Digitizing Touch with an Artificial Multimodal Fingertip

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ABSTRACT

Humans rely on touch to interpret and interact with the physical world, yet digitizing this complex modality remains a significant challenge. This work presents **Digit 360**, an artificial multimodal fingertip that integrates high-resolution visuotactile imaging with pressure, vibration, temperature, and gas sensing in a compact hemispherical design. The fingertip employs a silver-coated elastomer interface, custom optics, and optimized illumination, combined with on-device neural network acceleration to enable reflex-like processing. **Digit 360 demonstrates superhuman performance**, resolving spatial features as small as 7 μm, detecting normal and shear forces with millinewton precision, and capturing vibrations up to 10 kHz. These capabilities allow accurate classification of materials, object states, and interactions, highlighting applications in robotics, prosthetics, telepresence, and immersive virtual environments. By releasing Digit 360 as an open research platform, this work establishes a foundation for advancing digital touch as a fundamental sensing capability in artificial intelligence and human–machine interaction

1. INTRODUCTION

The sense of touch plays a fundamental role in human perception, enabling the recognition of object properties such as shape, texture, compliance, and temperature, as well as providing essential feedback for dexterous manipulation. Unlike vision and audition, which have been successfully digitized and integrated into artificial systems, replicating the richness of human touch remains an unresolved challenge. Traditional tactile sensors typically capture only a subset of modalities, such as pressure or vibration, and are often constrained by limited spatial resolution, narrow frequency response, or high latency. These limitations hinder the ability of robots and prosthetic devices to perform complex, human-like interactions with their environment.

To address these challenges, researchers have developed **Digit 360**, an artificial multimodal fingertip designed to digitize touch with high fidelity. This platform integrates multiple sensing modalities—including high-resolution visuotactile imaging, pressure and shear detection, vibration capture, thermal measurement, and gas sensing—within a compact hemispherical form factor. The fingertip further incorporates custom optics,

optimized illumination, and an on-device neural network accelerator to enable reflex-like responses with sub-millisecond latency.

By combining these technical innovations, Digit 360 achieves near-superhuman sensitivity and opens new opportunities for applications in robotics, prosthetics, telepresence, and immersive virtual environments. The present seminar report provides an overview of the system's design, experimental evaluation, key results, and potential implications for advancing artificial intelligence and human–machine interaction.

2.APPLICATIONS

The development of Digit 360 as an artificial multimodal fingertip provides broad opportunities across multiple domains where precise tactile perception is essential.

Robotics:
In robotics, the ability to sense fine surface details, forces, vibrations, and temperature significantly enhances dexterous manipulation and object handling. Digit 360 allows robots to grasp fragile items such as glassware or biological samples with greater precision and safety, while also enabling complex tasks such as assembly, inspection, and quality control in industrial environments.

Prosthetics:
For prosthetic devices, the integration of multimodal tactile sensing represents a major step toward restoring naturalistic touch for amputees. By detecting microforces and thermal or textural cues, Digit 360 can provide users with richer sensory feedback, improving both functionality and the sense of embodiment in prosthetic limbs.

Telepresence and Virtual Reality:
In telepresence and immersive virtual reality applications, Digit 360 enables the transmission of tactile sensations across distance, creating more authentic human–machine interactions. This capability is particularly relevant for remote collaboration, medical consultation, or training scenarios where physical contact cannot be directly established.

Healthcare and Surgery:
Within medical robotics, precise tactile sensing is critical for surgical interventions, diagnostics, and minimally invasive procedures. The fingertip's high spatial and force resolution supports delicate manipulation of tissues and instruments, thereby improving accuracy and patient safety.

Consumer and E-commerce Applications:
By digitizing touch, Digit 360 also opens possibilities for e-commerce and consumer technologies, where users may virtually feel the texture, stiffness, or weight of products before purchasing. This tactile dimension could transform the digital shopping experience by adding trust and realism.

In summary, the versatility of Digit 360 extends well beyond a single discipline. Its ability to combine multimodal sensing with reflex-like processing establishes a foundation for next-generation systems in robotics, healthcare, telepresence, and consumer technologies, marking a

significant advancement in the digitization of touch.

3. MATERIALS AND METHODOLOGY

The design of Digit 360 incorporates a combination of advanced materials, optical components, electronic subsystems, and computational techniques to replicate the multimodal richness of human touch. The methodology followed in its development can be outlined across key elements as described below.

3.1 Elastomer Interface
At the core of the fingertip is a compliant elastomer layer that simulates the softness and deformability of human skin. This layer is coated with a thin silver film through a controlled chemical deposition process. The reflective coating improves optical contrast for visuotactile imaging while maintaining compliance. By tuning parameters such as thickness, modulus, and surface finish, the elastomer interface enables sensitivity to microfeatures and forces at the millinewton scale.

