Smart Shelf System Utilizing Swept Frequency Capacitive Touch Sensing Grid

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CURRENT SCENARIO IN SHOPPING MALL SHELVES AND MISSING THE PROBLEMS

- Customer picks up various products like Parle-G, Bourbon, Good Day, examining them for price, taste, and reviews.
- We only capture the final purchase, not the products considered or almost selected.
- No data on packaging impact, price comparison moments, or previous experiences influencing decisions.

Source : commons.wikimedia.org

THE PROBLEM
MISSING SHELF INTERACTION DATA

Why final purchase along does not tell the whole story?

Data Blind Spots	Lost Influence Mapping	Inadequate Consumer Insight
Retailers only log the product purchased- ignoring what was picked, examined, or compared.	No visibility into factors like packaging, price comparison, or label reading that guide choices.	Customer preferences, hesitation points, and alternative considerations are not captured

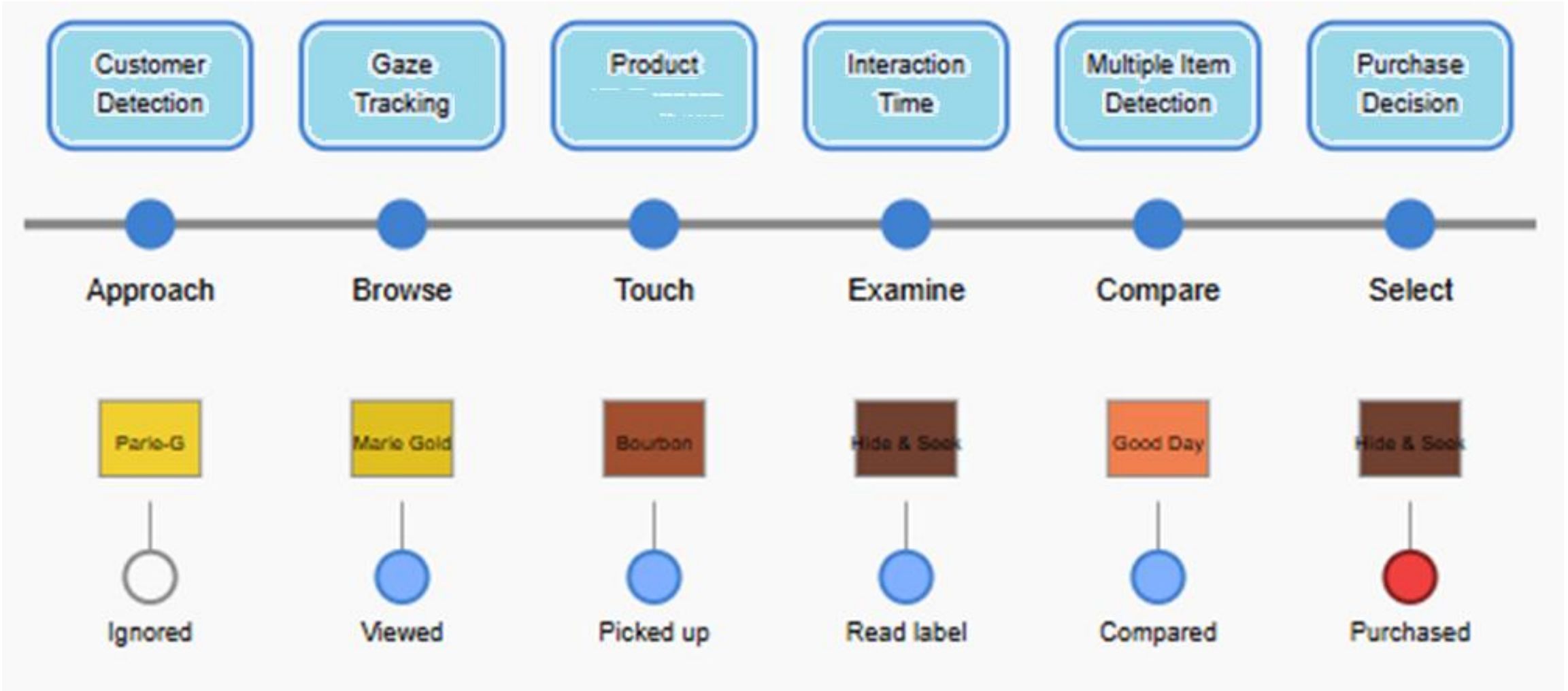
SMART SHELVE

OUR OBJECTIVE:
INTELLIGENT SHELF SYSTEM

Capturing the Full Scope of Customer Engagement.

Real-Time Interaction Capture	Behavioral Analytics	Enhanced Retail Intelligence
Using capacitive sensors to know when a customer touches a product, picks it up, or how long they keep it off the shelf.	Analyze the sequence and duration of engagements to understand preferences and decision factors.	Enable smarter inventory, targeted promotions, and personalized marketing using shelf-level data.

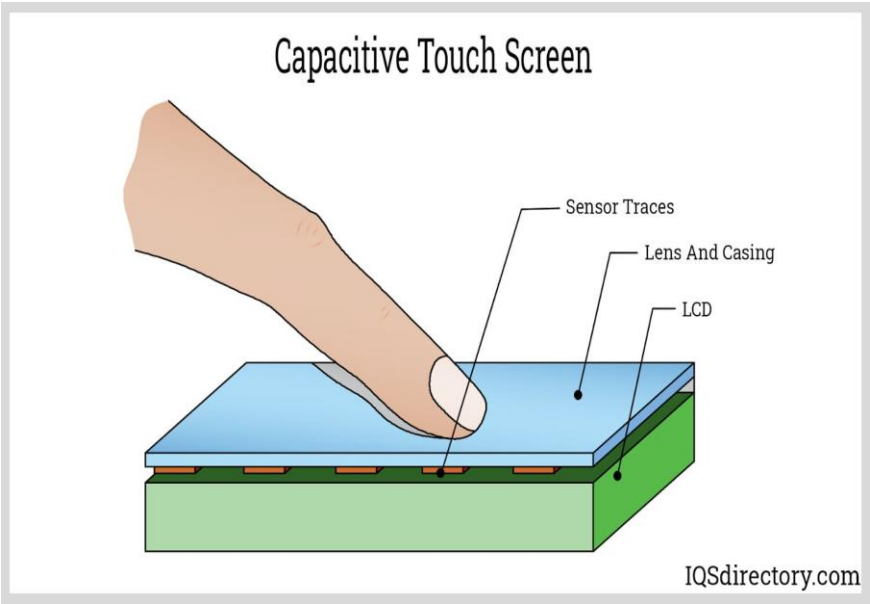
CUSTOMER PRODUCT INTERACTION FLOW



State of the Art

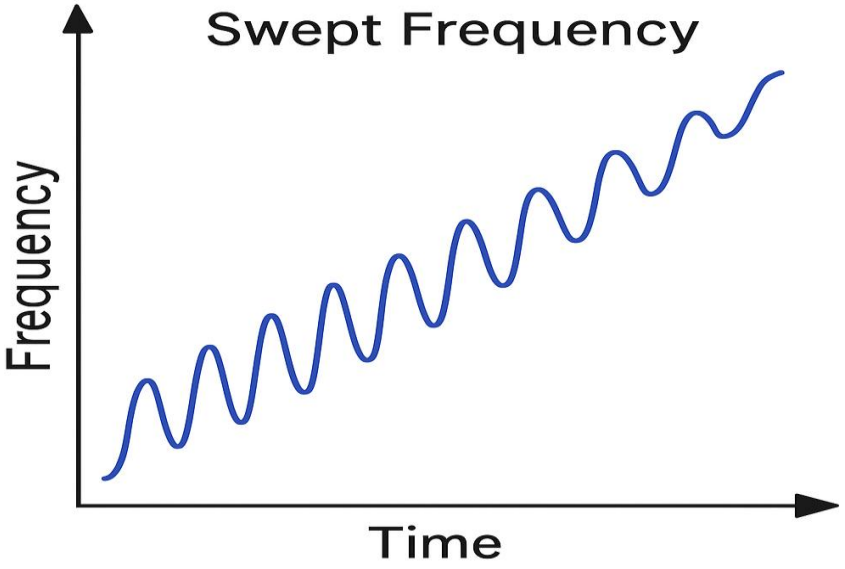
CAPACITIVE SENSING

- Capacitive sensing detects touch by measuring changes in an electric field
- It uses different frequencies to understand how the object interacts under various conditions.



