
Supplementary information

Touch-sensing digital pixel fibre enables interactive garment GUI

In the format provided by the
authors and unedited

Supplementary Information

Touch-Sensing Digital Pixel Fibre Enables Interactive Garment GUI

Heng Fu^{1#}, Ziang Li^{1#}, Swetika Chaturvedi¹, Xiaoyu Zhang¹, Xiaolong Li¹, Qianyi Li¹, Tural Khudiyev^{1*}

¹Department of Materials Science & Engineering, National University of Singapore, 9 Engineering Drive 1, 117574, Singapore

*E-mail: khudiyev@nus.edu.sg

#These authors contributed equally to this work.

The PDF file includes:

Supplementary Texts 1-6

Supplementary Figures 1-34

Supplementary Tables 1-2

Supplementary Videos 1-6

Supplementary Text 1 | CAI approach description

Planar microchip pad layouts are not naturally compatible with axially symmetric fibres, because microchip connectorization typically requires spatially defined interconnects that preserve the original pad geometry. In the CAI strategy (Supplementary Fig. 1), programmable interconnection is achieved by guiding multiple insulated microwires along a common propagation axis aligned with the chip-pad columns (C1, C2, C3, etc.). Each wire remains electrically isolated when its insulation is intact, but becomes electrically active when a programmed de-insulation window exposes the underlying copper. During solder reflow, molten solder selectively wets the exposed copper region. By contrast, the insulated wire surface is not wetted by the solder and is therefore excluded from the solder joint owing to interfacial-energy considerations and selective wetting. As a result, electrical connection forms only at the programmed de-insulated site.

This selective wire-activation mechanism is critical because it allows different micropads located in different rows (R1, R2, R3, etc.) along the same column to be independently interconnected, even when multiple wires pass over the same chip-pad region. The number of wires that can pass through a given column is determined by the pad width relative to the total width of the wire bundle. In principle, this layout can also be extended to multilayer interconnection, because exposed wire regions can form solder joints with target micropads regardless of their vertical stacking position. By preserving the original microchip pad layout while using intrinsically scalable process steps, the CAI strategy enables connectorization of thousands of microelectronic components along a one-dimensional fibre axis.

Supplementary Text 2 | Trimming strategies for scalable CAI manufacturing

Laser trimming was employed in this work because it provides a convenient and highly precise method for defining the final CAI circuit topology during prototyping. However, this step is not intrinsic to the CAI architecture. Since the trimming operation only requires selective severing of redundant wire segments, it can also be implemented using lower-cost mechanical cutting approaches, such as CNC-assisted blade cutting or customized punch-cutting tools. Such methods are compatible with batch manufacturing and could further reduce equipment cost and energy consumption in future large-scale production.

Supplementary Text 3 | Multitouch on single pixel fibre

By connecting two sets of voltage-dividing sensing circuits to both ends of the sensing layer and employing asymmetric driving, two-point touch detection can be achieved on a single pixel fibre (Supplementary Video 3). The principle of asymmetric driving based on dual-end connection is as follows:

The circuit schematic for the dual-end connection is presented in Supplementary Fig. 12. The two blue lines represent the top and bottom CPE layers of the pixel fibre sensing part. The left and right ends of the top layer are connected to two GPIOs (GPIO_L and GPIO_R) of the Sensing MCU. The two ends of the bottom layer are grounded through 1 Mohm resistors (R_f) and simultaneously connected to the ADC inputs of the Sensing MCU to capture the sensing voltage signals (V_L and V_R).

In the default initial state, the system uses GPIO_L to provide a 3.3 V reference voltage for sensing, while GPIO_R is set to a high-impedance (floating) state. For a single-point touch at position x (where $0 < x < 1$), the sensing layer is divided into two segments. For the bottom layer, the left-side resistance is $R_1 = x \cdot R_{total}$ and the right-side resistance is $R_2 = (1 - x) \cdot R_{total}$, where R_{total} is the total resistance of the bottom sensing layer. Letting V_p represent the potential at the contact point, we can derive expressions for V_L and V_R relative to V_p based on the voltage-dividing principle.

$$V_L = V_p \cdot \frac{R_f}{R_1 + R_f} \quad (S1)$$

$$V_R = V_p \cdot \frac{R_f}{R_2 + R_f} \quad (S2)$$

By rearranging these equations to eliminate V_p , we obtain an expression for the touch position x in terms of V_L and V_R :

$$x = \frac{R_{total} \cdot V_R + R_f(V_R - V_L)}{R_f(V_R + V_L)} \quad (S3)$$

During a single-point touch, the relationship between V_L and V_R is monotonic. For instance, if x is near the left side, V_L must be significantly greater than V_R . A scenario where both V_L and V_R become simultaneously large is physically impossible in a single-point-touch circuit because the resistance of the middle segment limits the current. This "dual-high" phenomenon is a characteristic signature of a two-point touch. Accordingly, we define a feature factor $\gamma = 1/V_L + 1/V_R$. When a two-point touch occurs, the value of γ decreases significantly, prompting the system to execute asymmetric driving sensing. While the default state is left-side driving, the system immediately performs right-side driving upon detecting a change in γ . In this mode, GPIO_L is set to floating, GPIO_R is set to 3.3 V, and the ADC captures the readings V_{L2} and V_{R2} .

For the left-side drive, the voltage of the left contact point V_{p1} can be expressed by V_{L1} :

$$V_{p1} = V_{L1}(1 + x_1k) \quad (S4)$$

Where $k = R_{total}/R_f$.

Applying Kirchhoff's Voltage Law (KVL), the voltage drops between V_{p1} and V_{R1} is generated by the current flowing through the middle and right sections:

$$V_{L1}(1 + x_1 k) - V_{R1} = \frac{V_{R1}}{R_f} \cdot (R_m + R_c) \quad (S5)$$

Rearranging, we get equation Suppl. Eq. 6:

$$x_1 \left(V_{L1} k + \frac{V_{R1} k}{2} \right) + x_2 \left(\frac{V_{R1} k}{2} \right) = V_{R1}(1 + k) - V_{L1} \quad (S6)$$

Similarly, for the right-side drive, Suppl. Eq. 7 is obtained using V_{L2} and V_{R2} .

$$x_1 \left(\frac{V_{L2} k}{2} \right) + x_2 \left(V_{R2} k + \frac{V_{L2} k}{2} \right) = V_{R2}(1 + k) - V_{L2} \quad (S7)$$

These two equations can be transformed into a standard matrix form:

$$\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} \quad (S8)$$

Where the coefficients (A_{11} , A_{12} , A_{21} , A_{22}) and constants (B_1 , B_2) are determined by the observed ADC values and known system parameters:

$$A_{11} = k \left(V_{L1} + \frac{V_{R1}}{2} \right) \quad (S9)$$

$$A_{12} = \frac{V_{R1} k}{2} \quad (S10)$$

$$A_{21} = \frac{V_{L2} k}{2} \quad (S11)$$

$$A_{22} = k \left(V_{R2} + \frac{V_{L2}}{2} \right) \quad (S12)$$

$$B_1 = V_{R1}(1 + k) - V_{L1} \quad (S13)$$

$$B_2 = V_{R2}(1 + k) - V_{L2} \quad (S14)$$

By applying Cramer's Rule, the two distinct touch positions x_1 and x_2 can be directly calculated:

$$x_1 = \frac{B_1 A_{22} - B_2 A_{12}}{A_{11} A_{22} - A_{12} A_{21}} \quad (S15)$$

$$x_2 = \frac{A_{11} B_2 - A_{21} B_1}{A_{11} A_{22} - A_{12} A_{21}} \quad (S16)$$

In brief, multi-touch detection on an individual pixel fibre can be achieved simply by connecting both ends of the fibre to the ADC inputs of the Sensing MCU. A single ESP32-U4WDH chip features 18 independent ADC channels, which is entirely sufficient to support independent multi-touch sensing for each group of 9-pixel fibres.

Supplementary Text 4 | Textile-derived and architectural advantages of the Garment GUI

Our work explores a textile-compatible display form factor designed to provide a display and user-interaction experience analogous to that of state-of-the-art commercial flexible display technologies (e.g., Samsung Galaxy Z Fold6, Huawei Mate X5, TCL CSOT, and Visionox), while maintaining the breathability, flexibility, and wearability of textiles.

The distinguishing features of the Garment GUI can be broadly categorized into fundamental textile-derived properties and architecture-enabled technological benefits.

Breathability, Permeability, and Thermoregulation: Both the Garment GUI and commercial flexible displays inevitably generate heat during operation, which tends to accumulate within clothing. Our textile system consists of discrete fibrous networks that form porous voids during interweaving, enabling efficient air and moisture transport and facilitating heat dissipation. As a result, thermal gradients arising from heat accumulation can be effectively mitigated. These porous pathways inherently provide excellent breathability and permeability, which are particularly beneficial during perspiration by helping maintain a favourable skin microenvironment and long-term wearer comfort. In contrast, replacing these fibrous structures with continuous planar electronic films would substantially reduce porosity, impede heat and moisture transport, and promote heat accumulation, potentially causing hardware degradation or, worse, latent risks to human health during prolonged wear.

Mechanical Compliance: The bending rigidity of the individual fibres (Supplementary Fig. 8) and the flexural rigidity of the integrated fabric (Supplementary Fig. 18) demonstrate that the fibre-based Garment GUI possesses textile-like mechanical compliance. Furthermore, Figs. 2e and f show that the pixel fibres can undergo multi-angle bending with radii as small as 1 mm. Such multidirectional deformability remains unattainable in conventional planar flexible display technologies. This high degree of compliance is critical for body conformability, wearer comfort, and seamless integration into garments subjected to continuous deformation during use.

Washability: Wearable textile systems must withstand repeated laundering throughout their service lifetime. We therefore evaluated the Garment GUI under detergent-based washing conditions and observed stable operation after 50 washing cycles. This washability is enabled by the fibre-integrated architecture, in which microelectronic components are embedded within fibres and protected by waterproof polymer cladding, while the resulting textile retains its structural integrity during laundering. Although some commercial flexible displays provide water resistance against incidental exposure, they are not designed to tolerate repeated washing processes involving detergent, agitation, and cyclic mechanical loading. The demonstrated washability establishes the compatibility of the architecture with a key operational requirement of textile systems, namely repeated laundering throughout the wearable lifetime.

Serviceability: Current commercial planar flexible display technologies, including those from Samsung (Dynamic AMOLED), TCL CSOT, and Visionox, are based on monolithic device architectures. As a result, localized failures typically necessitate replacement of the entire display module. In contrast, our 1D-to-2D textile architecture is intrinsically modular, allowing defective fibres to be individually identified, removed, and replaced. This capability enhances serviceability and supports long-term operation of large-area wearable electronic systems by enabling localized repair and replacement without requiring reconstruction of the entire device architecture.

