Influence Factor Analysis of MEMS and IC Integration Technologies

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Microelectromechanical system (MEMS) devices are typically combined with integrated circuits (ICs) for operation in electronic systems. A variety of possible factors could affect the decisions of integrating MEMS and IC components. This paper aimed to investigate the critical influence factors of MEMS and IC integration technologies through expert interviews, and to further analyze their causal relationships based on fuzzy decision-making trial and evaluation laboratory (fuzzy DEMATEL) method. We found that product footprints and product costs are the two major influence dispatchers in the cause group, while fabrication complexity is the major influence receiver in the effect group. Moreover, signal path length has very little strength of influence on other factors. The research analysis of fuzzy DEMATEL method could serve as a reference to future development strategies in the field of MEMS and IC integration technologies.

Keywords: MEMS, IC Integration, Fuzzy DEMATEL, Influence Factor, Expert Interviews

Introduction

The Internet of Things (IoT) can connect everything with everyone to form a global integrated network. The rapid development of IoT industry provides great opportunities for technological innovations. Of utmost importance, microelectromechanical system (MEMS) devices are the key enablers of IoT evolution. MEMS devices are typically combined with integrated circuits (ICs) for operation in electronic systems. Several viable technology solutions have been developed for integrating MEMS and IC components; however, a variety of possible factors could affect the decisions. Hence, this paper aimed to investigate the critical influence factors of MEMS and IC integration technologies through expert interviews, and to further analyze their causal relationships based on fuzzy decision-making trial and evaluation laboratory (fuzzy DEMATEL) method.

Integration schemes of MEMS and IC components

MEMS are typically transducer systems that sense or control physical, optical or chemical quantities, such as acceleration, radiation or fluids. To enable MEMS transducers to operate well, the electrical interfaces with the outside world are realized through ICs that provide the system with the necessary intelligence. MEMS and IC components can be integrated using two radical schemes based on literature and expert interviews—multi-chip solutions and system-on-chip (SoC) solutions. Multi-chip solutions can be further divided into two major technologies: (1) multi-chip modules (MCMs) and (2) system-in-package (SiP). SoC solutions can also be further categorized into two major technologies: (1) monolithic SoC integration and (2) heterogeneous SoC integration. Each alternative offers distinct advantages and disadvantages, which indicates that a variety of possible factors could affect the decisions of integrating MEMS and IC components.

Research Method: Fuzzy DEMATEL

To extend DEMATEL method for group decision-making in a fuzzy environment, the essentials of DEMATEL method and fuzzy logic were illustrated below.

DEMATEL method

DEMATEL is a comprehensive method for building and analyzing a structural model whose purpose is to find direct and indirect causal relationships and strength of influence between all factors of a complicated system based on matrix calculation. The procedures of DEMATEL method were briefly depicted as follows:

- Develop analysis factors and design fuzzy linguistic scales.
- Generate direct-relation matrices.
- Calculate normalized direct-relation matrices.
Obtain a total-relation matrix.
Construct a causal diagram.

Fuzzy logic
Zadeh proposed the fuzzy set theory and introduced the concept of membership function. The merit of using fuzzy logic is to assign the relative importance of factors using fuzzy numbers instead of precise numbers. This paper employed triangular fuzzy numbers (TFNs) to obtain ideal solutions from group decision-making. A TFN \( \hat{A} \) refers to the fuzzy set on a real line \( R \), and its membership function can be expressed as \( \mu_\hat{A}(x): R \rightarrow [0,1] \), which has the following characteristics:

- \( \mu_\hat{A}(x) \) is piecewise continuous;
- \( \mu_\hat{A}(x) \) is a convex fuzzy subset.

Moreover, for the purpose of converting triangular fuzzy numbers into crisp scores, we adopted the Centroid defuzzification technique to locate the Best Non-fuzzy Performance (BNP) values.

Numerical Analysis

Step 1 Obtain the critical influence factors
The six critical influence factors were obtained through expert interviews: product footprints (C1), fabrication complexity (C2), signal path length (C3), development cycles (C4), product costs (C5), and manufacturing yield (C6).