SWEPT FREQUENCY

- Swept frequency involves over time continuously varying the frequency of a signal within a specific range.
- It is utilized in applications such as on-body gesture sensing.



SWEPT FREQUENCY

$$x(t) = A \cdot \sin\left(2\pi \cdot \left(f_0 t + \frac{k}{2} t^2\right)\right)$$

Where:

$x(t)$ = the signal at time t

A = amplitude (constant or variable)

f_0 = starting frequency in Hz

k = sweep rate in Hz/sec (how fast frequency increases)

t = time in seconds

sweeping from frequency f_0 to f_1 over time T, then:

$$k = \frac{f_1 - f_0}{T}$$

Start freq: $f_0 = 100$ Hz

End freq: $f_1 = 1000$ Hz

Sweep time: $T = 5$ seconds

Types of Capacitive Sensing

Traditional Capacitive Sensing – Works with a fixed frequency to detect touch.

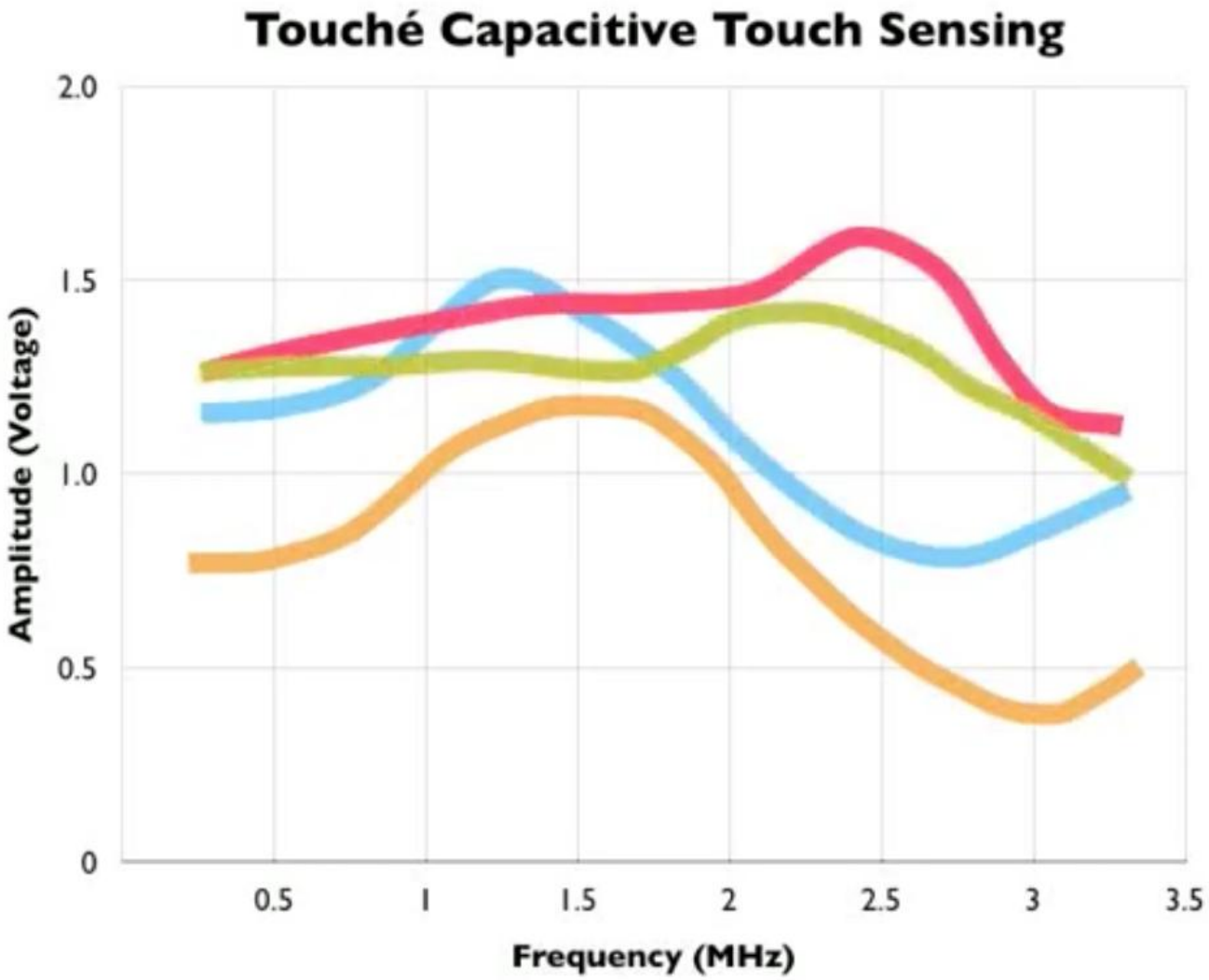
Examples :- Touchscreens and Touch Buttons

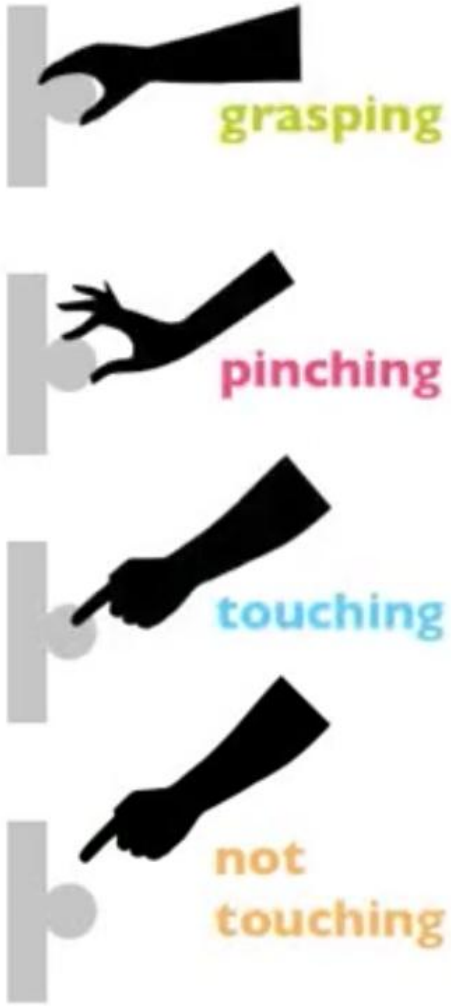
Swept Frequency Capacitive Sensing (SFCS) – Uses a wider range of frequencies for more detailed and accurate detection.

