

## DESIGN AND ANALYSIS OF CMOS MEMS FINGERPRINT SENSORS USING ELECTROMECHANICAL SIMULATION FOR ENHANCED IMAGING

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### ABSTRACT

*In this study a new design of MEMS capacitive fingerprint sensors is presented. The capacitive sensor is made of two parallel plates with air gap. In these sensors, the capacitance changes is very important factor. It is caused by deformation of the upper electrode of sensor. In this study with making slots in upper electrode, using T-shaped protrusion on diaphragm in order to concentrate the force from finger ridges, making holes in lower electrode to reduce the air damping and using low stress material for diaphragm, we have been succeeded to design a novel MEMS fingerprint sensor with high sensitivity compared with the previous one. Identification technology based on biometrics is a branch of research that employs the unique individual traits of humans to authenticate identity, which is the most secure method of identification based on its exceptional high dependability and stability of human biometrics. Common biometric identifiers include fingerprints, irises, and facial sounds, among others. In the realm of biometric recognition, fingerprint recognition has gained success with its convenient operation and fast identification speed. Different fingerprint collecting techniques, which supply fingerprint information for fingerprint identification systems, have attracted a significant deal of interest in authentication technology regarding fingerprint identification systems. mainly describes the technology related to the CMOS MEMS process platform provided by the Taiwan Semiconductor Research Institute (TSRI), including the process flow, design verification, back-end dicing, and packaging of the CMOS MEMS integrated sensing single chip.*

**Keywords:** MEMS capacitive, fingerprint sensor, CMOS MEMS integrated, human biometrics

### INTRODUCTION

CMOS MEMS represents the combination of these two technologies, which is able to

provide high-performance sensing and actuation capabilities with low power consumption. MEMS-electronics integration allows to determine the most important specification parameters together with the electronics. This grants the design of both the electronics and the MEMS at the same time, hence shortening the design cycle and reducing the time-to-market. The significant growth we see today in the MEMS sensor market is powered mainly by the increasing demand of wearables, human-interface devices and applications used by the consumers. Particularly, two of the most interesting CMOS-MEMSs used nowadays are the resonant pressure sensors and the accelerometers, which are exploited in different fields such as automotive, aerospace, medical devices, computer and general industries applications. Their structure is mainly based on a capacitive or piezoresistive diaphragms that is monolithically integrated with CMOS circuitry, a characteristic that has indeed paved the way for the integration of sensors and electronics in a single chip, thus allowing the immediate read out of pressure, or more generally of the external physical perturbation, sensed by means of electronics i.e., a system on chip designed on a digital platform Pressure sensors generally operate based on the detection of pressure-induced changes in the resonant frequency or on the quality factor of a

micro-mechanical structure, which is integrated with CMOS electronics, similarly, accelerometers are based on the external excitation force that moves a central floating movable resonator plate that provokes changes of the stress distribution within the resonator modifying its resonant frequency; the capacitance change between fixed and movable fingers electrodes can be detected in both the sensors. The fingerprint is a pattern created by the ridged skin at the tip of a human finger. The fingerprint is formed before birth, and its shape does not alter as the individual matures. There are several methods for acquiring fingerprint pictures, which is the initial stage of fingerprint identification. Many fingerprint acquisition methods exist: optical, capacitive, temperature, ultrasonic, and electromagnetic wave fingerprint acquisition technology. After fingerprint photos are accepted, pre-processing is undertaken to simplify the extraction of fingerprint features, classifying fingerprints according to several characteristic points, then comparing them to those stored in the database to determine if they are the same. Early fingerprint identification technology was mainly developed in cell phones. Finger-sensor surface contact is a key concept in fingerprint image acquisition. Physical contact is the most adopted image capture approach which is currently in use in many applications. Contact sensors such as optical with CCD, capacitive, and digital scanners have been used for contact-based image acquisition. Optical sensors are beneficial for fingerprint recognition with high-resolution images; However, they have large physical volumes with light sources, detectors and optical parts. The work in demonstrated. an ultrathin contact-based compact camera as an alternative,

where the CMOS sensor is integrated with a micro lens array and multiple block layers.