Supplementary Text 5 | Garment GUI mapping process from touch input to visual display

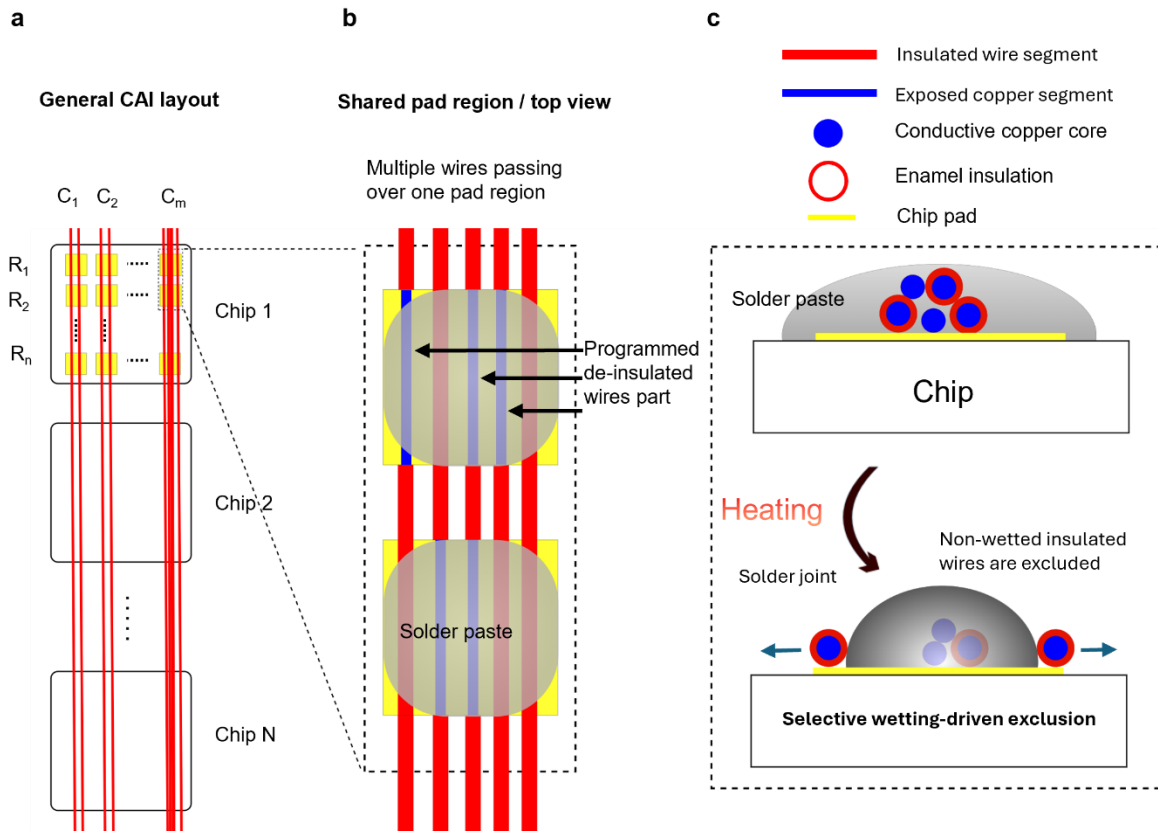
For the horizontal mapping, the ADC readings associated with touch events are converted into the corresponding resistance of the CPE pathway using the known voltage-divider setting. Because the LED chips are uniformly distributed along each pixel fibre, the independent variable axis in Fig. 3h can be equivalently expressed using an incrementing LED index value. This allows the derivation of a calibrated (approximately linear) mapping between the measured resistance and the LED index. For the transverse mapping, each pixel fibre is independently connected to the microcontroller, enabling a direct assignment between ADC sensing channels and LED display channels within the firmware.

Supplementary Text 6 | Maximum scaling limit of SW-RZ cascading structure

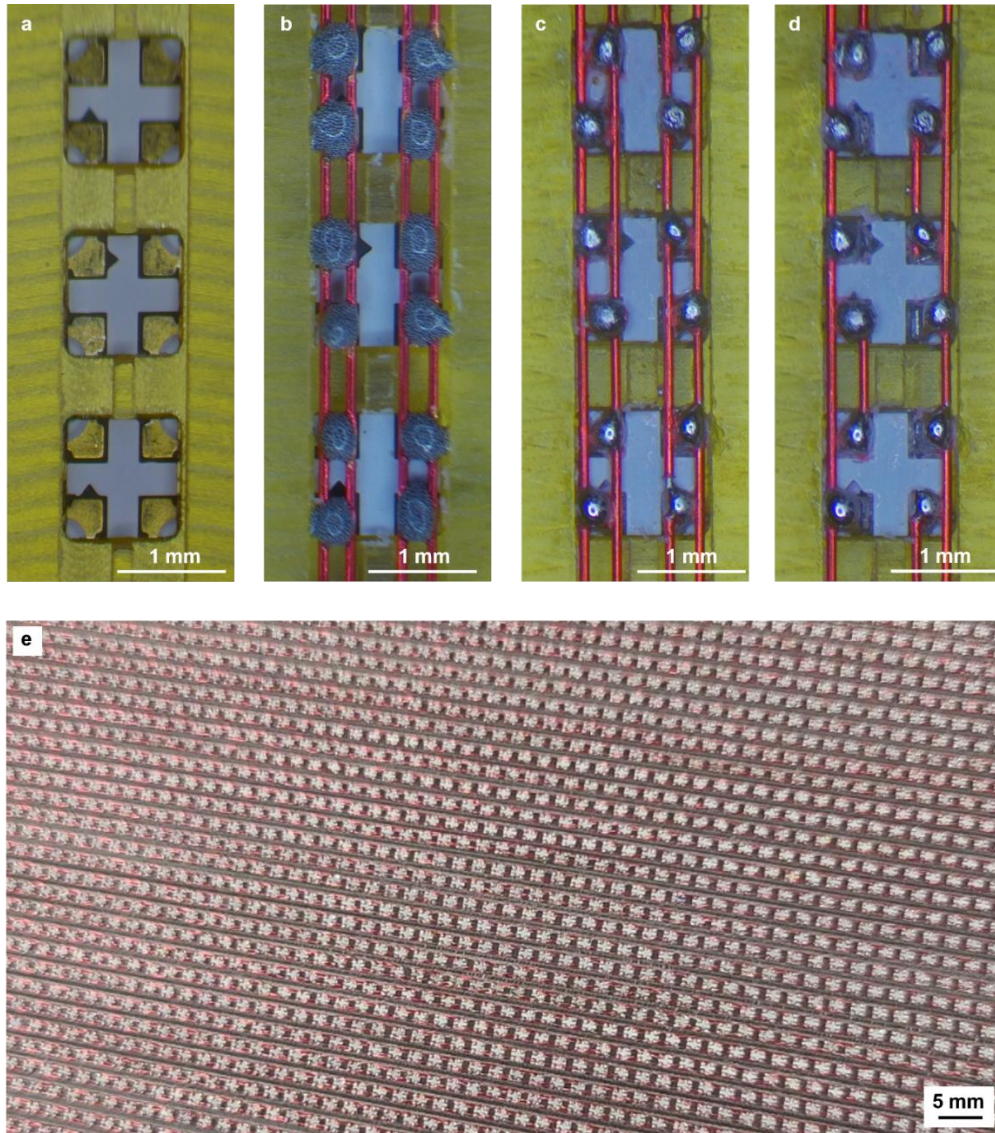
As the number of LEDs on a single data line increase, the total data volume required for each frame update grows proportionally. With the data transmission rate fixed at 800 kHz, the time required to transmit a full frame increases accordingly. To ensure fluid video playback at 30 fps, this transmission time must not exceed the frame interval of 33.3 ms. Notably, LEDs on a shared data line do not receive data simultaneously; instead, each LED intercepts its respective data before forwarding the remainder to the next unit. Our characterisation shows that this interception-forwarding process takes an average of 0.26 μ s per LED (Supplementary Fig. 28a). While seemingly instantaneous, this delay becomes non-negligible when a large number of LEDs are cascaded. Based on these parameters, the total time required for a single LED to receive its 24-bit signal (at 800 kHz, taking 30 μ s) and forward the rest is approximately 30.26 μ s. Consequently, cascading approximately 1,101 LEDs on a single data line reaches the 33.3 ms threshold for 30 fps video.

However, if the requirement for high-speed video playback is relaxed, the cascading limit is substantially higher. With up to 5,280 LEDs cascaded on a single data line, image could still be completely displayed. We also evaluated the encoding latency of the ESP32-U4WDH (the duration from the display command execution to the first LED illuminating) as a function of the number of cascaded LEDs. The results indicate that the encoding time remains stable, averaging only 7.33 ms even for 5,280 LEDs (Supplementary Fig. 28b). This underscores the robust computational capacity of the ESP32-U4WDH in supporting large-scale cascaded systems.

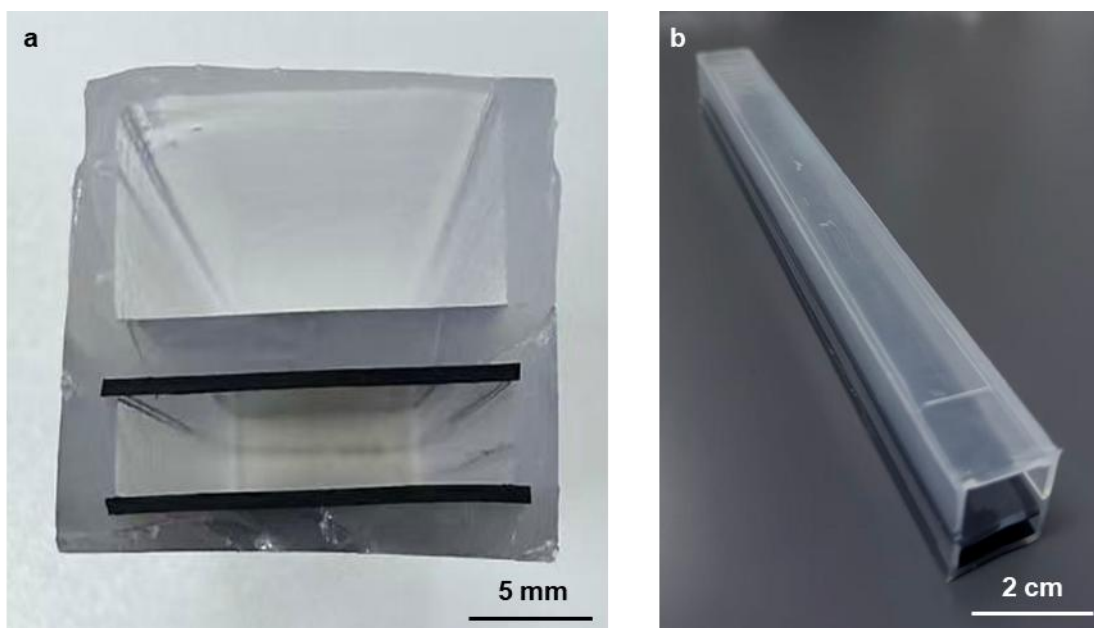
Based on the above analysis, the theoretical limit of the 800 kHz SW-RZ protocol is approximately 1,101 units for 30 fps video and exceeds 5,280 units for static or low-refresh displays. It is worth noting that the primary practical bottleneck for further cascading is the power delivery architecture. At a 159% LED-width pitch (1.75 mm), a 5,280-LED array requires a total power line length of approximately 9.24 m. The resulting cumulative resistance leads to significant voltage drops, which manifest as reduced luminance and chromatic aberration in the distal LEDs.