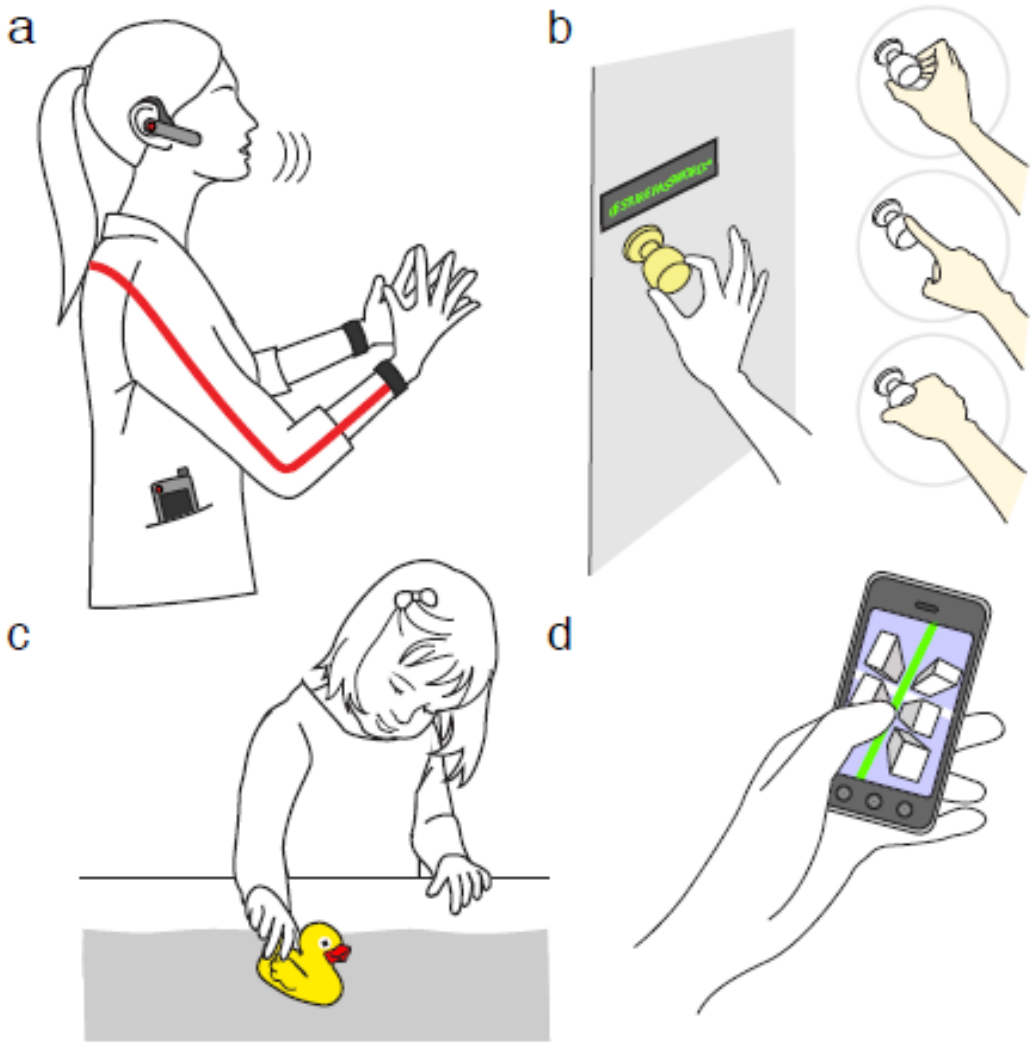
Examples : - Advanced Gesture Recognition and Liquid Level Detection

APPLICATIONS OF SWEPT FREQUENCY SENSING

1. Everyday Objects:	2. Liquid Interaction:	3. Human Interaction:
Smart doorknobs that respond to gestures like grasping or pinching.	Detecting touches on water surfaces or fingers dipped into water.	Detecting body postures or gestures like hand placement.


Touché Capacitive Touch Sensing
Amplitude (Voltage)
2.0
1.5
1.0
0.5
0
0.5
1
1.5
2
2.5
3
3.5
Frequency (MHz)


grasping
pinching
touching
not
touching



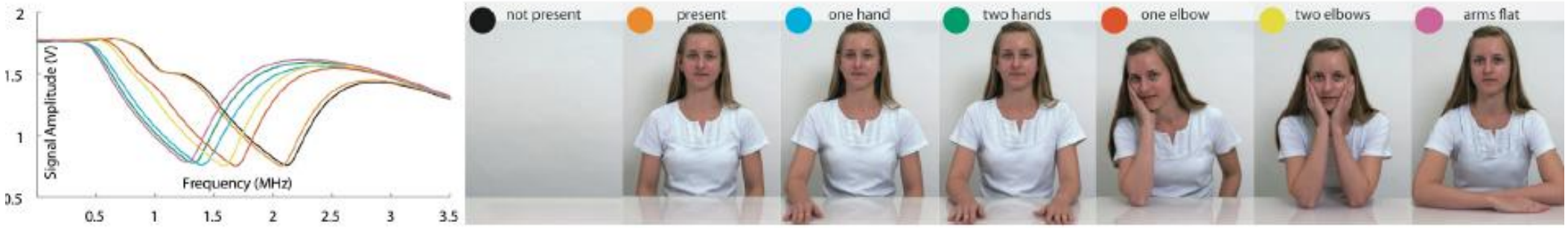
(a)on-body gesture sensing.

(b) a smart doorknob with a “gesture password”.

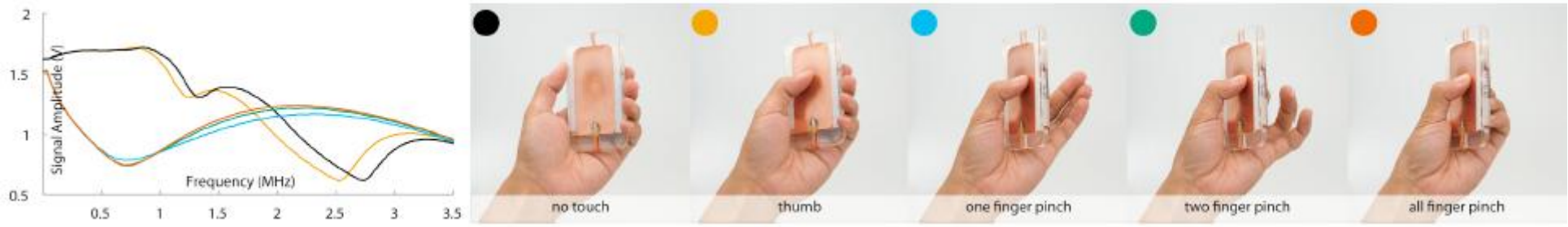
(c) Interacting with water.

(d) hand postures in touch screen interaction.

Capacitive profiles for making objects touch and grasp sensitive (doorknob example).



Capacitive profiles for sensing body postures (table examples).



Capacitive profiles for enhancing touchscreen interaction with a hand posture sensing.

Capacitive profiles for on-body Sensing with wrists-mounted Touch sensors.

Capacitive profiles for interacting with water.

Sensor Board Design and Components

Key Hardware Elements of Touché

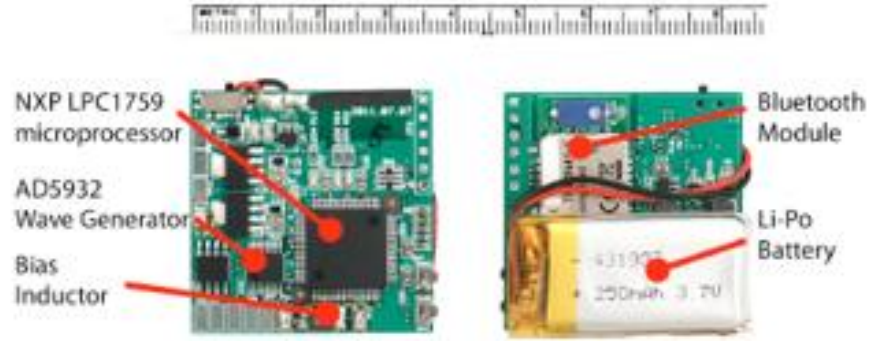


Figure 3: Touché sensing board: 36x36x5.5 mm, 13.8 grams.

