# QFT 를 이용한 위치제어 및 IPMC 액추에이터 설계

# Design a Position Control Using Quantitative Feedback Theory (QFT) for Ionic Polymer Metal Composite Actuator

*도안녹치남 [1], #안경관 [2], 딩광졍 [1], 윤종일 [1]
*D. N. C. Nam[1], #K. K. Ahn(kkahn@ulsan.ac.kr)[2], D. Q. Truong[1], , J.I. Yoon[1]
[1] 울산대학교 기계자동차공학과, [2] 울산대학교 기계자동차공학부

Key words: Ion Polymer Metal Composite (IPMC), Biometric Material, Quantitative Feedback Theory (QFT), Position Robust Control.

## 1. Introduction

A typical ion polymer metal composite (IPMC) sheet [1] is constructed with a thin ionic polymer membrane and two metal electrode layers outside. When a low voltage electrical field is applied, the transport of hydrated cations within the IPMC and the associated electrostatic interactions lead to bending motions of the IPMC sheet. Fig. 1 illustrates the operating mechanism of an IPMC as an actuator.

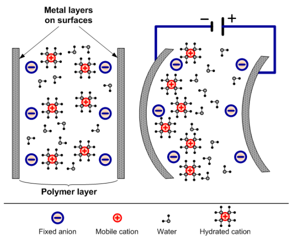


Fig. 1 Operating fundamental of an IPMC actuator

Because of the low driven voltage, flexible operation, and self sensing ability, IPMC has been widely applied in many micro applications such as snake-like robot with IPMC actuator, micro pump, scale biped walking robot, underwater micro robot, etc.

However, control of IPMC faces many unfavorable features such as hysteresis, creep behaviors and also the largely variance of IPMC characteristics depends on the working conditions [2, 3], etc. To deal with these difficulties, this work proposes an effective solution for IPMC robust position control with high precision by using quantitative feedback theory [4]. The design process contains two parts: derivation of a nominal plant model with the uncertain bounds for the dynamics of the IPMC and a position control loop design based on the QFT. The controller is designed to satisfy the robust performance requirement, tracking performance specification, and noise attenuation requirement. Experiments are carried out to show the high robustness of the control performance even in the varying external noise as in real working conditions.

## 2. Robust position controller design

### 2.1 Experimental apparatus

The test rig for the IPMC position control was shown in Fig. 3. The actuator is a sheet of IPMC (size of 40 x 6 x 0.2 mm) manufactured by Environmental Robots Inc., and can operate in both the wet and dry environments. The processing system is built on a personal computer (Intel ® CoreTM2 Duo 1.8 GHz) within Simulink environment combined with Real-time Windows Target Toolbox of Matlab. Two multi-function data acquisition Advantech cards, A/D 1711 and D/A 1720, are installed on the PCI slots of the PC to perform the peripheral buses. In addition, a CCD laser displacement sensor, LK-081, from Keyence Corp. is used to measure the IPMC tip displacement. Setting parameters for the IPMC control system are listed in Table 1.

Table 1 Setting parameters for IPMC system

| Parameters | Specifications |
|---|---|
| Operating environment | Dry environment |
| Max Operating frequency | 0.05 Hz |
| Sampling time | 0.001s |
| Driving voltages | 0~5V |
| Max driving current | 1A |

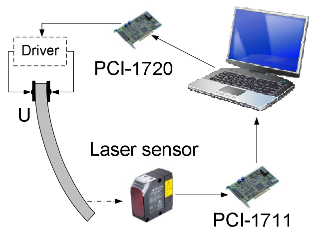


Fig. 2. IPMC actuation configuration

### 2.2 *Design of position control using quantitative feedback theory*

The Quantitative Feedback Theory (QFT) method proposes a general control strategy as in Fig. 3.

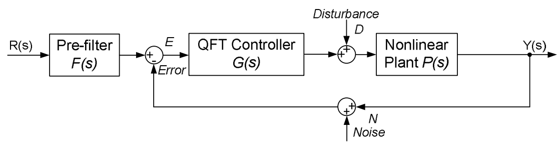


Fig. 3. Structure of the QFT control algorithm

#### 2.2.1 Model identification

The first step in designing a robust QFT controller is to derive a family of uncertain plant transfer functions. The identification process is done by employing PRBS signal as command input and the estimation process in MATLAB. A family of second-order transfer functions in which each one contains no zeros and two real poles was chosen to represent for the IPMC actuator.

$$P(s)=\frac{k}{(1+as)(1+bs)}, \quad (1)$$

here: $k\in[0.18,0.39]$; $a\in[2.8321,4.5984]$; $b=0.001$.

#### 2.2.2 QFT control synthesis

Base on the IPMC characteristics and its application purposes (for conducting the mini motion control with high precision), the IPMC should be controlled to satisfy the following control criteria with respect to the unit step response: settling time about 1.5 [s], maximum percentage of overshoot $\le 2[\%]$.