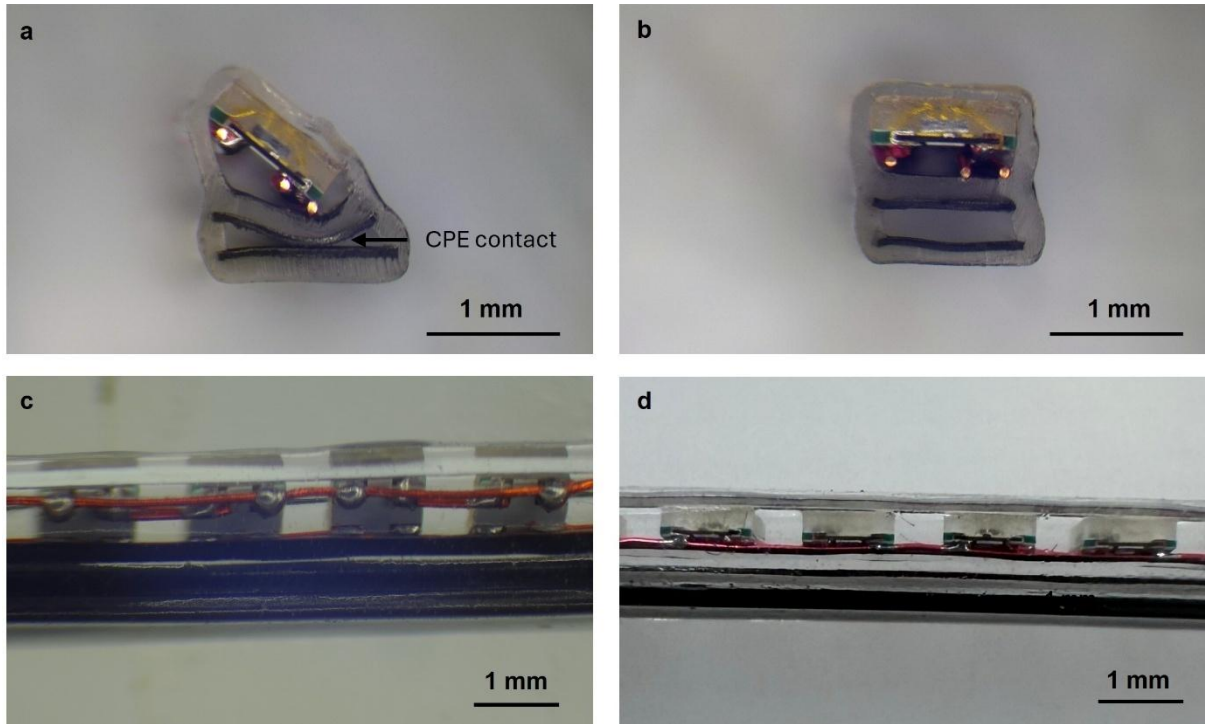
Supplementary Fig 1 | Generalized CAI approach for selective multi-wire interconnection on a shared chip pad. **a**, CAI layout in which multiple insulated microwires are guided along chip-pad columns ($C_1, C_2, \dots, C_m$) while preserving the original row-column pad geometry. **b**, Enlarged top-view schematic showing multiple wires passing over the same chip pad. Only the programmed de-insulated segments expose the copper core and form electrical connections, whereas neighbouring insulated segments remain isolated. **c**, Cross-sectional schematic of selective solder wetting during reflow. Molten solder wets the exposed copper segment to form a solder joint, while enamel-insulated segments are excluded by capillary-driven reflow. This pad-sharing mechanism enables scalable one-dimensional microchip connectorization.



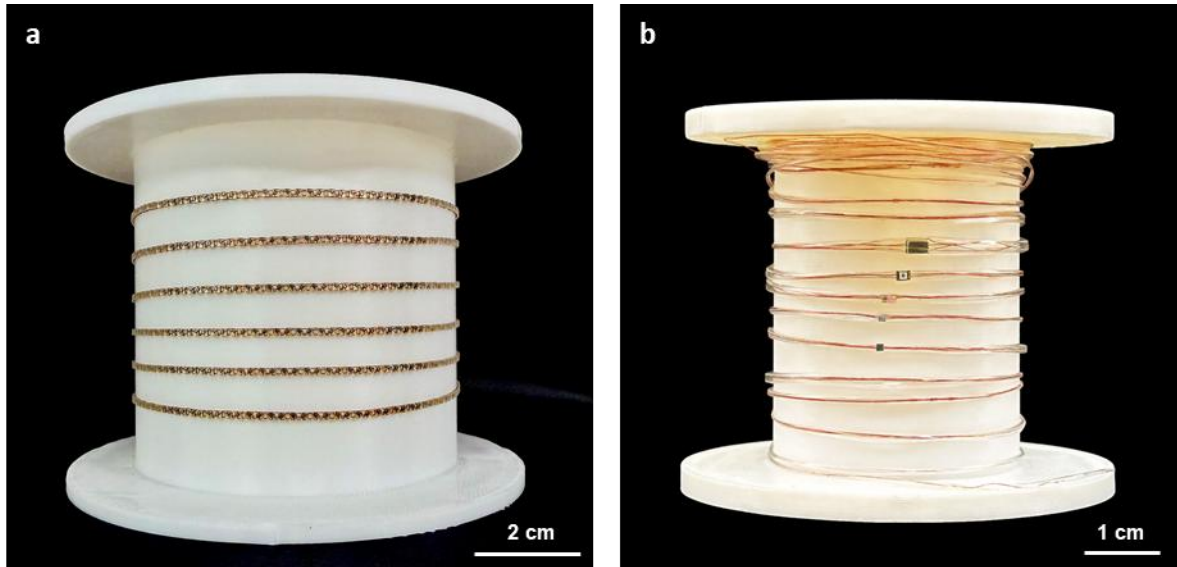
Supplementary Figure 2 | Demonstration of the CAI process. **a**, Placement of LED chips into the mould. **b**, Micro-dispensing of solder pastes onto the chip pads and placement of programmable de-insulated conductors. **c**, Reflow of the solder during heating to form electrical connections via wetting. **d**, Removal of excess wires after interconnection. **e**, Construction of the aligned pixel array from several thousand LEDs interconnected using the CAI approach.



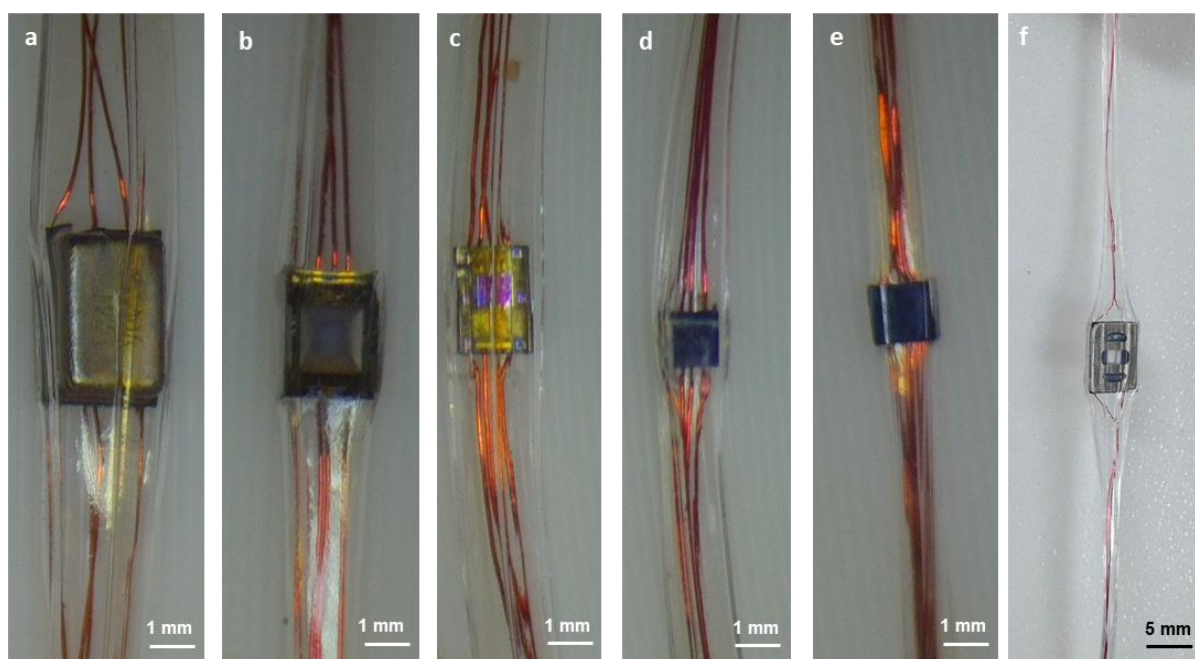
Supplementary Figure 3 | Preform structure for thermal drawing of pixel fibre. a, Cross-sectional view of the multimaterial preform. **b,** Photograph of the assembled preform ready for thermal drawing.



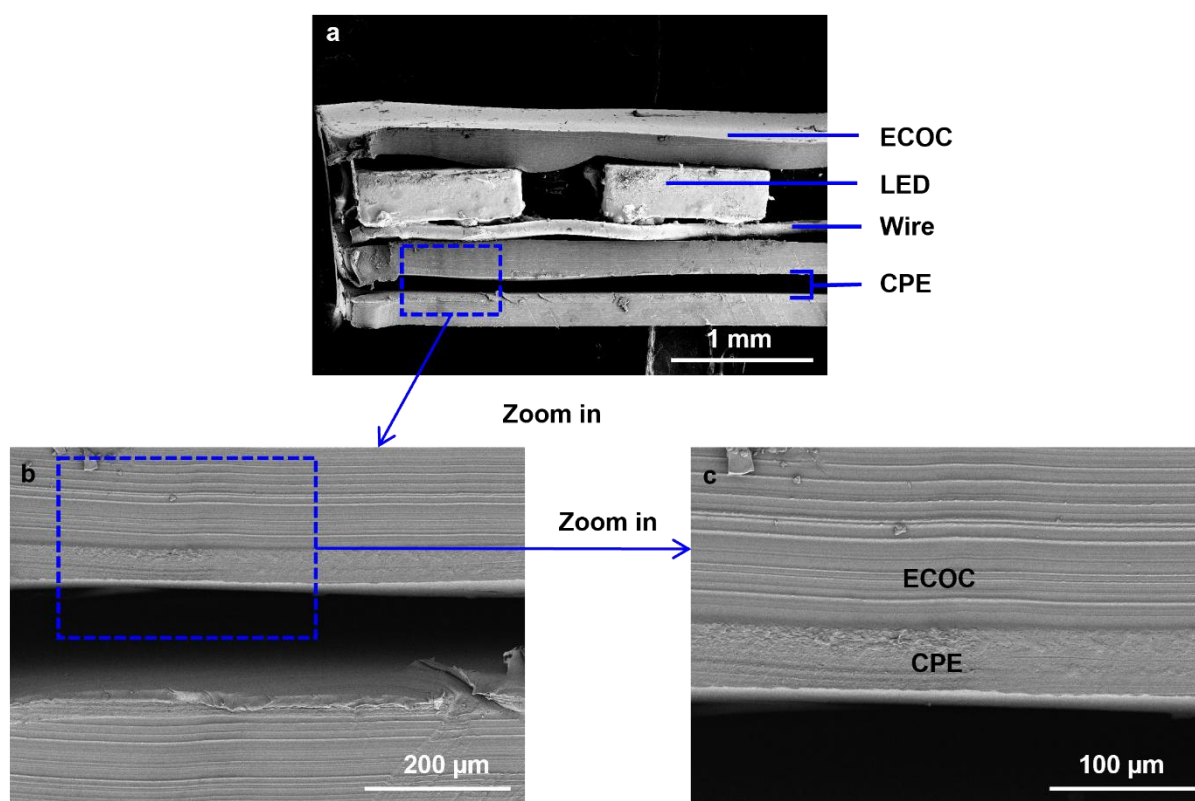
Supplementary Figure 4 | Fibre structure before and after alignment-funnel correction. **a**, Cross-sectional view of a pixel fibre before alignment, showing LED chip rotation and displacement during thermal drawing, which causes unintended contact of the CPE sensing layers. **b**, Cross-sectional view after passing through the alignment funnel, showing preserved chip orientation. **c**, Side-view image of the fibre before alignment. **d**, Side-view image of the fibre after alignment.



