching motor, the flux linkage that is created by field and armature windings aligns the stator and rotor and applies the necessary current to each position, which in turn rotates the rotor by creating reluctance torque to minimize the self-reluctance between rotor and stator poles.



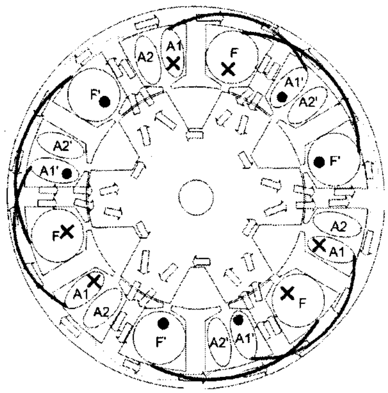
(a) F(+), A1(+),=0



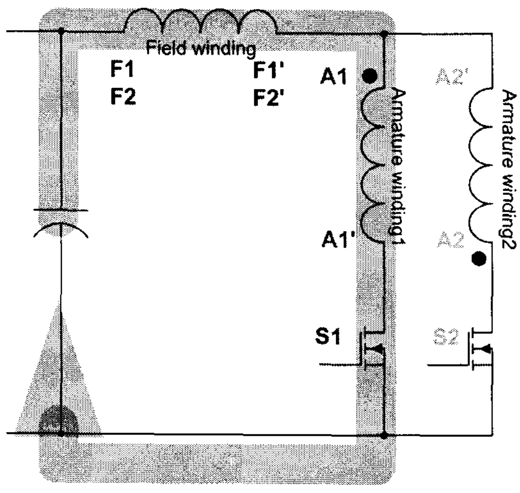
(b) F(+), A1(+), =30



(c) F(+), A1(+), =60

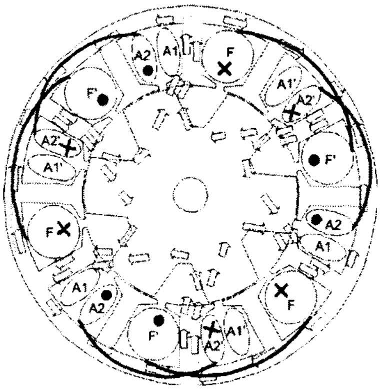


(d) F(+), A1(+), =90

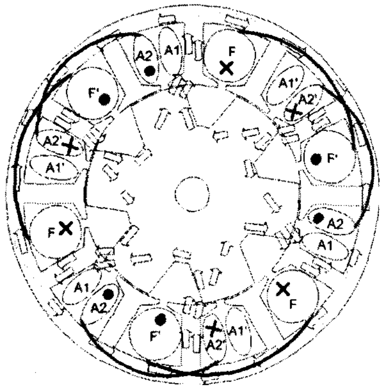


(e) Drive configuration

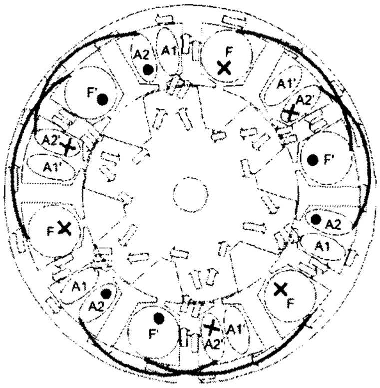
Fig. 2. Flux pattern for field and armature (A1) winding excitations