Base on the criteria to the step input, the bounds for tracking specifications correspond to the trajectory were derived by using the SISO design toolbox – MATLAB. For a satisfactory design, an acceptable response $y(t)$ of the system must lie between these bounds. After using the iteration process based on the control criteria to find acceptable models, the two response boundaries TL and TU functions were obtained:

$$T_u(s)=\left|\frac{0.0145s^2+0.2812s+0.9950}{4.1736\times10^{-6}s^4+3.9249\times10^{-4}s^3+0.0218s^2+0.2929s+1}\right| \quad (2)$$

$$T_l(s)=\left|\frac{0.5634s^2+1.5882s+0.9909}{0.0212s^4+0.3751s^3+1.3645s^2+2.0539s+1}\right|$$

Therefore, the QFT control loop of the IPMC was designed how the tracking signal meets the acceptable range of variation with respect to a reference as follows:

$$|T_l(j\omega_i)|\le|T(j\omega_i)|\le|T_u(j\omega_i)| \quad (3)$$

where T(s) was the closed-loop transfer function:

$$T(s)=\frac{F(s)G(s)P(s)}{1+G(s)P(s)} \quad (4)$$

In the QFT approach, designed controller must satisfy the closed-loop robust stability and the closed-loop noise attenuation. The robust stability constrain was described as:

$$\left|\frac{L(j\omega)}{1+L(j\omega)}\right|\le M=1.4(3\,dB)\ ,\ \omega\ge0 \quad (5)$$

And the general upper bound for the sensitivity was set to limit the peak value of noise amplification as following:

$$\left|\frac{1}{1+L(j\omega)}\right|_{\max}\le M_D(\omega), M_D>1\ (M_{dB}>0dB),\ \omega\ge0 \quad (6)$$

Next, the constraints (3), (5) and (6) were used to determine the tracking performance, robustness and output noise rejection boundaries on the Nichol chart at each critical frequency as $\omega=\{0.05,0.01,0.1,0.2,0.5,1,2,5,10,20,50,100\}$ rad/s. A feedback design satisfies these bounds if for each critical frequency, the corresponding value of the loop gain is on or above the boundaries (the performance boundary and output noise boundary), and is to the right or on the robustness forbidden region. Consequently, the generated QFT bounds (by constrains (3), (5) and (6)) and the final loop shaping for the IPMC were designed as in Fig. 4.

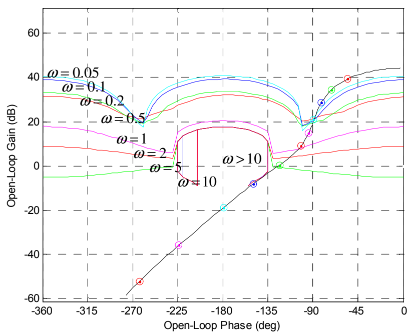


Fig. 4. Superposition of all bounds

Based on the above analysis, the robust QFT controller was determined using the design method in frequency domain:

$$G(s)=\frac{27908345.4836\ (s+0.2767)}{(s+0.01549)(s+262)\ (s+298.2)} \quad (7)$$

Finally, a pre-filter was designed to make sure that the closed-loop transfer functions $L(s)$ satisfy the performance robustness specifications:

$$F(s)=\frac{1560\ s^2\ +8.028\times10^5\ s+9.081\times10^7}{s^3\ +1941\ s^2\ +1.843\times10^6\ s+8.403\times10^7} \quad (8)$$

## 3. Experimental results

The QFT position control was verified in a comparison with PID control. A large noise signal as shown in Table 2 was added to the experiment to perform complex working condition. Fig. 5 and Fig. 6 display the multistep response of the IPMC.

Table 2 Added noise parameters for controller evaluation

| Parameters | | | Specification |
|---|---|---|---|
| **Sine wave** | Amplitude | Volt | 0.1 |
| | Frequency | Rad/s | 1 |
| **White Noise** | Power | Volt | 0.1 |
| **Sampling Time** | T | sec | 0.001 |

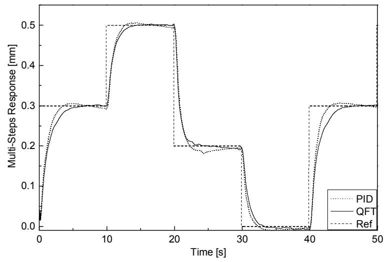


Fig. 5. Multistep responses in ideal condition

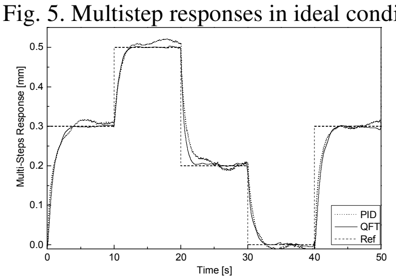


Fig. 6. Multistep responses in noise condition

The results proved that, in all the cases of different setting-points, the IPMC actuator using the proposed controller has better tracking performance than that using the conventional control method especially in case there are perturbations in the working environment. It is clear that a good position regulation is realized when using QFT technique to design a robust position controller for the IPMC actuator.

## 4. Conclusions

In this research, a robust controller using the QFT design technique was developed and successfully applied to one kind of smart material actuator called IPMC with position control target. Experimental results prove convincingly that the position controller designed by QFT methodology for the IPMC actuator could satisfy the robust performance requirement, tracking performance specification, and noise attenuation requirement.

## Acknowledgement

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MEST) (No. 2009-0080924).

## Reference


1. Ba-Cohen, Y., "Electro-Active polymer actuators as artificial muscles - reality, potential, and challenges", Spie press, 2001.
2. Jung, H., and Gweon, D., G., "Creep characteristics of piezoelectric actuators", Rev. Sci. Inst., **71**, 1896-1900, 2000.
3. Chen, Z., and Tan, X., "A Control-Oriented and Physics-Based Model for Ionic Polymer–Metal Composite Actuators", IEEE/ASME Trans. on Mech. **13**, 519-529, 2008.
4. Horowitz, I., M., "Quantitative Feedback Design Theory (QFT)", Boulder, CO: QFT, 1992.