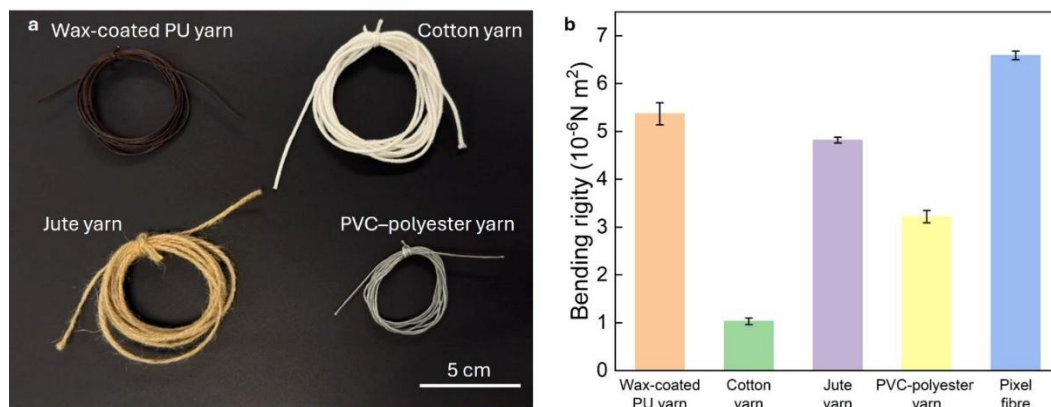
Supplementary Figure 5 | Spooling of long pixel and peripheral-fibre assemblies. **a**, One-metre-long continuous pixel strip, uniformly wound onto a storage spool. **b**, Peripheral fibre containing microelectronic sensor and actuator chips, wound onto a spool.



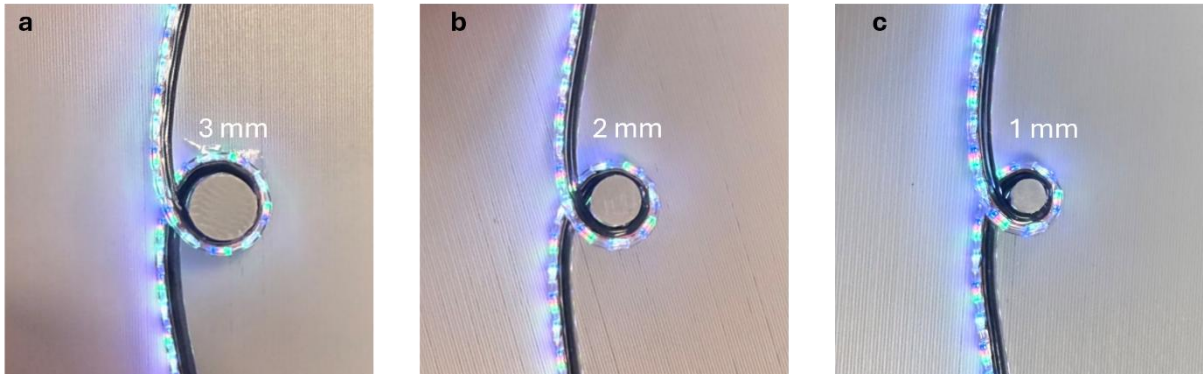
Supplementary Figure 6 | Optical micrographs of peripheral fibres. a, Microphone-integrated fibre (2 rows $\times$ 2 columns layout). **b,** Accelerometer-integrated fibre (3 $\times$ 2 layout). **c,** Ambient-light-sensor-integrated fibre (3 $\times$ 2 layout). **d,** Temperature-sensor-integrated fibre (2 $\times$ 2 layout). **e,** Magnetometer-integrated fibre (2 $\times$ 2 layout). **f,** Speaker-integrated fibre (2 $\times$ 1 layout).



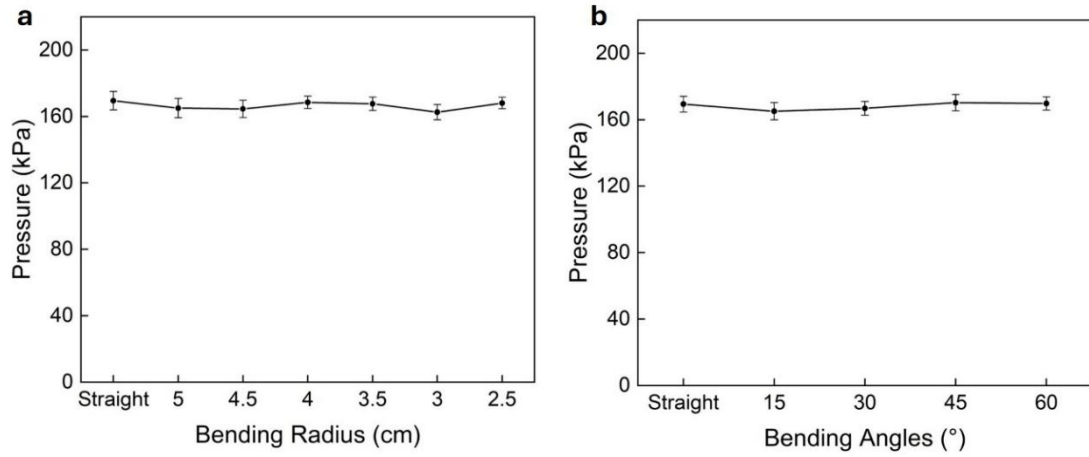
Supplementary Figure 7 | Side-view SEM images of the pixel fibre at increasing magnification. a, overview showing the LED chips, conductive wires, Elastic cyclic olefin copolymer (ECOC) cladding, and CPE sensing layer. **b,** higher-magnification side view highlighting the CPE sensing layer. **c,** high-magnification view of the ECOC–CPE interface.



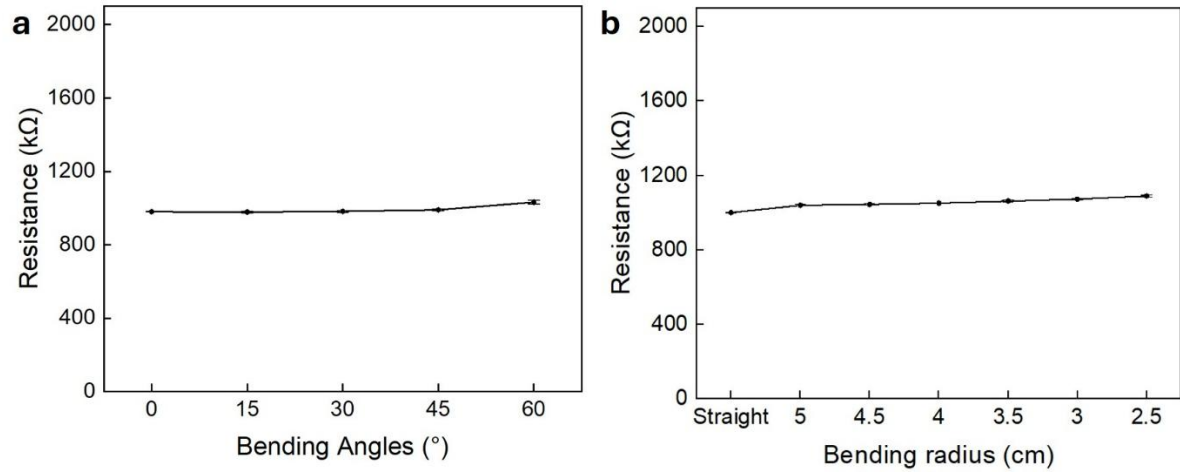
Supplementary Figure 8 | Comparison of bending rigidity between representative commercial yarns and the pixel fibre. a, Representative commercial yarns used for comparison. **b,** Comparison of the bending rigidity of the pixel fibre and representative commercial yarns. Error bars represent mean $\pm$ standard deviation ($n = 3$).



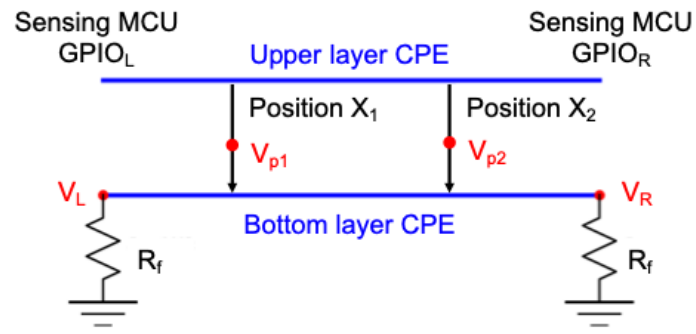
Supplementary Figure 9 | Bending-to-failure test of the pixel fibre. a–c, Demonstration of the pixel fibre wrapped around cylindrical mandrels with bending radii of 3 mm (a), 2 mm (b) and 1 mm (c), respectively.



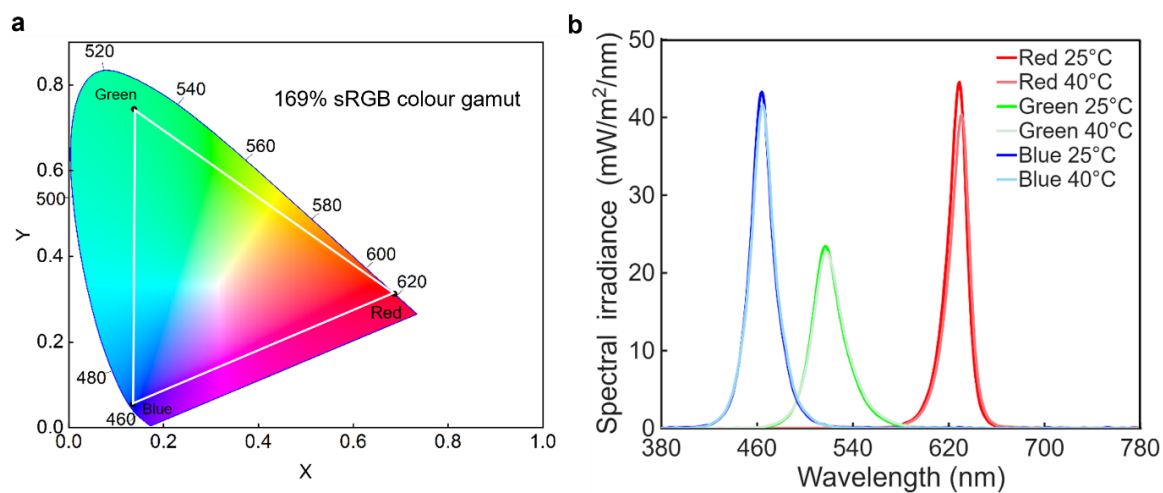
Supplementary Figure 10 | Bending-dependent touch activation threshold. **a**, LED activation threshold of the pixel fibre measured in the straight state and under bending radii of 5, 4.5, 4, 3.5, 3, and 2.5 cm. **b**, LED activation threshold measured in the straight state and under bending angles of 15°, 30°, 45°, and 60°. Error bars represent mean $\pm$ standard deviation ($n = 3$).