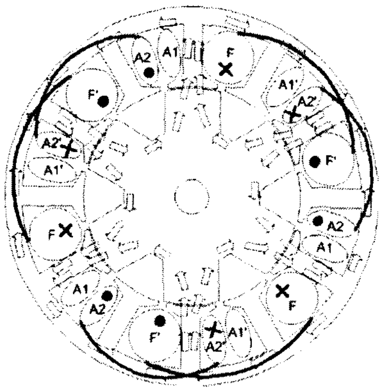
(a) F(+), A2(+),=90



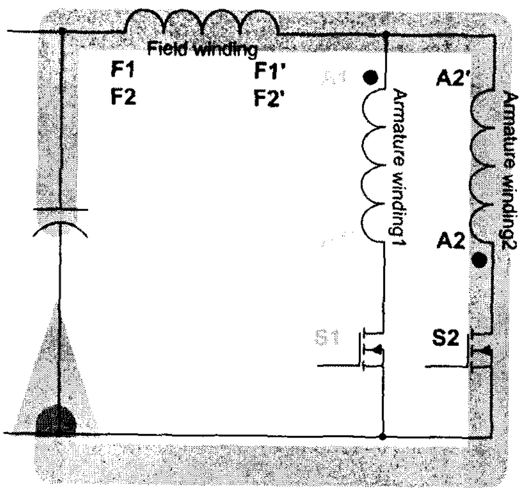
(b) F(+), A2(+), =120



(c) F(+), A2(+), =150



(d) F(+), A2(+), =180



(e) Drive configuration

Fig. 3. Flux pattern for field and armature (A2) winding excitations

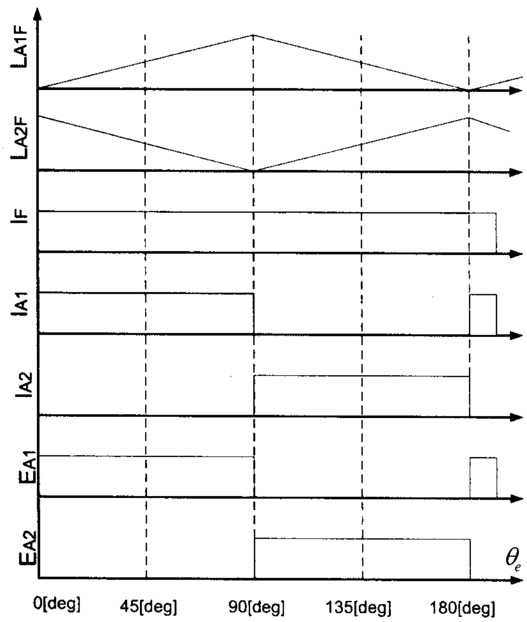


Fig. 4. Idealized mutual inductance and current waveforms

The phase voltage of flux switching motors can be stated as shown in Equation (1). If the self-inductance is set to '0,' the equation can be restated as Equation (2):

$$V_{A1} = V_{dc} - (i_F R_F + i_{A1} R_{A1} - \frac{dL_F}{dt} i_F - \frac{dL_{A1F}}{dt} i_F - \frac{dL_{A1}}{dt} i_{A1} - \frac{dL_{A1F}}{dt} i_{A1})$$
$$V_{A2} = V_{dc} - (i_F R_F + i_{A2} R_{A2} - \frac{dL_F}{dt} i_F - \frac{dL_{A1F}}{dt} i_F - \frac{dL_{A2}}{dt} i_{A2} - \frac{dL_{A1F}}{dt} i_{A2}) \qquad (1)$$

$$V_{A1} = V_{dc} - (i_F R_F + i_{A1} R_{A1} - \frac{dL_{A1F}}{dt} i_F - \frac{dL_{A1F}}{dt} i_{A1})$$
$$V_{A2} = V_{dc} - (i_F R_F + i_{A2} R_{A2} - \frac{dL_{A2F}}{dt} i_F - \frac{dL_{A2F}}{dt} i_{A2}) \qquad (2)$$

Here, R_F, R_{A1} and R_{A2} refer to the phase resistance of A1, A2 and F respectively while L_{A1F} and L_{A2F} stand for mutual inductance between A1-F and A2-F and self-inductance of A1, A2 and F, respectively. Torque can be stated as shown in Equation (3). If self-inductance is assumed to be constant, the equation can be restated as Equation (4):

$$T_e = \frac{1}{2} i_{A1}^2 \frac{dL_{A1}}{d\theta_e} + \frac{1}{2} i_{A2}^2 \frac{dL_{A2}}{d\theta_e} + \frac{1}{2} i_F^2 \frac{dL_F}{d\theta_e} + i_{A1} i_F \frac{dL_{A1F}}{d\theta_e} + i_{A2} i_F \frac{dL_{A2F}}{d\theta_e} \qquad (3)$$

$$T_e = i_{A1} i_F \frac{dL_{A1F}}{d\theta_e} + i_{A2} i_F \frac{dL_{A2F}}{d\theta_e} \qquad (4)$$

As shown in Equation (4), if phase current flows when the derivative of mutual inductance is negative, negative torque occurs. To generate positive torque, the conditions of Equation (5) should be met [5]:

$$i_{A1} i_F > 0, \frac{dL_{A1F}}{d\theta_e} > 0 \qquad i_{A1} i_F > 0, \frac{dL_{A2F}}{d\theta_e} > 0 \qquad (5)$$

3. System configuration

To verify the feasibility of flux switching motors, a system was configured (Fig. 5). A bridge rectifier was used, and 2 FETs have been used for inverter configuration. To measure speed and calculate commutation information, a 2048 [PPR] incremental encoder was used. A Texas Instruments' TMS320F2812 DSP was used to verify the algorithm.

Fig. 6 shows the implemented algorithm. To fix the location of the initial rotor, the rotor is aligned by randomly exciting voltage vectors. Reference speed is then read from the outer ADC at a 1KHz cycle, and motor RPM is calculated. An interrupter occurs at every 20KHz. Using signals from the encoder, the position information is computed. Based on current position information, the necessary switching patterns are created. In accordance with the reference speed from ADC,

Table 1. Parameters of prototype FSM

No. of armature winding turns	700	Inner diameter of stator	88[mm]
No. of field winding turns	600	Outer diameter of stator	51[mm]
Outer diameter of rotor	50[mm]	Length of rotor	40[mm]

then, a proper PWM duty ratio is determined. Fig. 7 shows prototype flux switching motors while Table 1 shows parameters of prototype flux switching motors.