ARM Cortex-M3 microprocessor

The ARM Cortex-M3 microprocessor serves as the computational backbone of the Touché technology, enabling rapid processing of sensor inputs for real-time interaction.

AD5932 wave generator

The AD5932 wave generator is integral to the functioning of Touché, providing high-frequency signals necessary for accurate capacitive measurements and profile generation.

Signal filtering and amplification

Effective filtering and amplification techniques are crucial for enhancing signal clarity and reliability, ensuring accurate detection of user interactions at varied levels.

Signal Processing Techniques

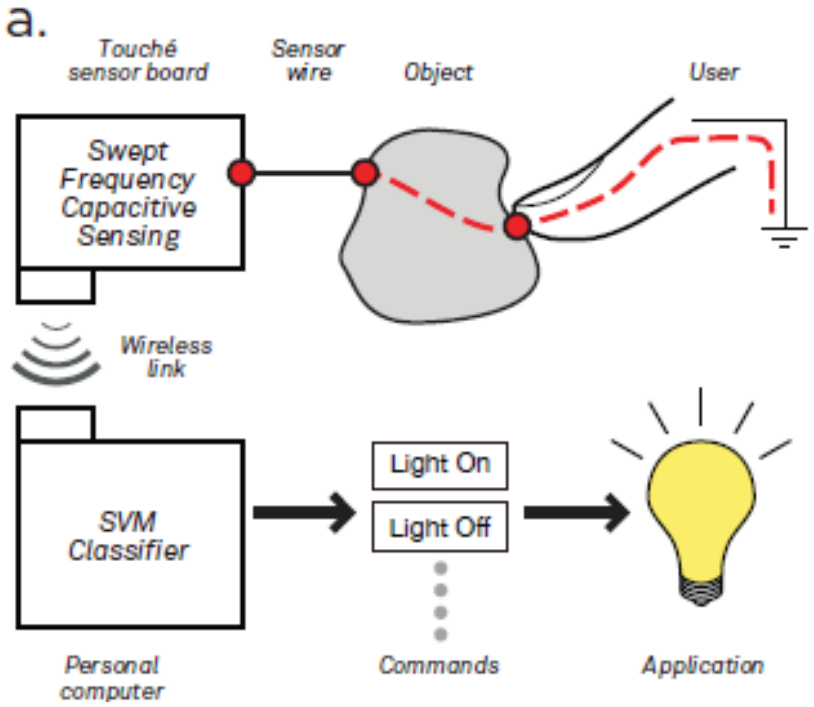
Robust Methods for Data Interpretation

Envelope detection
This technique aids in extracting meaningful signals from capacitance variations, enabling a clear understanding of user interactions and minimizing interference from noise.

Analog-to-digital conversion
Converting analog signals into digital format is vital for processing, ensuring that the Touché system can analyze, interpret, and react to user actions accurately.

Sampling rate limitations
Understanding the limitations of sampling rates is essential for optimizing the speed and accuracy of signal processing, informing design choices and system capabilities.

SYSTEM ARCHITECTURE & IMPLEMENTATION



- **User-Object Interaction :** Describes how the user touches a wired object either directly conductive or embedded with an electrode.

Touch Sensor Board : Compact board with ARM Cortex-M3 powering Swept Frequency Capacitive Sensing (SFCS).

- **Signal Processing :** Generates sinusoid sweeps and captures capacitive profiles based on signal return.

Capacitive Profiling : Current version omits phase shift data, only signal amplitude analyzed.

- **Gesture Recognition Pipeline :** Data sent via Bluetooth to a computer for classification and function triggering.

Touch Sensor Board Design

Hardware Configuration for High-Resolution Capacitive Sensing

- **Wave Synthesis:** AD5932 chip driven by ARM Cortex-M3 (NXP LPC1759) generates sinusoidal sweeps from 1 KHz to 3.5 MHz in 17.5 KHz steps.
- **Signal Conditioning:** Amplified to 6.6 Vpp, filtered to eliminate noise and high frequencies, then used to excite conductive object.
- **Biasing Techniques:** Uses 100 mH inductor for enhanced capacitive sensitivity; bias capacitor can be used for inductive sensing.
- **Signal Conversion & Sampling:** Return signal converted via sensing resistor, buffered, and envelope detected to DC. Sampled at 200 KHz by 12-bit ADC.
- **Speed Constraints:** 33 Hz standard update rate; high-frequency-only sweeps boost rate to ~100 Hz due to ADC speed limitations.

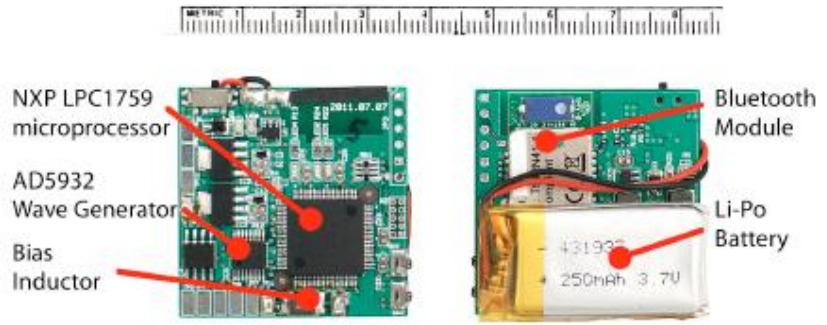


Figure 3: Touché sensing board: 36x36x5.5 mm, 13.8 grams.

Making Objects Touch and Grasp Sensitive

- **Touch Sensing Technology:**

Lightweight, non-invasive approach that easily adds touch and gesture sensitivity to everyday objects.

- **Smart Door Knob Example:**
- Grasp tightly → Locks the door
- Pinch grip → Sets an away message ("back in five minutes")
- Sequence of grasps → Acts as a "grasp password" to unlock the door
- **Single-Wire Instrumentation:**

Existing conductive structures (e.g., brass doorknobs) can serve as electrodes.

Touche connects with **a single wire**, unlike traditional sensor matrices.

Capacitive profiles for making objects touch and grasp sensitive (doorknob example).

On-Body Gesture Sensing

- **Touche Approach:**

Uses the body's natural conductivity to sense touch with **minimal hardware** —no cameras, EMG, or complex wearables.

- **Wearable Configuration:**

One electrode (source/sink) worn like a **wristwatch**

Second electrode placed on **opposite wrist**, **waist**, **collar**, or **lower back**

- **Gesture Detection Mechanism:**

As users touch different body parts, **impedance changes** uniquely per gesture.

Touché captures this **capacitive profile** to recognize hand-to-hand gestures and touch locations.

Capacitive profiles for on-body Sensing with wrists-mounted Touch sensors.