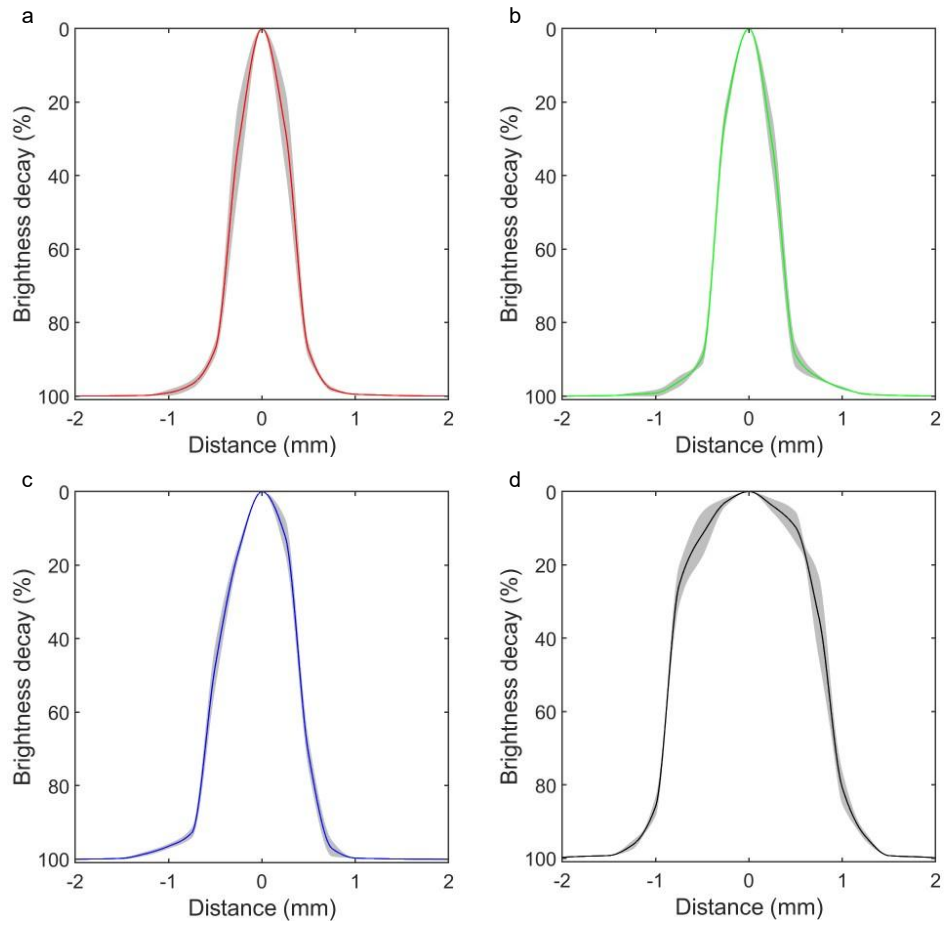
Supplementary Figure 11 | Bending-induced baseline resistance variation of the touch-sensing layer. a, Baseline resistance measured when the fibre was wrapped around cylindrical mandrels with bending radii from 5 to 2.5 cm. **b,** Baseline resistance measured under different bending angles from 0° to 60°. Error bars represent mean $\pm$ standard deviation ($n = 3$).



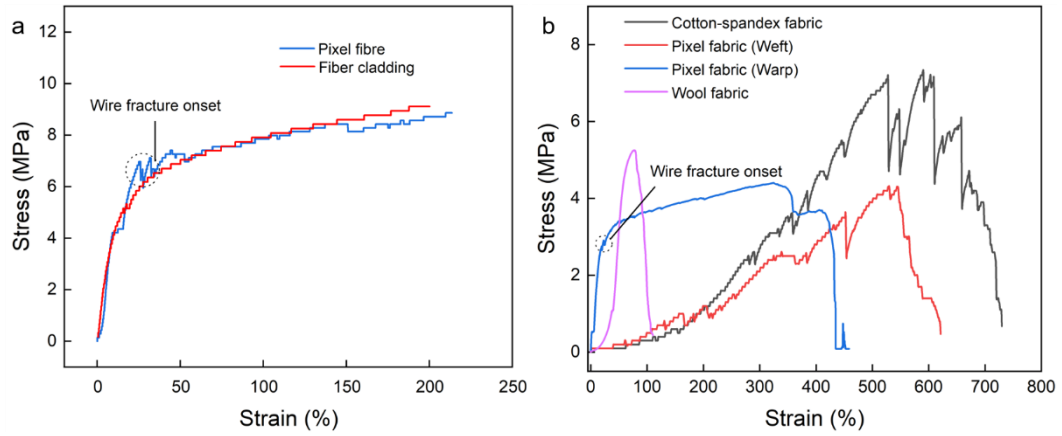
Supplementary Figure 12 | Circuit schematic of the dual-end asymmetric driving system for multi-touch detection on an individual pixel fibre.



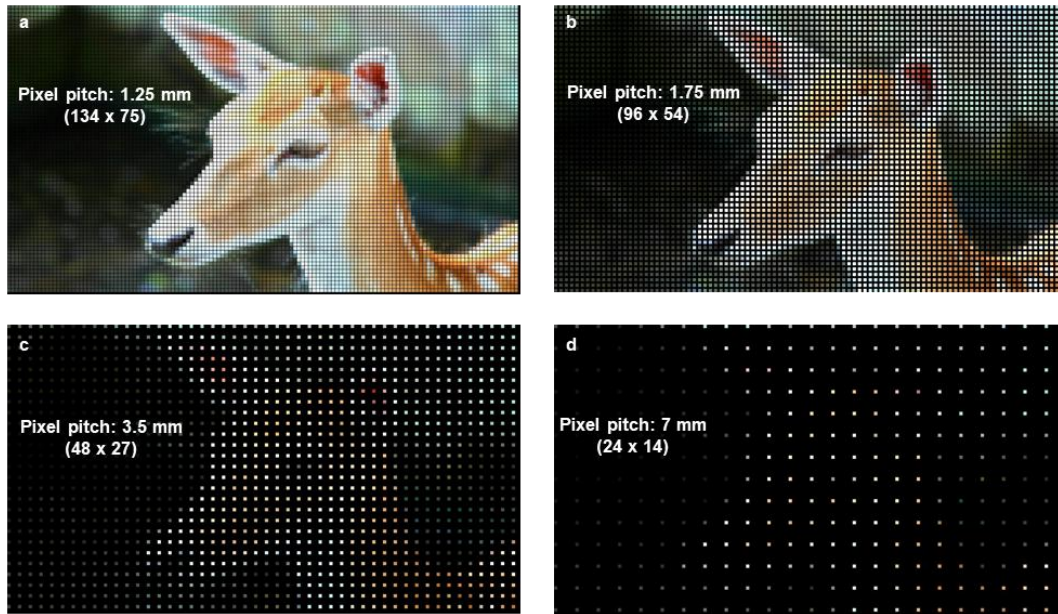
Supplementary Figure 13 | Optical performance of the pixel fibre. a, CIE 1931 chromaticity diagram showing the colour gamut of the pixel fibre compared with the sRGB standard. **b,** Emission spectra of red, green and blue subpixels at 25 °C and 40 °C.



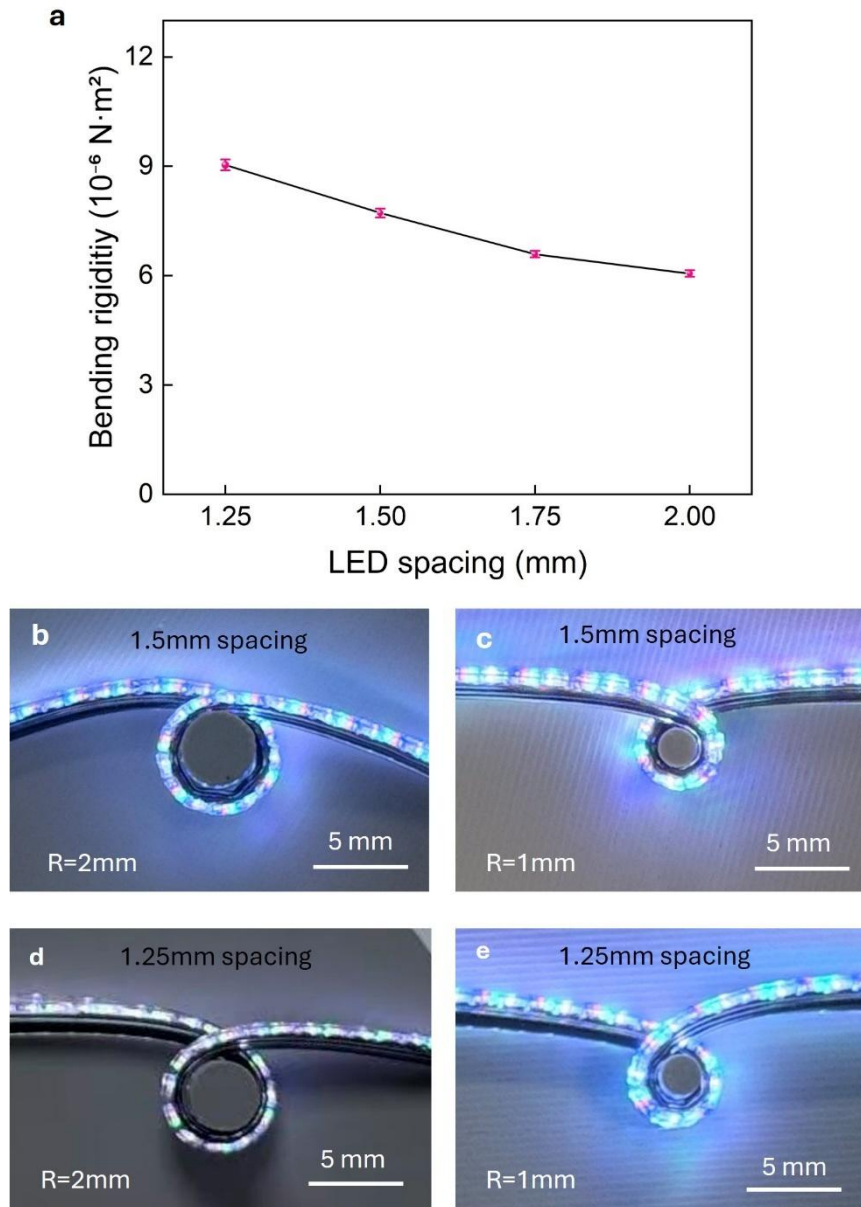
Supplementary Figure 14 | Characterisation of the spatial luminance distribution for the pixel fibre. a–d, Spatial luminance profiles of a single LED within the pixel fibre illuminated in pure red (**a**), pure green (**b**), pure blue (**c**), and white (**d**). The grey shaded area represents error band.