#### LITERATURE REVIEW

**Nayem Hossain (2024)** MEMS, or micro electromechanical systems, have greatly transformed multiple industries with their small size and adaptable capabilities. MEMS technology in biosensing allows for rapid and accurate identification of biological analytes, assisting in medical diagnoses and therapies. MEMS-based biosensors provide label-free detection, improving early disease screening and customized medicine administration. MEMS devices in healthcare enable uninterrupted patient monitoring and telemedicine, leading to substantial enhancements in healthcare results. Nevertheless, obstacles remain, such as the requirement for improved biocompatibility and durability under very demanding conditions. In order to overcome these restrictions, current research is dedicated to advancing materials that are compatible with living organisms, improving processes used to create small-scale structures, and incorporating wireless monitoring systems. To fully exploit the capabilities of MEMS biosensors, it is crucial to prioritize these improvements. This will facilitate their smooth integration into different industries and contribute to the industry's significant growth.

**Martin J. Prest (2023)** Even though the recent progress made in complementary metal-oxide-semiconductor (CMOS) image sensors (CIS) has enabled numerous applications affecting our daily lives, the technology still relies on conventional methods such as antireflective coatings and ion-implanted back-surface field to reduce optical and electrical losses resulting in limited device performance. In this work,

these methods are replaced with nanostructured surfaces and atomic layer deposited surface passivation. The results show that such surface nano engineering applied to a commercial backside illuminated CIS significantly extends its spectral range and enhances its photosensitivity as demonstrated by >90% quantum efficiency in the 300–700 nm wavelength range. The surface nano engineering also reduces the dark current by a factor of three. While the photo response uniformity of the sensor is seen to be slightly better, possible scattering from the nanostructures can lead to increased optical crosstalk between the pixels. The results demonstrate the vast potential of surface nano engineering in improving the performance of CIS for a wide range of applications.

**Udit Rawat (2022)** Monolithic integration of Micro electromechanical Systems (MEMS) directly within CMOS technology offers enhanced functionality for integrated circuits (IC) and the potential improvement of system-level performance for MEMS devices in close proximity to biasing and sense circuits. While the bulk of CMOS-MEMS solutions involve post-processing of CMOS chips to define freely-suspended MEMS structures, there are key applications and conditions under which a solid, unreleased acoustic structure composed of the CMOS stack is preferred. Unreleased CMOS-MEMS devices benefit from lower barrier-to-entry with no post-processing of the CMOS chip, simplified packaging, robustness under acceleration and shock, stress gradient insensitivity, and opportunities for frequency scaling. This paper provides a review of advances in unreleased CMOS-MEMS devices over the past decade, with focus on dispersion engineering of guided waves in CMOS,

acoustic confinement, CMOS-MEMS transducers, and large signal modeling.

**Thi Thu Do and Weileun Fang (2021)**

The booming growth in environmental conditions sensing and monitoring pushes the need of inexpensive environment sensors with small size and low power consumption. The micro-electrical-mechanical-systems (MEMS) technologies are considered as promising solutions to realize the required environment sensors. The mature complementary metal-oxide-semiconductor (CMOS) process platforms available in many foundries can be extended to fabricate MEMS sensors to offer the advantage of relatively easier commercialization. Moreover, by leveraging the characteristics of CMOS process platforms, the integration of multiple sensors and sensing circuits to form a compact sensing system can also be achieved. This review paper will focus on introducing the miniaturized environmental sensing devices implemented and integrated using the CMOS-MEMS technologies. In general, the CMOS chips for environment sensing are firstly fabricated using the foundry-available CMOS processes, and then the post-CMOS micromachining processes are performed to implement the CMOS-MEMS environment sensors.