Touch Study Cases

STUDY 1: MAKING OBJECTS TOUCH AND GRASP SENSITIVE

- - Real-time per-user accuracy: 96.7% (SD=5.6%)
- - Without circle gesture: 98.6% (SD=2.5%)
- - Walk-up accuracy: 76.8% (SD=9.2%)
- - Without circle gesture: 95.8% (SD=7.4%)

STUDY 2: BODY CONFIGURATION SENSING

- - Real-time accuracy (7 gestures): 92.6% (SD=9.4%)
- - Without 2 elbows: 96.0% (SD=6.1%)
- - Walk-up accuracy (7 gestures): 81.2%
- - With 5 gestures: 91.6% (SD=7.8%)
- - With 3 gestures: 100% (all participants)

STUDY 3: ENHANCING TOUCHSCREEN INTERACTION

- - Per-user accuracy (5 gestures): 93.3% (SD=6.2%)
- - Without 2 finger pinch: 97.7% (SD=2.6%)
- - Walk-up accuracy (5 gestures): 76.1% (SD=13.8%)
- - With 3 gestures: 100% (all participants)

STUDY 4: ON-BODY GESTURE SENSING

- - Per-user accuracy (5 gestures): 84.0% (SD=11.4%)
- - Without 1 finger: 94.0% (SD=7.4%)
- - Walk-up accuracy (5 gestures): 52.9% (SD=13.8%)
- - With 3 gestures: 87.1% (SD=12.5%)

STUDY 5: TOUCHING LIQUIDS

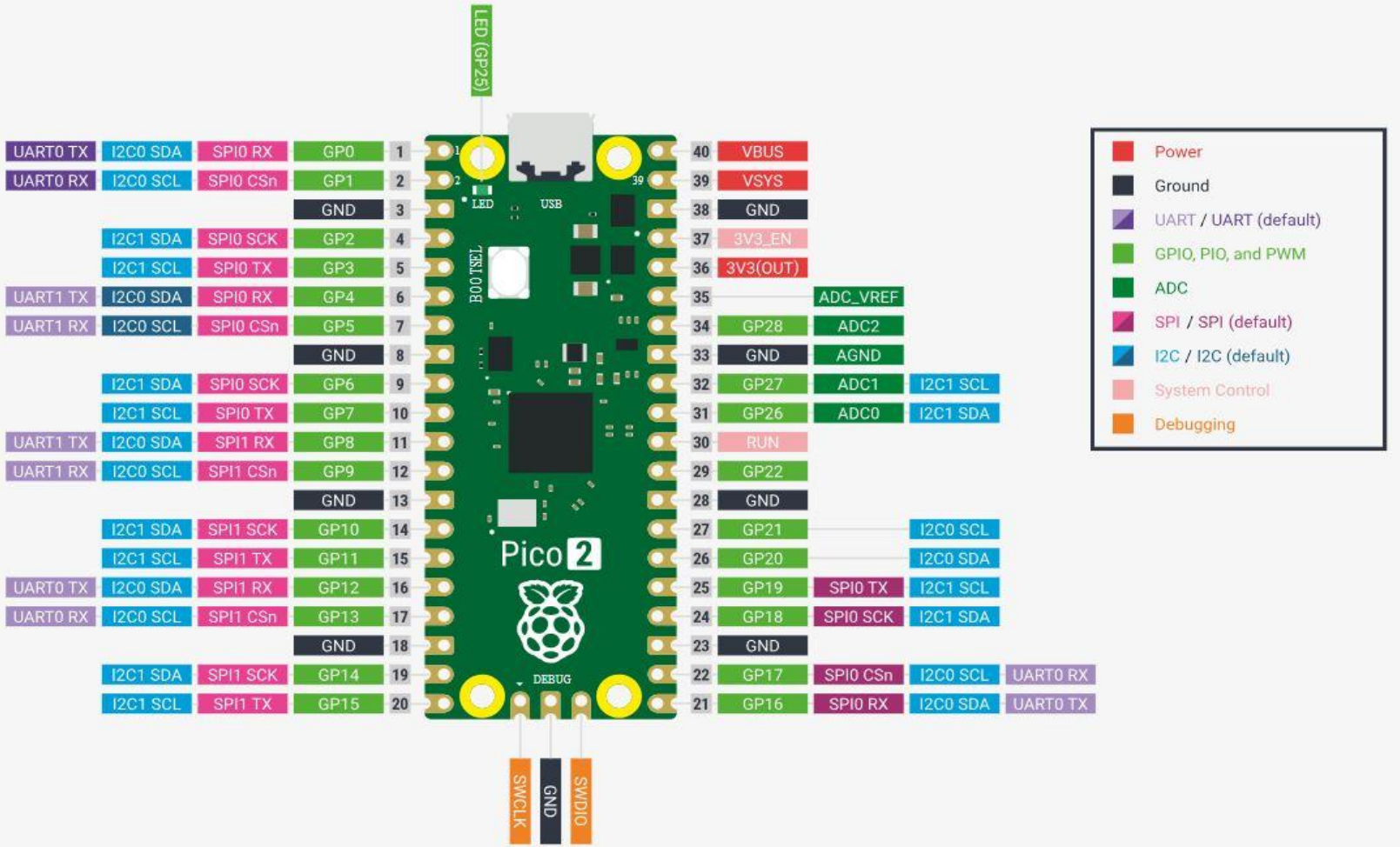
- - Per-user accuracy (5 gestures): 99.8% (SD=0.8%)
- - Walk-up accuracy (5 gestures): 99.3% (SD=1.4%)
- - Without 3 finger tips: 99.9%

Our Proposed Prototype Components used in smart shelf:

- **Raspberry pi Pico 2:**

Raspberry Pi Pico 2 is a low-cost, high-performance microcontroller board with flexible digital interfaces.

Pinout and design files

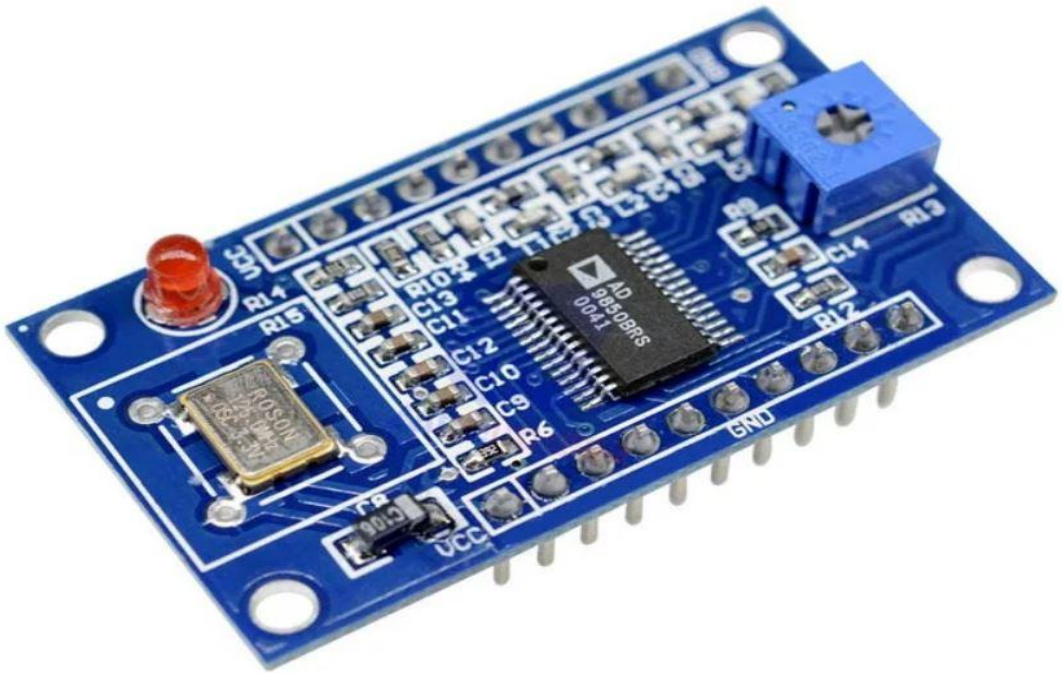


Key features include:

- RP2350 microcontroller chip designed by Raspberry Pi in the United Kingdom.
- Dual Cortex-M33 or Hazard3 processors at up to 150MHz
  520 KB of SRAM, and 4MB of on-board flash memory.
- USB 1.1 with device and host support
- 26× multi-function GPIO pins including 3 that can be used for ADC
- 2× SPI, 2× I2C, 2× UART, 3× 12-bit 500 ksps Analogue to Digital
- Temperature sensor