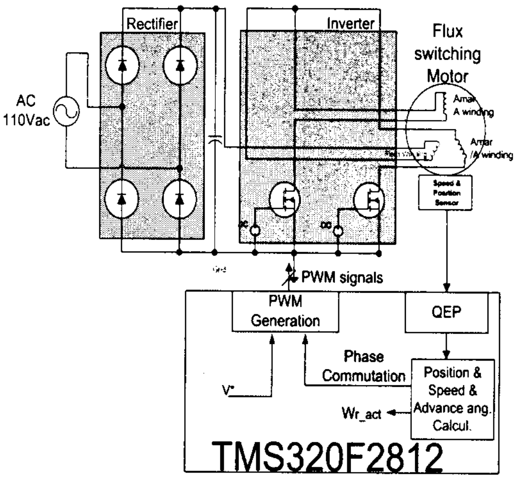


Fig. 5. System configuration

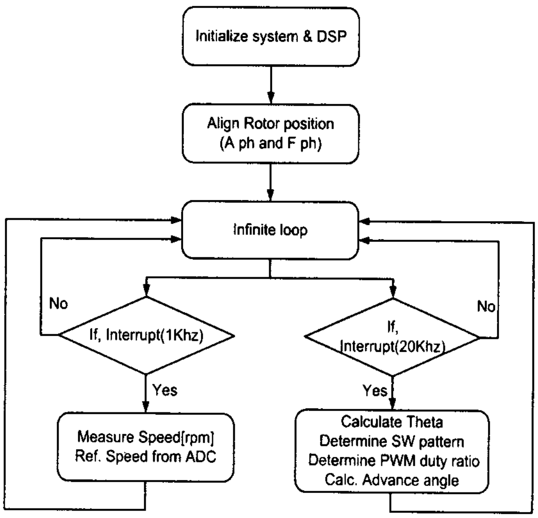


Fig. 6. Program flowchart

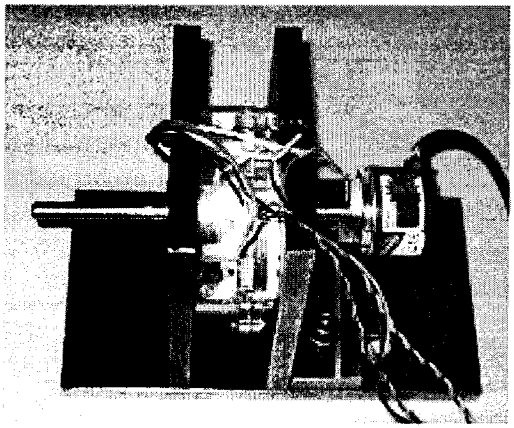


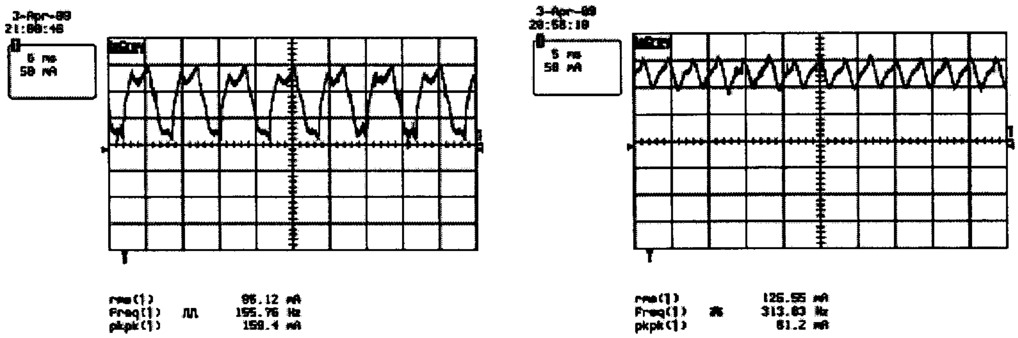
Fig. 7. Prototype flux switching motor

4. Test results

Fig. 8 shows the field and armature winding current waveforms. According to this figure, 95mA and 125mA of current was detected in the armature and field windings, respectively. Table 2 shows the motor speed when voltage is applied by changing the PWM duty ratio in the system (Fig. 5) and the measured values of DC-link current. Voltage (E) is calculated by multiplying DC-link voltage by PWM duty ratio while supplied power is obtained by multiplying DC-link current by supplied voltage. Fig. 9 illustrates motor speed and current against supplied voltage. Fig. 10 shows the speed error during steady state. According to the figure, an error (22[rpm]) can be detected.