3.2 Optical and Illumination System
To achieve high-resolution tactile imaging, Digit 360 employs a custom hyper-fisheye solid-immersion lens coupled with a high-frame-rate CMOS image sensor capable of capturing at 240 frames per second. A carefully optimized illumination system scatters light through the reflective elastomer, producing uniform background intensity and high-contrast surface contact patterns. This design allows spatial resolution down to approximately 7 μm, far surpassing the capability of conventional tactile sensors.

3.3 Multimodal Sensing Subsystems
Beyond imaging, Digit 360 integrates additional modalities:

- **Pressure and shear sensing** for quantifying contact forces.

- **Surface-audio microphones** capable of capturing vibrations up to 10 kHz.

- **Thermal sensors** for detecting temperature variations across contact surfaces.

- **Gas sensors** for identifying volatile compounds, enabling detection of object states such as freshness or contamination.

- **Inertial measurement units (IMUs)** to track fingertip motion and orientation during interactions.

3.4 On-Device Neural Processing
To reduce latency in robotic control loops, the fingertip is equipped with an embedded neural network accelerator. This on-device processor enables real-time feature extraction and inference directly at the sensor, reducing action-response latency to approximately 1.2 milliseconds. This reflex-like capability is particularly critical for robotic manipulation tasks where slip detection and correction must occur rapidly.

3.5 Evaluation Methodology
The performance of Digit 360 was validated through a series of experimental evaluations:

- **Spatial resolution testing** using calibrated micro-indenters.

- **Force measurement benchmarks** with tribo-indenter equipment to assess normal and shear force precision.

- **Dynamic response analysis** to measure vibration sensing and frequency bandwidth.

- **Multimodal classification tasks**, involving a four-finger robotic setup, to evaluate material, state, and object recognition accuracy.

- **Latency measurements**, comparing on-device versus host-based inference pipelines.

This structured methodology ensured rigorous characterization of Digit 360 across its multimodal sensing capabilities, establishing benchmarks that highlight its advancement over prior tactile sensor designs.

4. TECHNOLOGIES VS. REALITY

The pursuit of digitizing touch has long been guided by advances in tactile sensing technologies; however, bridging the gap between theoretical capabilities and practical deployment presents significant challenges. Traditional tactile sensors, such as capacitive arrays, resistive films, and piezoelectric devices, have demonstrated the ability to capture limited modalities such as pressure or vibration. While these technologies are effective in controlled laboratory conditions, they often struggle with issues of scalability, durability, and multimodal integration when applied in real-world environments.

4.1 Limitations of Prior Technologies
Most existing tactile sensors lack the spatial resolution necessary to capture microscale surface details that humans perceive effortlessly. Furthermore, latency in data transmission and processing reduces their utility for real-time applications such as robotic grasping or surgical interventions. Many devices are also constrained by material fatigue, susceptibility to noise, and difficulty in integrating multiple sensing channels within a compact form factor. As a result, the translation of tactile research prototypes into robust, deployable systems has remained limited.

4.2 Advancements with Digit 360
Digit 360 addresses these limitations by integrating multiple sensing modalities—visuotactile imaging, force detection, vibration capture, temperature, and gas sensing—into a single hemispherical fingertip. Unlike earlier technologies that focused narrowly on one or two modalities, Digit 360 replicates the multimodal richness of human touch. With its customized elastomer interface, optimized optical system, and embedded neural processing unit, the platform achieves near-superhuman sensitivity while maintaining low latency and high durability.

4.3 Practical Implications
By closing the gap between technological development and practical usability, Digit 360 represents a significant step toward making tactile sensing a reliable and scalable capability. Its open-source release further ensures that researchers and engineers can adapt the platform to diverse real-world applications, including robotics, prosthetics, telepresence, and consumer technologies. Thus, while previous tactile sensing systems remained largely experimental, Digit 360 demonstrates a pathway for translating research breakthroughs into functional, real-world solutions

5. CONCLUSION

The development of Digit 360 marks a significant advancement in the digitization of touch by uniting high-resolution visuotactile imaging with complementary modalities such as force, vibration, thermal, and gas sensing. Through its innovative elastomer interface, custom optical design,

optimized illumination, and embedded neural processing, the fingertip demonstrates spatial sensitivity at the micrometer scale, millinewton-level force detection, and reflex-like low-latency responses. These capabilities extend beyond the limits of human tactile perception, establishing Digit 360 as a platform with superhuman sensing performance.

The implications of this work are far-reaching. In robotics, Digit 360 enables dexterous manipulation and safer human–robot collaboration. In prosthetics, it brings the potential for restoring naturalistic touch to users, thereby improving both functionality and quality of life. In domains such as telepresence, virtual reality, and healthcare, the ability to transmit and interpret rich tactile signals transforms the depth and fidelity of remote interactions.

By open-sourcing the platform, the creators of Digit 360 have laid the groundwork for collaborative research and innovation across multiple disciplines. This initiative not only accelerates progress in tactile sensing technologies but also fosters new applications at the intersection of artificial intelligence and human–machine interaction. In conclusion, Digit 360 establishes a new benchmark for artificial tactile systems and provides a foundation for realizing the long-standing vision of fully digitizing the human sense of touch

6.REFERENCES

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