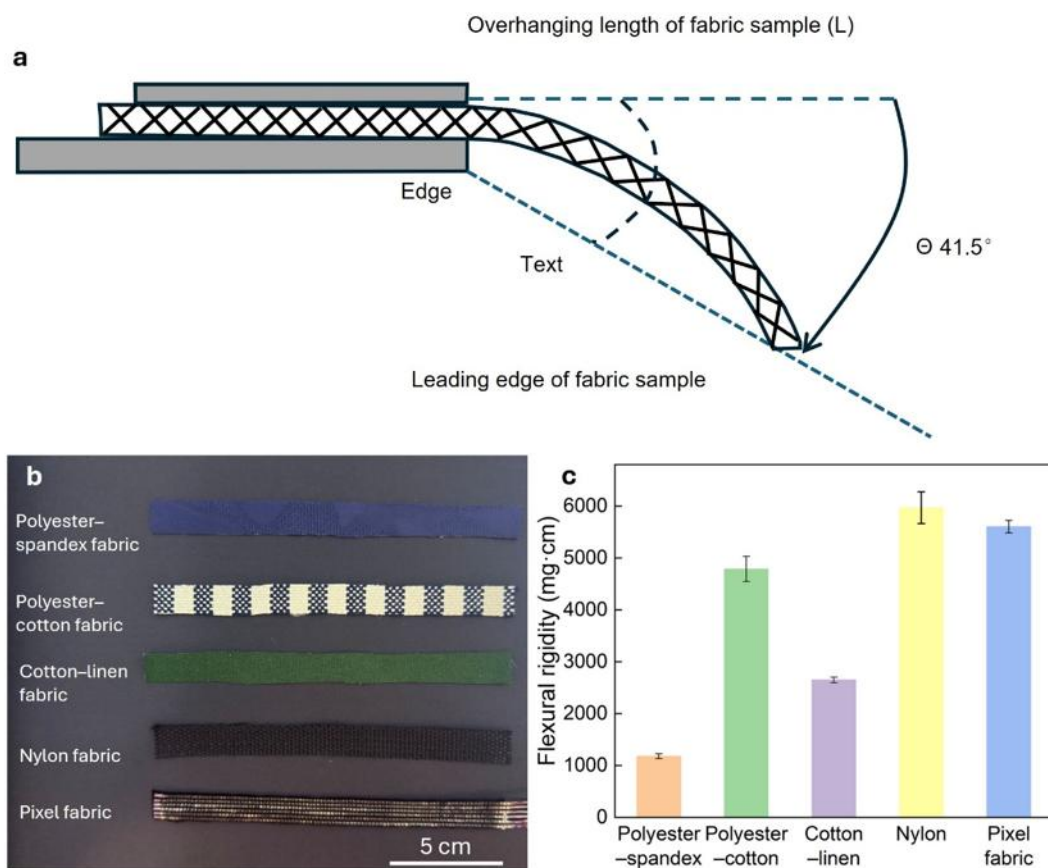
Supplementary Figure 15 | Tensile mechanical performance of the fibres and textiles. **a**, Stress–strain curves of a pixel fibre and a fibre cladding (identical fibre structure without embedded microelectronic strips). The abrupt stress drop in the pixel-fibre curve marks the onset of magnet-wire fracture. **b**, Stress–strain curves of cotton–spandex fabric, wool fabric, and pixel fabric tested along the warp and weft directions. The onset of magnet-wire fracture in the pixel fabric is indicated by the abrupt stress drop. Warp and weft directions are defined as parallel and perpendicular to the pixel fibres, respectively.



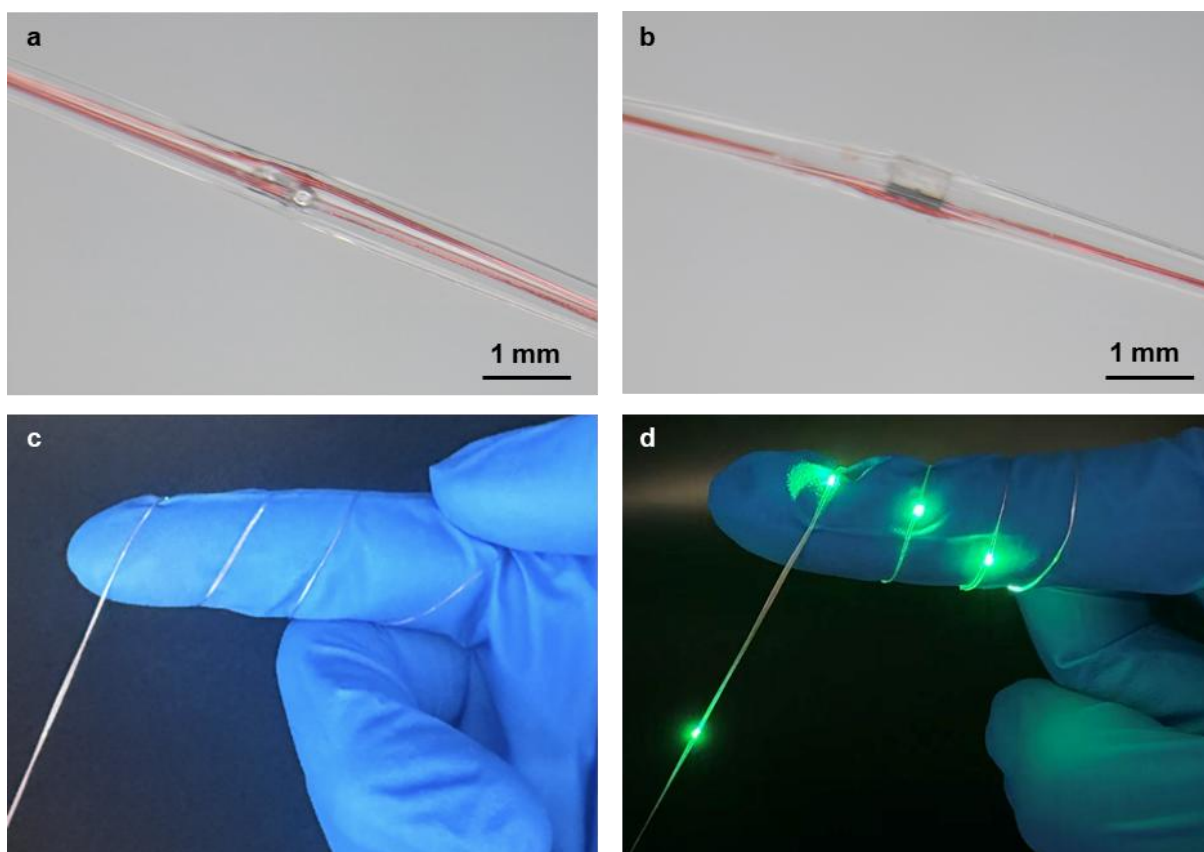
Supplementary Figure 16 | Display quality of rendered images at different pixel pitches for the same screen size. a–d, Displayed images using pixel pitches of **(a)** 114% LED-width (1.25 mm), **(b)** 159% LED-width (1.75 mm), **(c)** 318% LED-width (3.5 mm) and **(d)** 636% LED-width (7 mm), showing the change in visual resolution and image clarity with increasing pixel spacing.



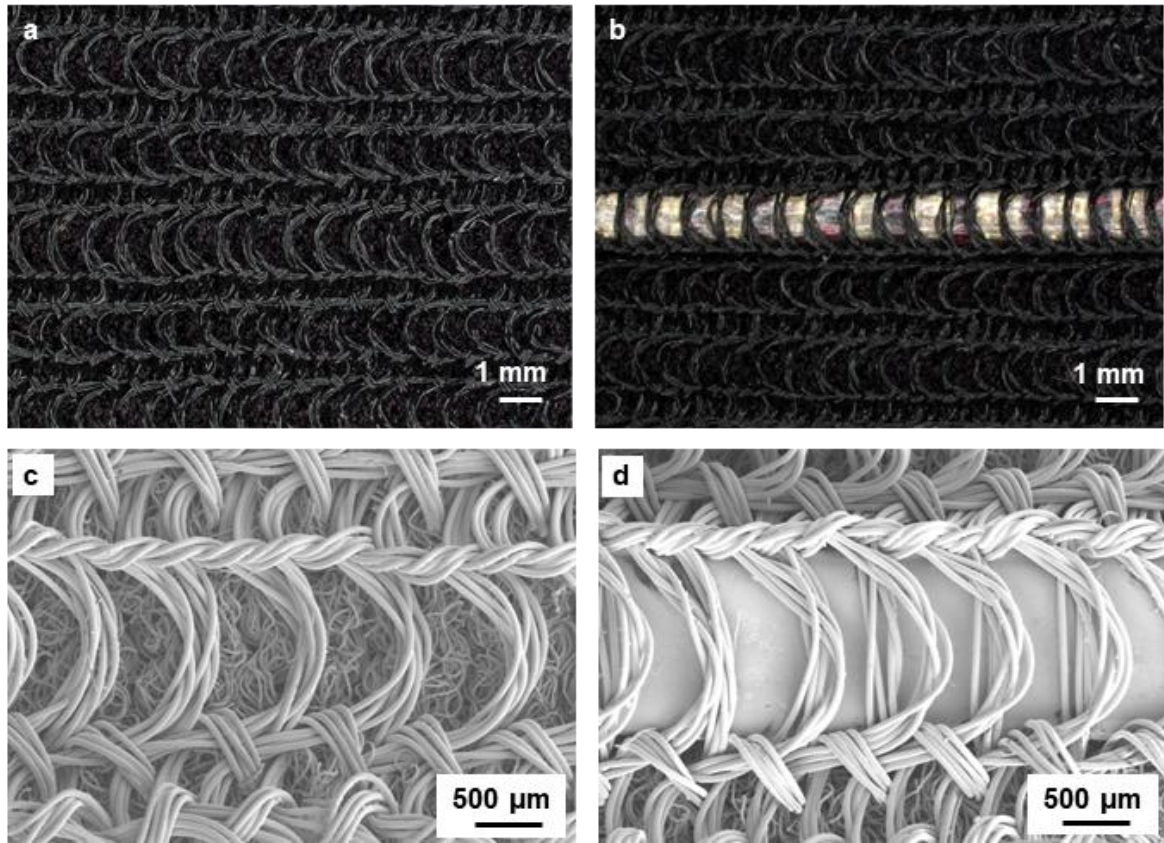
Supplementary Figure 17 | Effect of LED spacing on fibre bending rigidity and robustness. **a**, Bending rigidity of pixel fibres with different LED spacings. Error bars represent mean $\pm$ standard deviation ($n = 3$). **b–e**, Illuminated pixel fibres with 1.50 mm spacing under bending radii of 2 mm (**b**) and 1 mm (**c**), and 1.25 mm spacing under bending radii of 2 mm (**d**) and 1 mm (**e**).



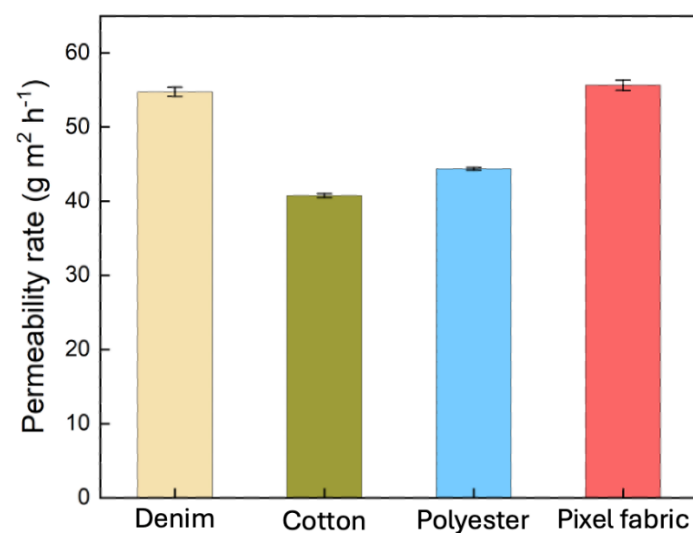
Supplementary Figure 18 | Fabric-level flexural rigidity of the pixel fabric. **a**, Schematic illustration of the cantilever bending test used to determine fabric flexural rigidity according to ASTM D1388. **b**, Representative photograph of the cantilever bending measurement for pixel fabric, performed according to ASTM D1388. **c**, Representative commercial fabrics and pixel fabrics used for comparison. **d**, Comparison of the flexural rigidity of the pixel fabric with representative commercial fabrics.