**Comparing MEMS and CMOS fingerprints**

There have been many physical authentication proposals on many platforms. The reader can refer for a detailed survey of the literature. gives the most commonly used sources for generating digital fingerprints, their typical technology nodes, the source of variation, overhead of the operations and the measured variations. The sources that can be utilized are SRAMs, Microprocessors,

delays or MEMS sensors. Propose the first MEMS sensor based physical authentication method. The proposed method uses the measured light level variations of photodiodes. This sensor has an array of on-chip photodiodes and a coating that contains swirls of dark material in a translucent base to provide a medium of non-uniform optical transmittance. The variations between the amounts of light sensed by the photodiodes are used as digital fingerprints. This sensor is specifically built for authentication and has no other use, whereas we propose an authentication method on the general-purpose MEMS sensors of the low-cost platforms. Demonstrates a sensor-based authentication for mobile platforms. Furthermore, while the initial results of the looks promising, there is still need for a detailed statistical analysis of the uniqueness and reliability of the MEMS fingerprints.

### **Image Enhancement**

Image enhancement is a pre-processing step which is used to improve the quality of the image by removing blur and noise. Among the security variables fingerprint is the most commonly and widely used entity since they are unique and do not change over time and moreover, they never need to be remembered. Image enhancement means "making an image more vivid for human vision". Fingerprint recognition has been used in identifying individuals for a long time and it was being the most popular method in biometric authentication at present. Consequently, no single standard method of enhancement can be said to be "the best". Besides that, the nature of each image in term of distribution of pixel values range will change from one area to another. Fingerprint recognition has been used in identifying individuals for a long time and

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### **Fingerprint Enhancement Techniques**

Fingerprint enhancement is a pre-processing technique to make the image clearer than the original image, for further operations. In other words, enhancement techniques improve the quality of the fingerprint images. The quality is determined by many factors, which sometime may be difficult to control, therefore a fingerprint system must be able to handle also the images of medium and low quality (recoverable). The process of enhancing the image before the feature extraction is also called pre-processing. The reason for degradation lies in the fact that images acquired from sensors or other media are not always assured of perfect quality. Several types of filters in both spatial and frequency domains have been proposed in the literature. This section reviews some of these works. One of the most widely cited fingerprint enhancement techniques is the method employed by, which is based on the convolution of the image with Gabor filters tuned to the local ridge orientation and ridge frequency.

### **Mechanical MEMS**

Pressure sensors belong to the oldest MEMS and are used under harsh conditions in cars, for instance, controlling the air-fuel ratio for the engine and the hydrocarbon emission, or monitoring the tire pressure. They are used in medicine for invasive and non-invasive blood pressure measurement, for the control of infusion pumps, micro pumps, etc. They can be integrated in sports

watches, but also in cell-phone to support level-detection in the upcoming in door navigation systems. Their market share in 2010 was about 15 % of the overall MEMS device market. MEMS microphones for portable electronics and especially for cell-phones quickly gained market shares. Due to their solder ability they offer substantial cost advantages against the excellent electret microphones. Autofocus and zoom actuators for digital cameras are another high-volume application of mechanical MEMS. For instance, capacitive comb actuators are used to move lenses within the photo objective. MEMS with movable nanometre-sharp tips are used for material surface investigation down to the atomic scale as, e.g., in the atomic force microscopes. Mechanical MEMS actuators for driving cutting tools in microsurgical applications have become indispensable tools in medicine, especially for neurosurgeons.