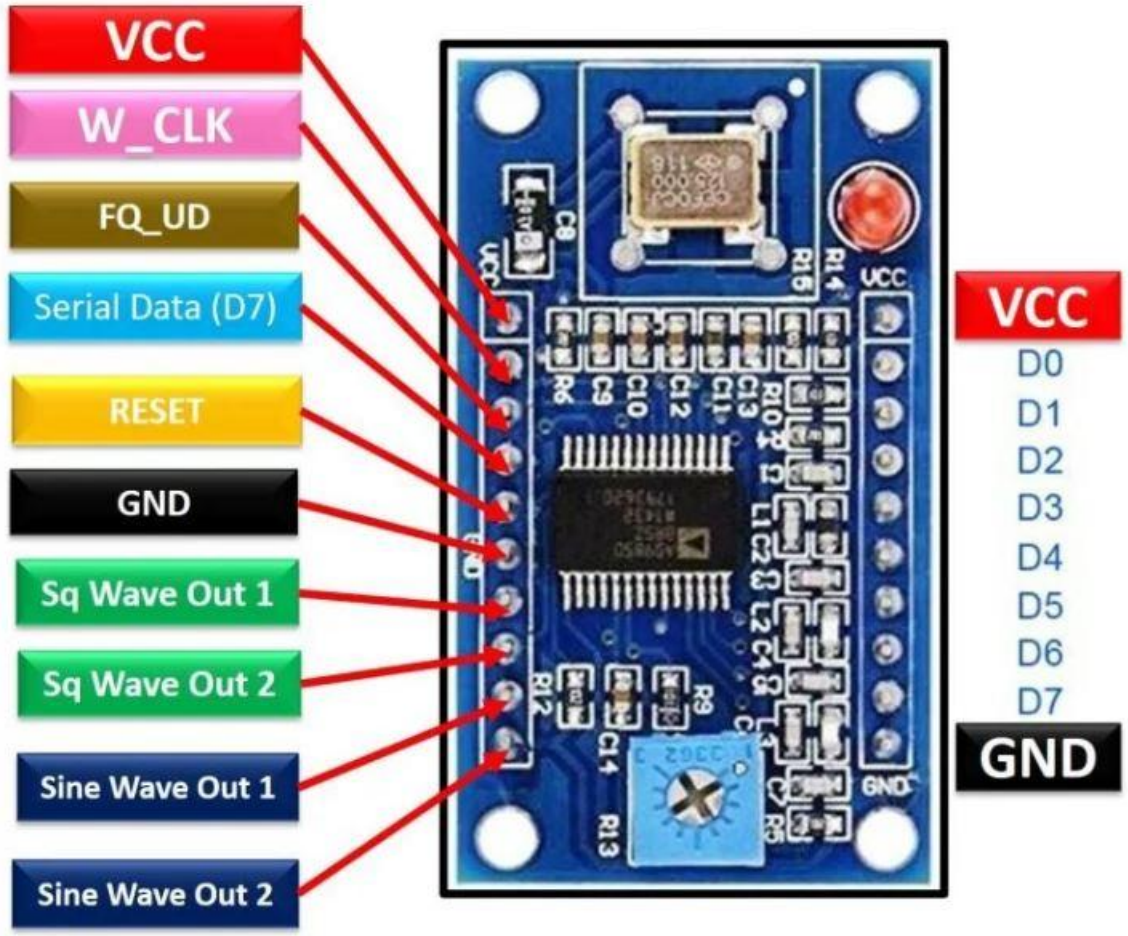
- **AD9850 DDS Signal Generator:**

AD9850 DDS Signal Generator Module is one of the small, low-cost boards to generate analog signals. This integrated board can be controlled through a microcontroller and can be digitally programmed using Direct Digital Synthesis Technology (DSS).



AD9850 Pinout

The following diagram shows the pinout of the AD9850 DDS Signal Generator Module:



Key features include:

- It contains a power-down function for a short boot time.
- Data transmission can either be parallel or serial.
- Power Dissipation depends on the power supply voltage.
- Four Analog signal outputs i.e., Sine-Wave 1, Sine-Wave 2, Square-Wave 1, and Square-Wave 2
- Direct Digital Synthesizer is based on CMOS Technology for better functionality and performance.
- A small high-performance module with a surface-mount package to be operated at industrial temperature

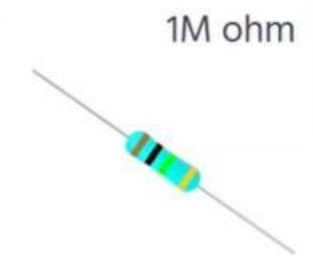
Applications of AD9850 Signal Generator:

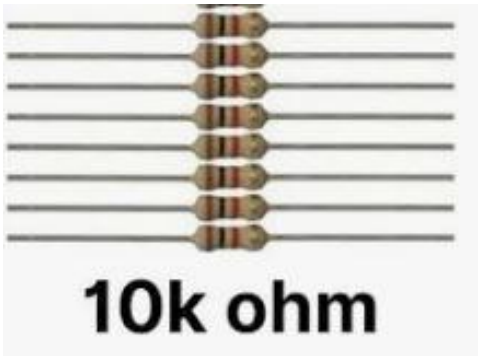
- Waveform Generator
- Communication systems
- Analog-to-Digital Converters