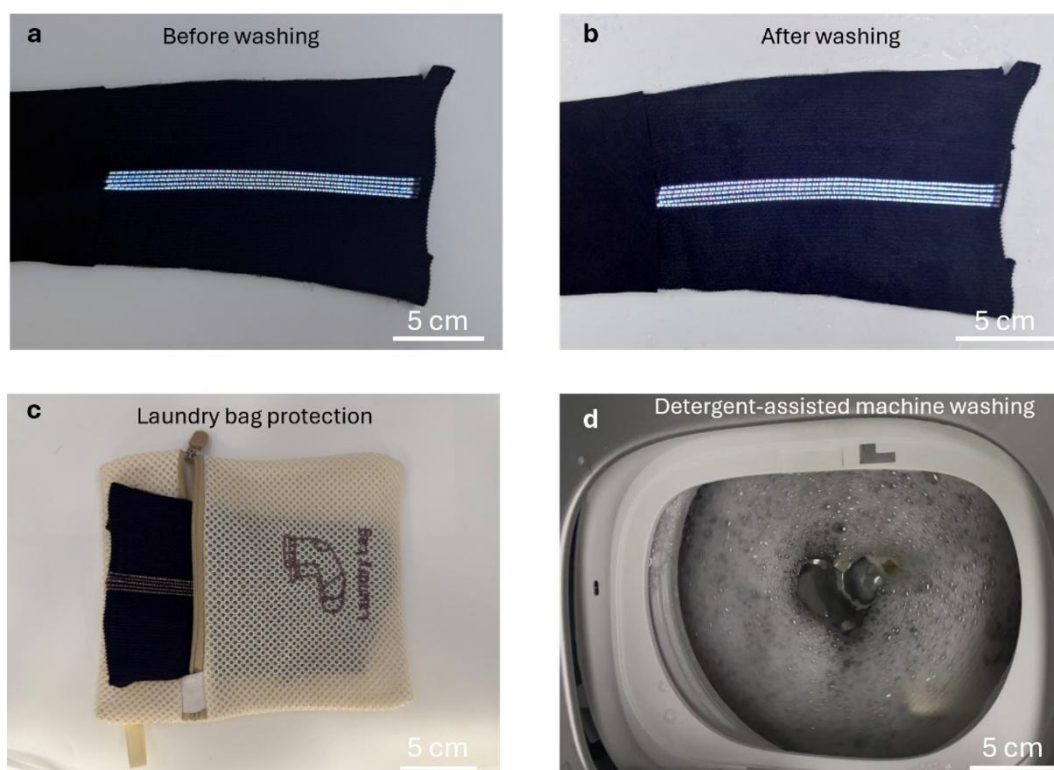
Supplementary Figure 19 | Micro-scale LED fibre. **a**, Backside optical micrograph of the fibre. **b**, Side-view optical micrograph of the fibre. **c**, **d**, Photographs of the fibre wrapped around a finger before (**c**) and after (**d**) power-on.



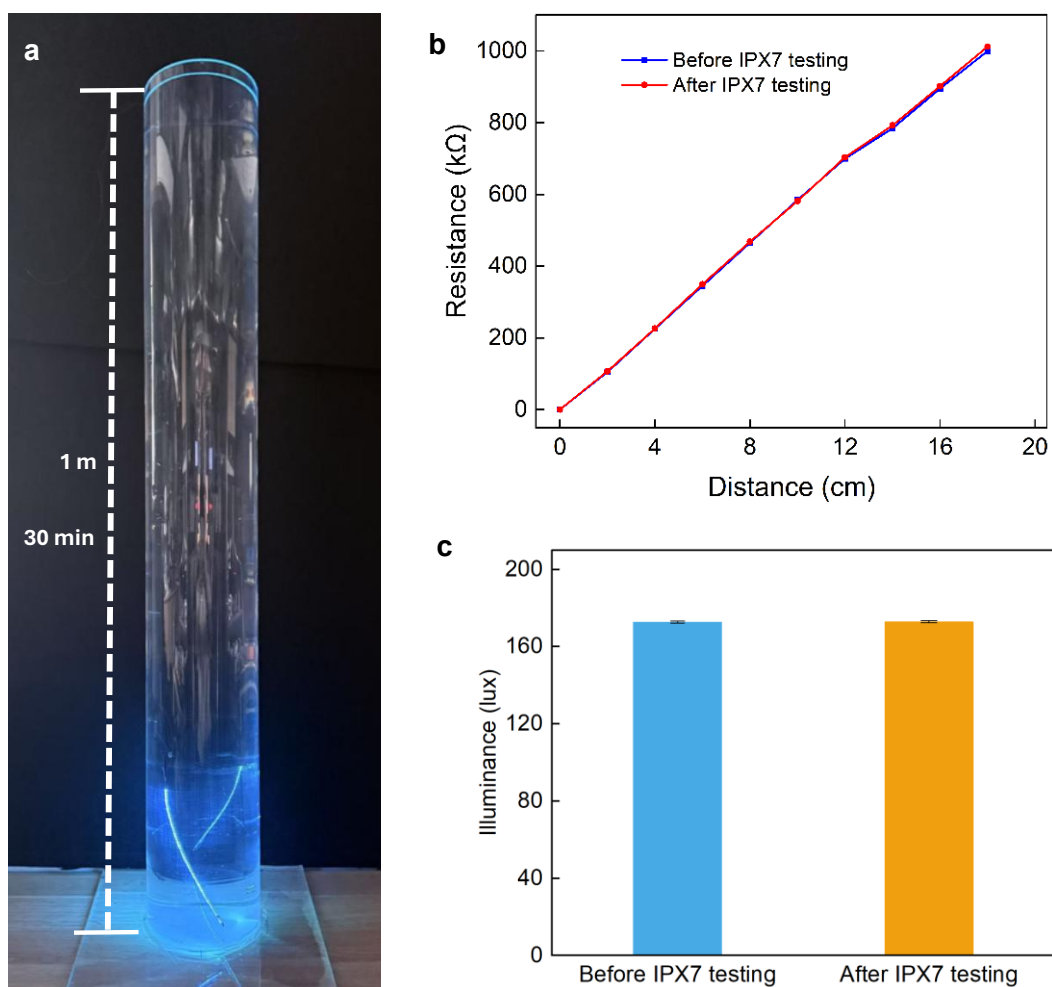
Supplementary Figure 20 | Morphological characterization of the fabric before and after fibre integration.
a, b, Optical micrographs of the fabric before (**a**) and after (**b**) pixel fibre integration. **c, d,** SEM images of the fabric before (**c**) and after (**d**) pixel fibre integration.



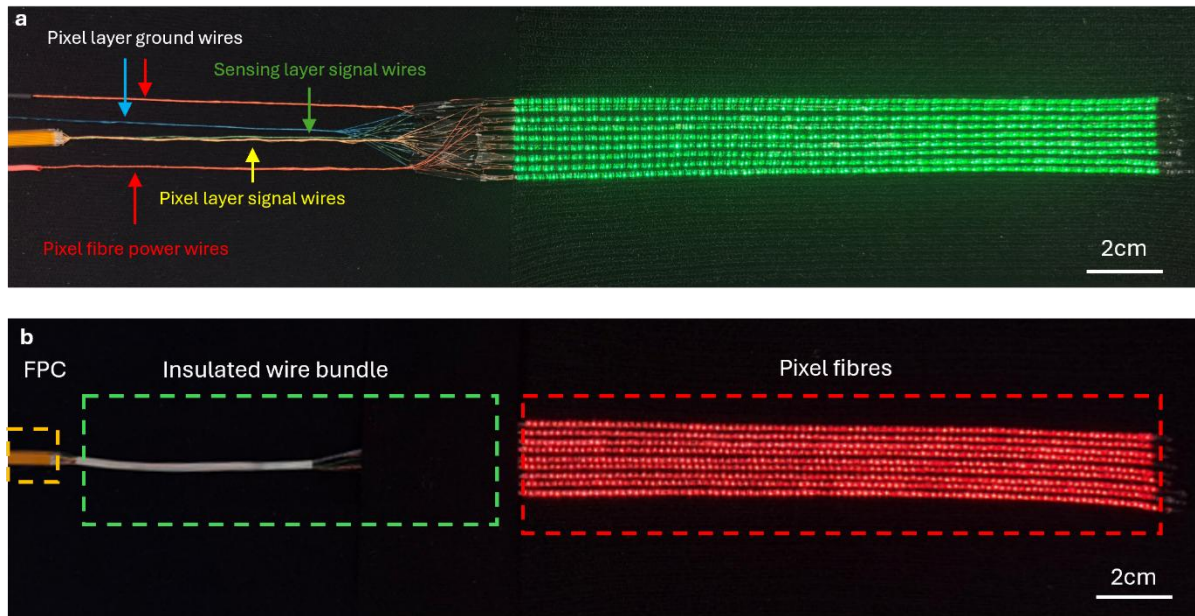
Supplementary Figure 21 | Permeability rate of the Pixel fabric sample, denim fabric, polyester fabric and cotton fabric, with error bar indicating standard deviation. Error bars represent mean $\pm$ standard deviation (n = 3).



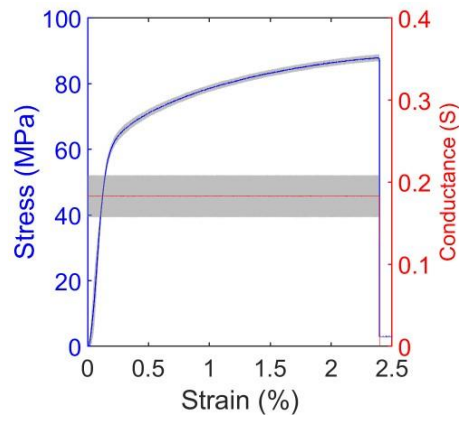
Supplementary Figure 22 | Detergent-assisted machine-washing procedure. **a**, Pixel fabric before washing. **b**, Pixel fabric after washing. **c**, The sample placed inside a polyester laundry bag, which served as a flexible physical barrier during washing. **d**, Detergent-assisted machine washing under gentle-cycle conditions.