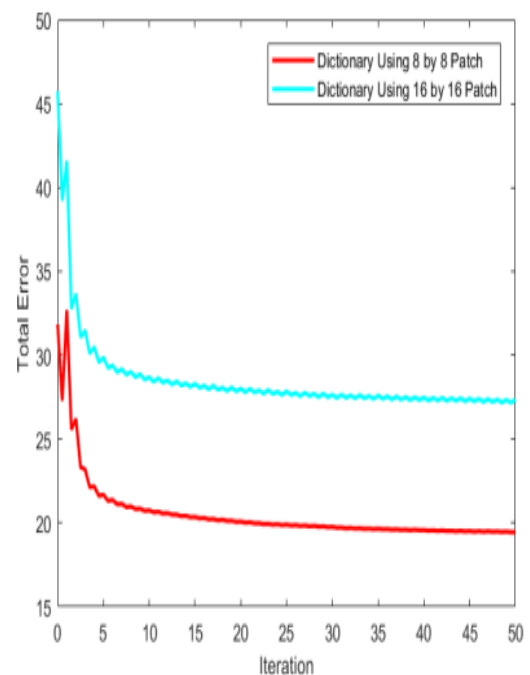
### METHODOLOGY

The development of MEMS requires design, simulation, and performance analysis to make the final result optimal. Therefore, the sensor's performance presented in this work or the MOSFET based MEMS pressure transducer circuit is investigated by varying geometry of the sensor MOSFET and the diaphragm used at fixed applied pressure value. Furthermore, the proposed device's performance study is crucial to further put the device in various applications such as sensors array. In this chapter, the performance of the MEMS pressure sensor has been studied to test its reliability and suitability for building sensor arrays. Like the previous work, a batch-based design and simulations via an integrated design and simulation approaches have been employed for the design and simulation task of the sensor

array. The integrated simulation approach is used to repeat the simulation of the SPICE model of the sensor array components using MATLAB script several times. Moreover, LT Spice is used to design the sensor circuit and signal acquisition components of the array like, the differential amplifier, the row decoder, and the column decoder. The combination of these components used to construct a sensors array with a sample 8 by 8 sensors arrangement is done by MATLAB script as a sample demonstration.

### RESULTS AND DISCUSSIONS

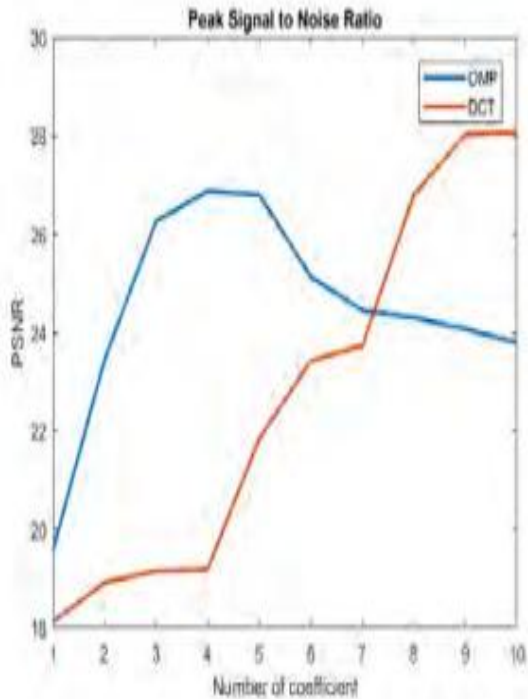
The addition of the Gaussian noise on each training, fingerprint image is analyzed with the help the absolute error convergence observed in the K-SVD algorithm-based during dictionary matrix learning. The computation is performed for about 50 iterations in dictionary learning.