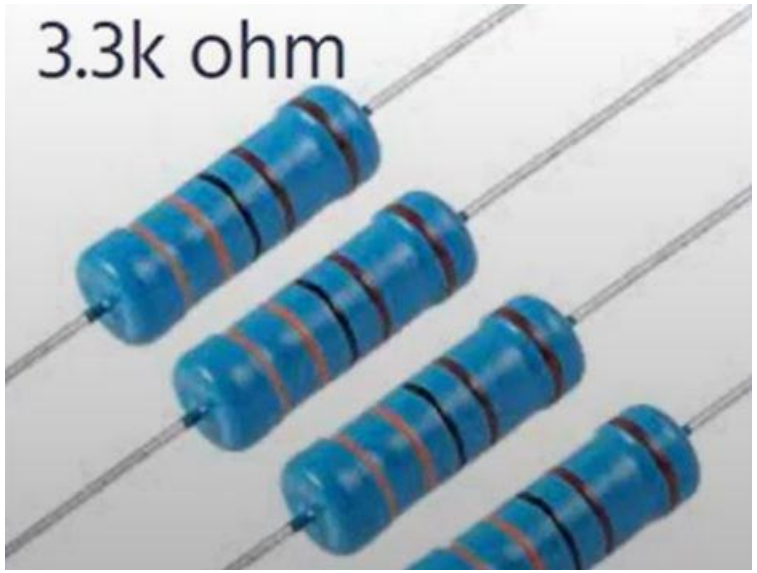
COMPONENTS REQUIRED TO CONNECT CIRCUIT DIAGRAM

❖ Register

- 10k ohm
- 1M ohm
- 3.3k ohm







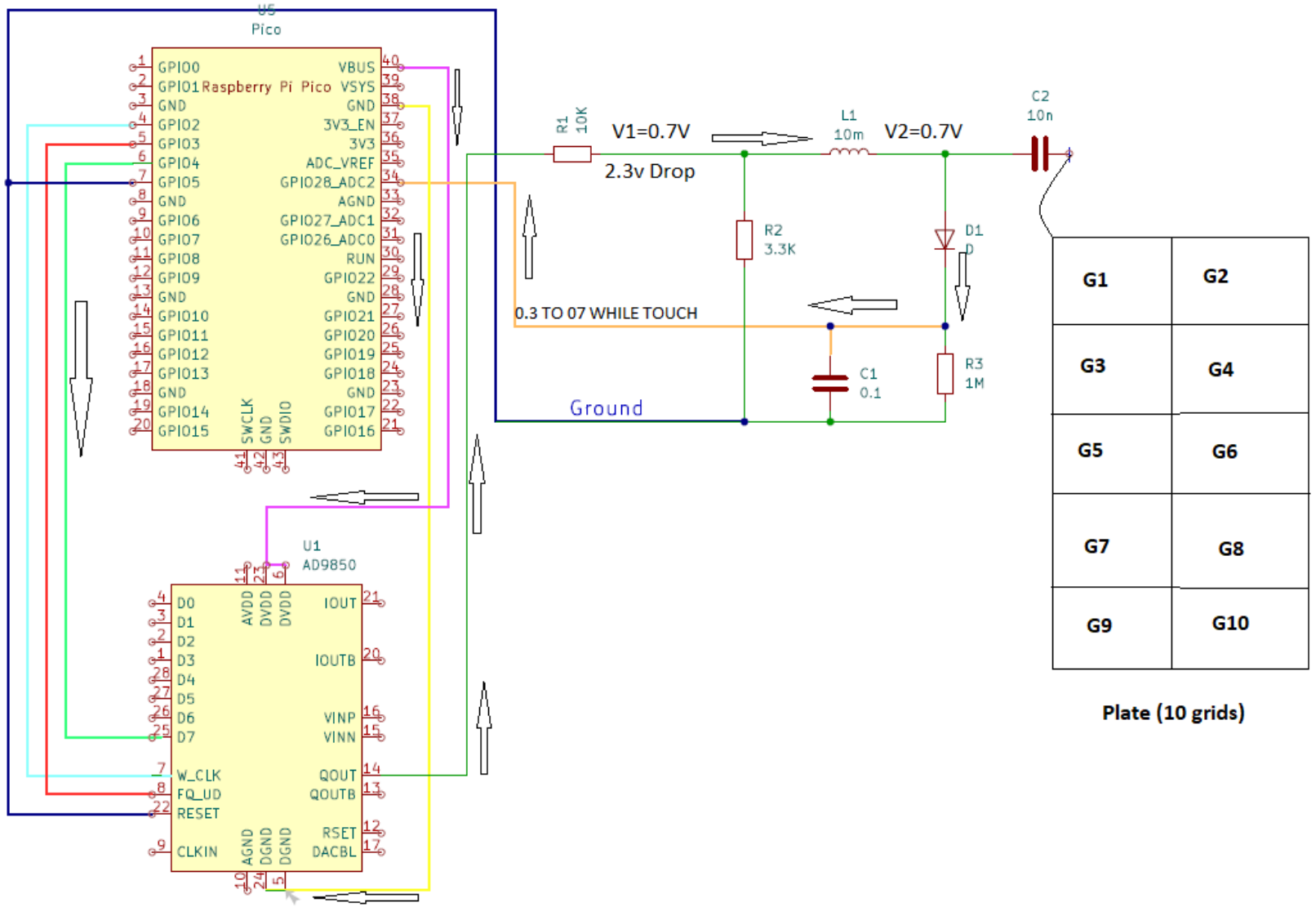
COMPONENTS REQUIRED TO CONNECT CIRCUIT DIAGRAM

- Capacitor: 100pf, 10nf
- Diode: 1N4148 diode
- Coil/inductor: 10mH

Connect to Hardware

Pico 2							AD9850						
PICO 2 Position	Pin	Functionality	Input/Output	What we're getting?	Connected to AD9850	Connected to CIRCUIT	AD9850 Position	Pin	Functionality	Input/Output	What we're getting?	Connected to PICO	Connected to CIRCUIT
4	GPIO 2	GPIO2 (Digital I/O)	Output	W_CLK Signal	W_CLK		7	W_CLK	Word Clock Input	Input	Clocks in each bit (serial) or byte (parallel)	GPIO2	
5	GPIO 3	GPIO3 (Digital I/O)	Output	Frequency Update Pulse	FQ_UD		8	FQ_UD	Frequency Update	Input	Updates the frequency output	GPIO3	
6	GPIO 4	GPIO4 (Digital I/O)	Output	Serial Data	D7		25	D7	Serial Data Input	Input	Receives serial data (bit stream)	GPIO4	
7	GPIO 5	GPIO5 (Digital I/O)	Output	Reset Pulse	RESET	GND	22	RESET	Reset Input	Input	Resets internal registers	GPIO5	GND
34	ADC2		Input	Decoupling Capacitor		C2 0.1nF							
38	GND	Ground		Ground Reference	DGND		5	DGND	Digital Ground		Ground	GND	
40	VBUS	5V Supply	Output	Power Supply	DVDD		23	DVDD	Digital VDD	Input	Power (3.3V typical)	VBUS	
							14	QOUT/SQUARE WAVE	Square wave	Output	Sending Square wave		R1 10k

Circuit Diagram



How the System Works

1. Signal Generation (AD9850 Module):

❖ The AD9850 generates a square wave which is fed to the touch plate.

❖ It is controlled via 4 GPIO pins of the Pico:

- GPIO2 (W_CLK) – Word Clock Input
- GPIO3 (FQ_UD) – Frequency Update
- GPIO4 (D7) – Serial Data Input
- GPIO5 (RESET) – Resets AD9850

❖ The output square wave (pin 14, QOUT) is sent through the conditioning circuit to the touch plate.

2. Signal Conditioning:

❖ The square wave passes through a filtering network:

- R1 (10k) limits current.
- C2 (40nF), C1 (0.1μF), and R2 (3.3k) smooth the signal.
- D1 provides clamping to avoid overvoltage.
- L1 (inductor) helps suppress noise or smooth spikes.