Step 2 Design a questionnaire for data collection
A questionnaire was designed for data collection. A pairwise comparison matrix was thus generated to express the influence of each score, with scores of 0, 1, 2, 3 and 4 representing, respectively: no influence (No), very low influence (VL), low influence (L), high influence (H), and very high influence (VH).

Step 3 Determine the fuzzy linguistic scales
The proposed TFNs for the fuzzy linguistic variables were shown in Figure 1.

Step 4 Generate the fuzzy direct-relation matrix \( T \)
Each evaluator was given a 6x6 fuzzy linguistic scale direct-relation matrix \( T \) for a comparison of the six critical influence factors.

Step 5 Obtain the initial direct-relation matrix \( F \)
The Centroid technique was used to defuzzify TFNs for developing a crisp value direction-relation matrix for each evaluator, thereby obtaining the initial direct-relation matrix \( F \).

Step 6 Integrate evaluator’s judgements
All of the evaluators’ judgements were integrated by averaging the crisp values of all initial direct-relation matrices.

Step 7 Obtain the normalized direct-relation matrix \( S \)
The integrated direct-relation matrix was further computed for normalization, thereby obtaining the normalized direct-relation matrix \( S \) as Table 1.

Step 8 Obtain the total-relation matrix \( M \)
The total-relation matrix \( M \), as shown in Table 2, was acquired using the formula \( M = S(I - S)^{-1} \), where \( S \) is a normalized direct-relation matrix and \( I \) is denoted as a unit matrix.
Step 9 Compute the centrality degree and causal degree

The sum of rows and the sum of columns were separately denoted as D and R within the total-relation matrix \( M \). The degrees of influence for each factor were obtained as Table 3.

Step 10 Construct the causal diagram

The causal diagram and digraphical relationships were constructed by mapping the dataset of the \((D + R, D – R)\) shown as Figure 2. This diagram allowed a clearer visualization of the patterns and relationships among the factors.

Result and Discussion

The centrality degree \((D_X + R_X)\) represents the strength of influences both dispatched and received, while the causal degree \((D_X - R_X)\) divides factors into cause or effect groups\(^{17}\). If \((D_X - R_X)\) is positive, the factor X dispatches the influence to other factors more than it receives, and so belongs to the cause group. Conversely, if \((D_X - R_X)\) is negative, the factor X receives the influence from other factors more than it dispatched, and so belongs to the effect group. According to the Figure 2, the influence dispatchers (causal factors) that are part of the cause group include C1 (product footprints), C3 (signal path length), and C5 (product costs). The influence receivers (effect factors) that are part of the effect group include C2 (fabrication complexity), C4 (development cycles), and C6 (manufacturing yield). As for the centrality degree, C1 (product footprints) has the most strength of influence and the strongest connection to other factors, while C3 (signal path length) has very little strength of influence on other factors. Moreover, C1 (product footprints) \((2.97, 1.26)\) is the major influence dispatcher in the cause group, which indicates that MEMS and IC integration technologies pursues the ultimate goal of miniaturized systems, thus making them attractive for portable product applications. C5 (product costs) \((2.60, 0.31)\) is also another important influence dispatcher in the cause group, which indicates that cost-efficient implementation is a key driving factor for success in global competitive markets. On the other hand, C2 (fabrication complexity) \((2.93, -0.23)\) is the major influence receiver in the effect group, which indicates that high requirements for integration density of MEMS and IC components may result in high fabrication complexity.

Conclusion

MEMS devices are the key enablers of IoT evolution which typically integrate ICs that act as electrical interfaces to the outside world. A variety of possible factors could affect the decisions of integrating MEMS and IC components. As a contribution towards explicitly understanding the future development of MEMS and IC integration technologies, this paper successfully deployed expert interviews and fuzzy DEMATEL method for exploring the six critical influence factors, analyzing their causal relationships and detecting their influential intensity. The research analysis of fuzzy DEMATEL method could serve as a reference to future technology development in the field of MEMS and IC integration.

References