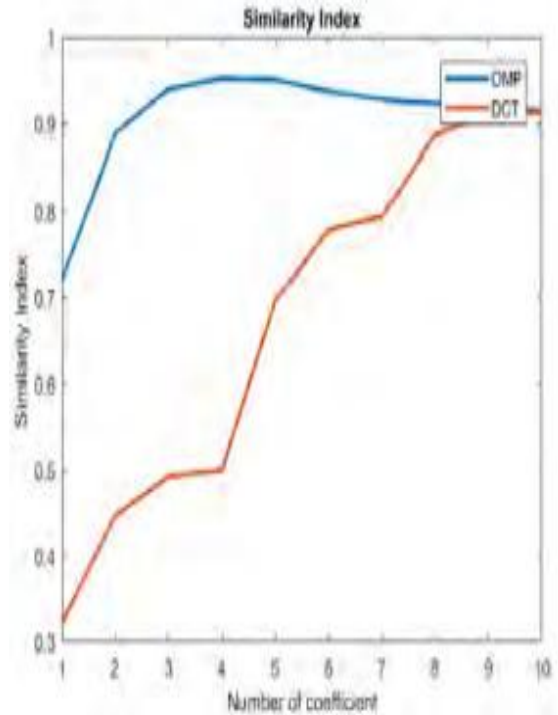
**Graph 1: Convergence plot for 8 by 8 and 20 by 20 image patch-based dictionary learning using K-SVD algorithm**

Like we studied in the previous chapter, for the purposes of testing of the proposed

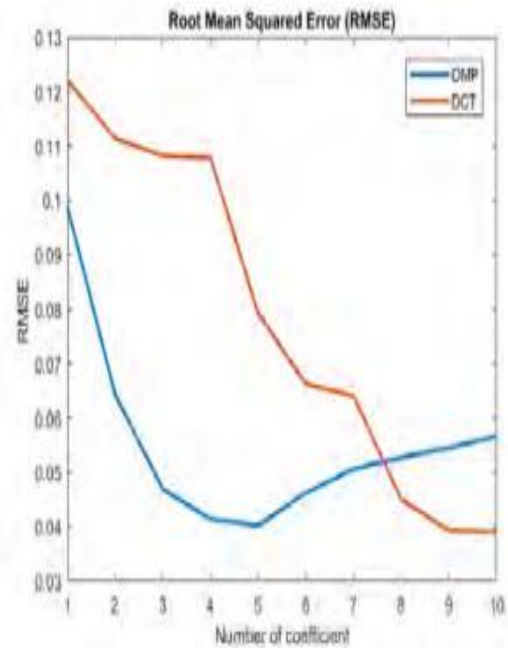
approach we have used data that collected from the NIST public database. All the fingerprint images that we have gathered from the aforementioned database are used for constructing the dictionary matrix to transform the inputs signal to its sparse equivalent and to test the overall proposed scheme performance. There was an option to collect a fingerprint in live mode using fingerprint scanner that available in the market. However, the problem with these scanning devices is, they store the recorded fingerprint data in the form of encrypted templates to avoid any unauthorized access. process it. In spite of that, the DCT based approach is not recommended.



**Graph 2: PSNR vs. samples for DCT (Fourier transform) and OMP based compressed sensing system**



**Graph 3: Similarity Index vs. samples for DCT (Fourier transform) and OMP-based compressed sensing system**



**Graph 4: Root Mean Squared Error (RMSE) vs. samples for DCT (Fourier transform) and OMP-based compressed sensing system**

When we look in to from the security point of view another set of output data will be seen. From security point of view means,

number of fingerprint minutia. However, a secured encryption feature was not added to the system to save computational time.

## CONCLUSION

The first step in this research project is a thorough analysis of the general features of several fingerprint imaging systems. The review covers the signal processing strategies and sensor approaches. According to the previous analysis of such technologies, the capacitive sensing technology measures the capacitance difference caused by the finger skin's ridge and valley in order to accomplish its goal. Similar to this, the ultrasonic operates by determining the difference in ultrasonic wave intensity between the incident and reflected beams for both ridge and valley. The integration of complementary metal–oxide–semiconductor (CMOS) technology with micro electromechanical systems (MEMS) has enabled the design and realization of high-performance fingerprint sensors that combine miniaturization, low power consumption, and superior imaging capabilities. In this study, the electromechanical simulation of CMOS-MEMS fingerprint sensors has been carried out to evaluate their structural behavior, sensing performance, and contribution to enhanced image quality. The results not only validate the feasibility of such integrated sensors but also highlight key aspects that determine their effectiveness in next-generation biometric systems.

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