3. Touch Detection:

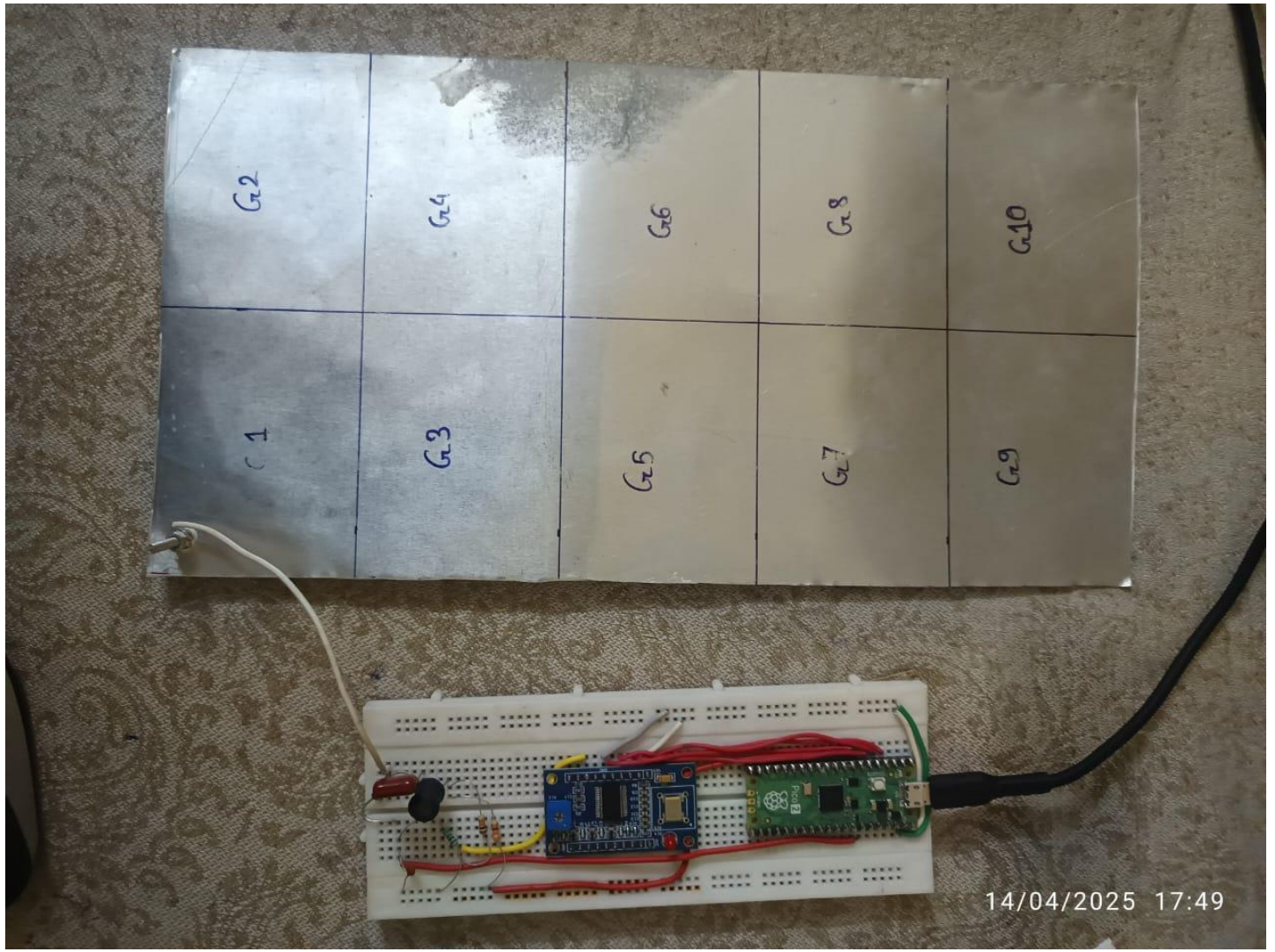
❖ The touch plate is connected to this circuit.

❖ When a human touches a grid (G1–G10), capacitance changes, which causes a voltage drop on the signal line.

❖ The Pico reads this voltage via ADC2 (GPIO 28).

❖ Touch leads to a voltage drop at R1 (10k) from 2.3V to 0.3–0.7V.

Final circuit



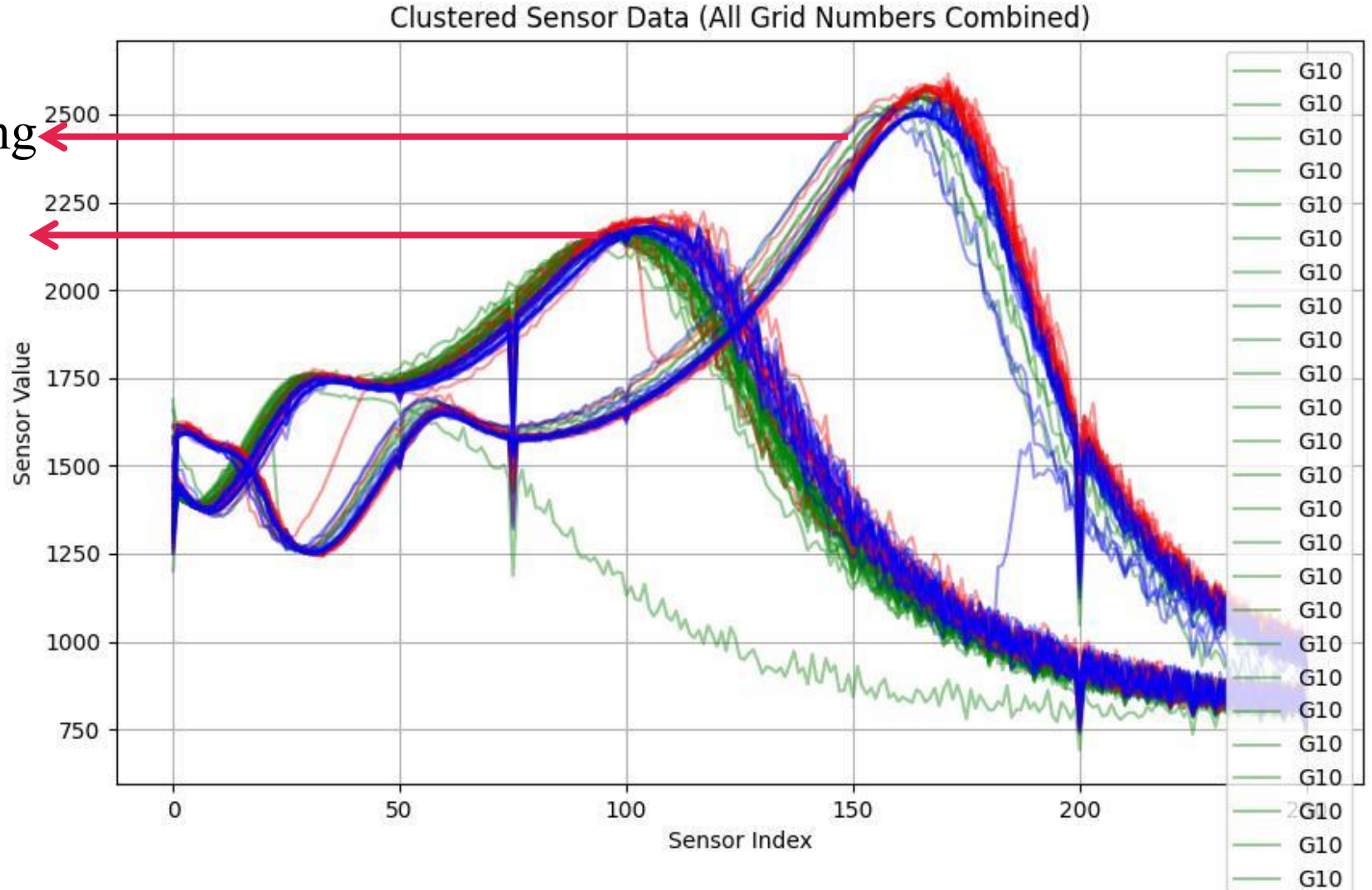
Serial Data Visualization

Timestamp	Grid No	User Name	Location	Scenario	Serial Data
12-04-2025 10:09	G1	Vinod	Hostel	On_woode	1576,1496,1550,1571,1607,1642,
12-04-2025 10:17	G2	Vinod	Hostel	On_woode	1465,1558,1539,1543,1859,1590,
12-04-2025 10:21	G3	Vinod	Hostel	On_woode	1713,1676,1613,1646,1667,1694,
12-04-2025 10:26	G4	Vinod	Hostel	On_woode	1471,1625,1631,1679,1720,1760,
12-04-2025 10:29	G5	Vinod	Hostel	On_woode	1653,1617,1596,1635,1611,1628,
12-04-2025 10:33	G6	Vinod	Hostel	On_woode	1577,1581,1578,1593,1554,1597,
12-04-2025 10:37	G7	Vinod	Hostel	On_woode	1555,1562,1553,1572,1668,1576,
12-04-2025 10:41	G8	Vinod	Hostel	On_woode	1756,1578,1564,1557,1607,1625,
12-04-2025 10:45	G9	Vinod	Hostel	On_woode	1557,1605,1636,1570,1590,1639,
12-04-2025 10:48	G10	Vinod	Hostel	On_woode	1532,1598,1551,1562,1610,1740,

Data visualization

Without Touching

While Touching



G2 Sensor data

G5 Sensor data

G10 Sensor data

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Thank you