5. Conclusion

In this paper, a simply structured 50W flux switching motor (12 stator / 6 rotor poles) for fan



(a) Armature winding current waveforms (b) Field winding current waveforms

Fig. 8. Current waveforms

Table 2. Measured characteristics of flux switching motor

Vin_Mea[Vac]	PWM Duty	E[V]	I[mA]	Speed [rpm]	Pi_Calc[Watt]
114	0.15	23.25	16.88	0	0.39246
114	0.2	31	20.8	0	0.6448
114	0.3	46.5	36	454	1.674
114	0.4	62	52.88	1230	3.27856
114	0.5	77.5	67.9	1757	5.26225
114	0.6	93	86	2100	7.998
114	0.7	108.5	102.4	2329	11.1104
114	0.8	124	117.5	2556	14.57
114	0.9	139.5	132.2	2709	18.4419

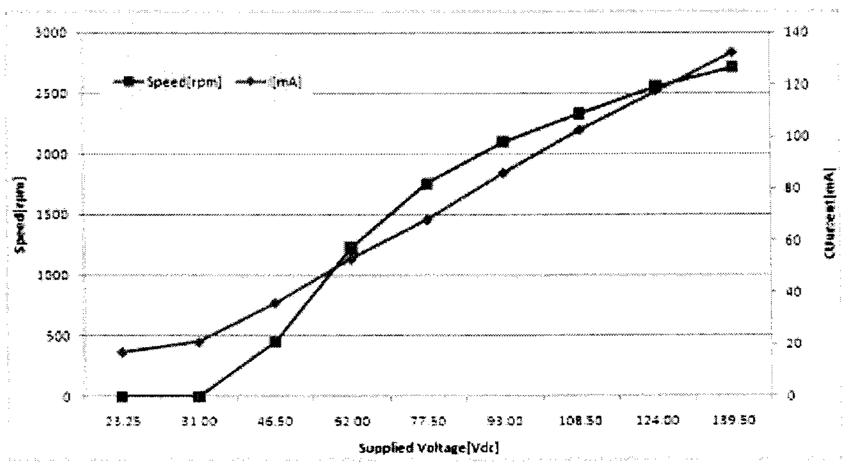


Fig. 9. Motor speed and current against supplied voltage

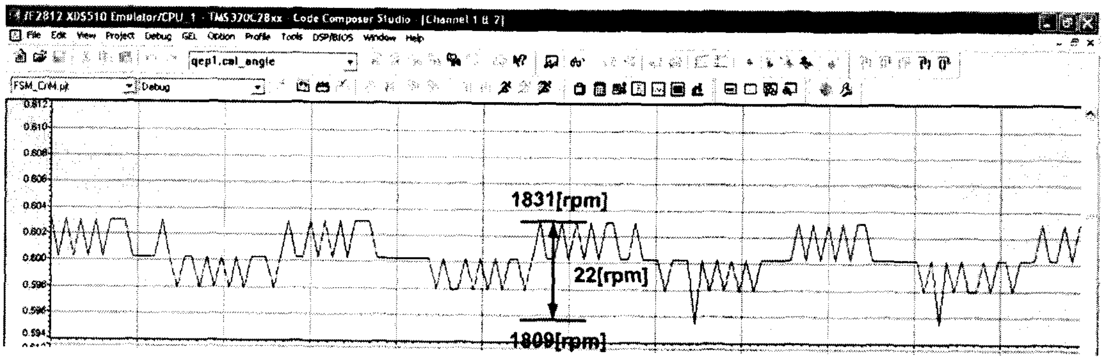


Fig. 10. Speed error during steady state

application that generates commutation using electronic switches and makes use of reluctance torque has been designed. To analyze characteristics, it was driven under a basic algorithm using DSP and an encoder. This paper also presents the principle of the flux switch motor and the related numerical formulas.

To verify the feasibility of the flux switching motor for fan application, it was implemented using a simple algorithm. As a result, stable speed characteristics have been obtained against supplied voltage. In addition, speed error of only 1.2% was detected during steady state. It is known that flux switching motors make less noise than switched reluctance motors and are more efficient than inductor motors. As shown in the test above, it appears that flux switching motors could be widely used in an air purifier or air conditioner fan.

More studies are needed to further improve efficiency and reduce noise by the application of various algorithms.

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Biography

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Born in 1973. Earned a BS in control and instrumentation engineering at Samcheok National University in 1998. Earned a MS in electrical engineering at Yeungnam University in 2000. Earned a Ph.D in electrical engineering at Yeungnam University in 2003. Post-doc work was done at Texas A&M University(2004~2007). Full-time instructor at Cheongju University(2007~).