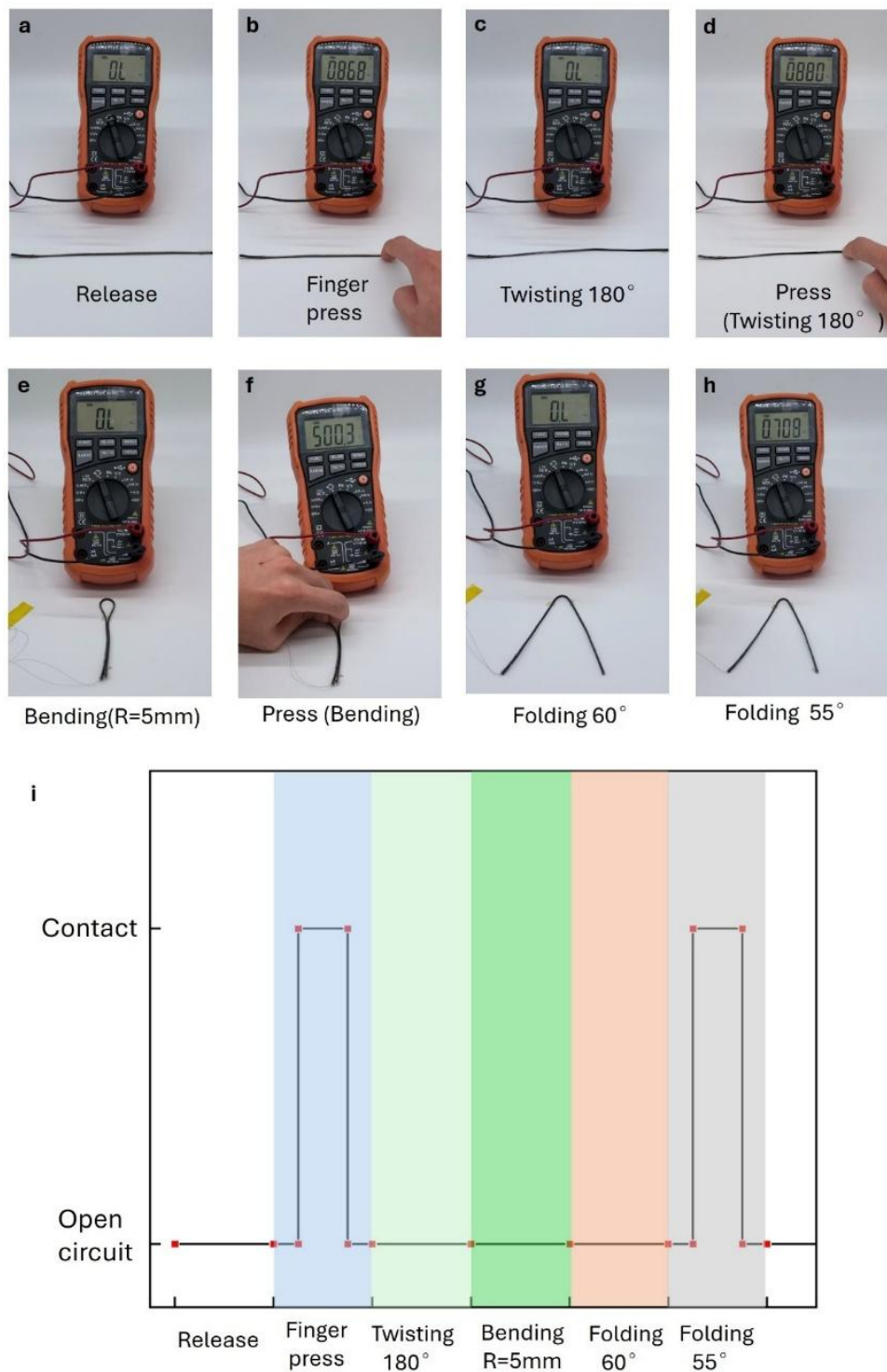
Supplementary Figure 23 | IPX7 immersion test of the pixel fibre. **a**, Operation of the pixel fibre during the IPX7 immersion test. **b**, Resistance profile along the pixel fibre before and after the IPX7 test. **c**, Illuminance of the pixel fibre before and after the IPX7 test. Error bars represent mean $\pm$ standard deviation ($n = 3$).



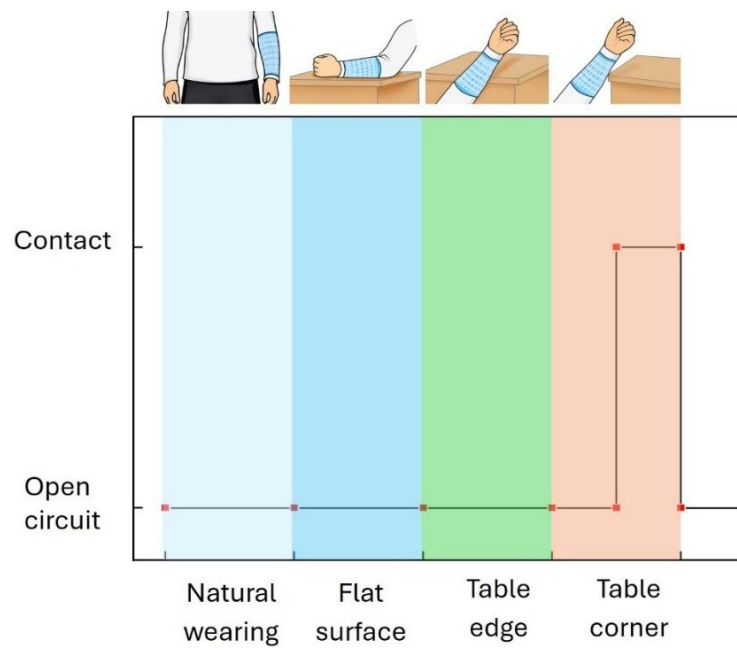
Supplementary Figure 24 | Electrical connection interface for one display group. **a**, Separated electrical connections for one group of nine-pixel fibres, including the pixel-layer power, data and ground wires, as well as the touch-sensing-layer signal and power wires. **b**, Compact interface in which the conductors are routed through an insulated wire bundle between the FPC transition region and the garment-integrated pixel fibres.



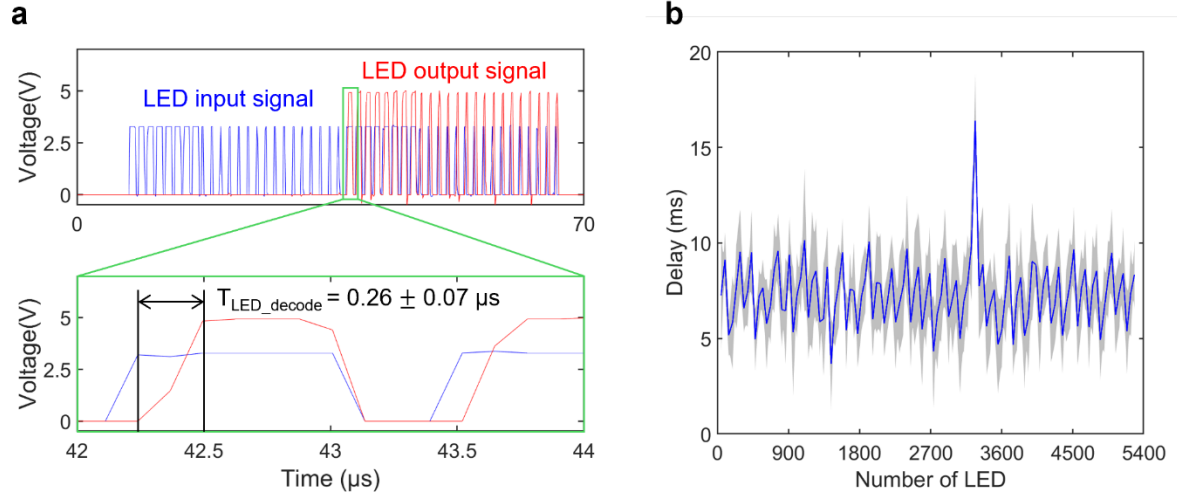
Supplementary Figure 25 | Mechanical reliability characterisation of the electrical connections. Stress–strain (blue curves, left axes) and conductance–strain (red curves, right axes) profiles for the solder joint between the copper wire and the FPC. The grey shaded regions represent the error bands.



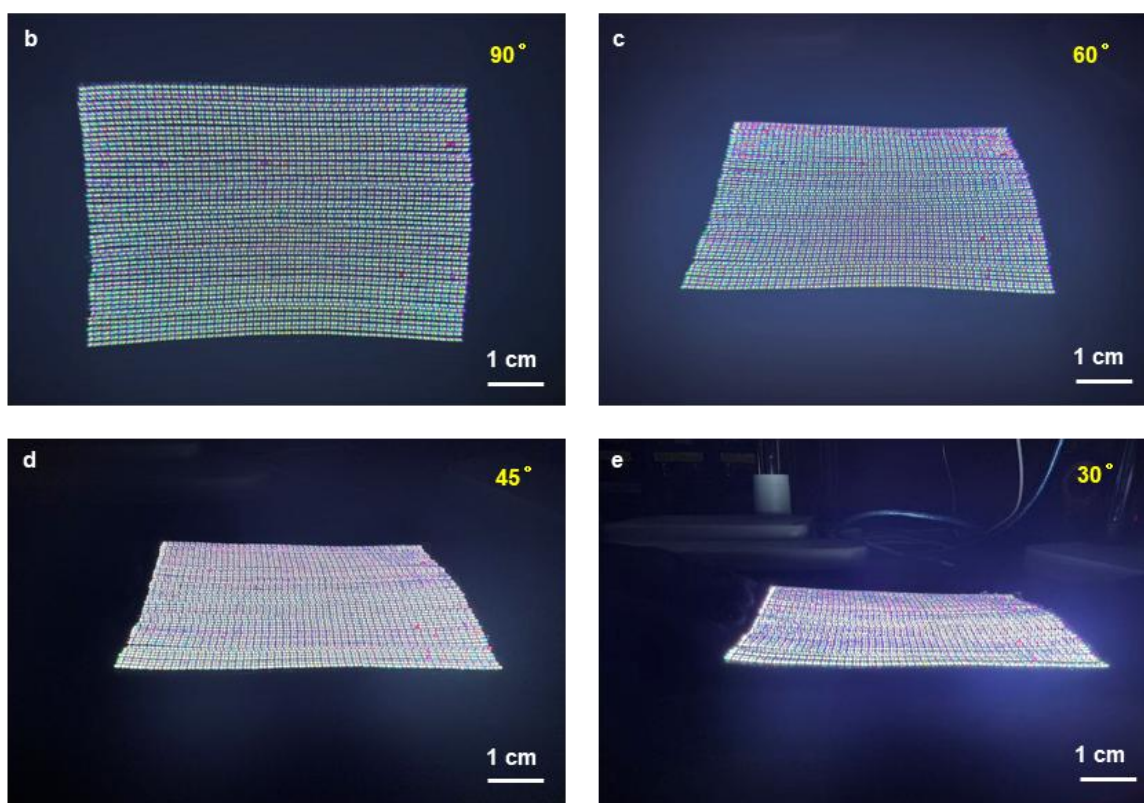
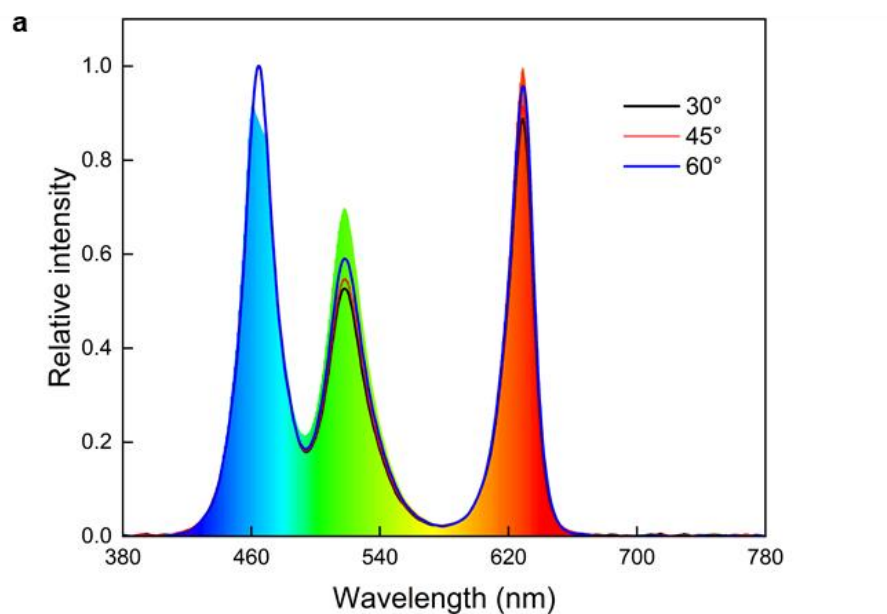
Supplementary Figure 26 | Motion-artifact rejection of the touch-sensing fibre under deformation conditions. **a, b**, Resistance readout of the fibre in the released state and under deliberate finger pressing. **c, d**, Resistance readout during 180° axial twisting without and with intentional pressing. **e, f**, Resistance readout during bending with a radius of 5 mm without and with intentional pressing. **g, h**, Resistance readout under acute folding conditions of 60° and 55° , respectively. **i**, Binary contact-state response under sequential deformation conditions.



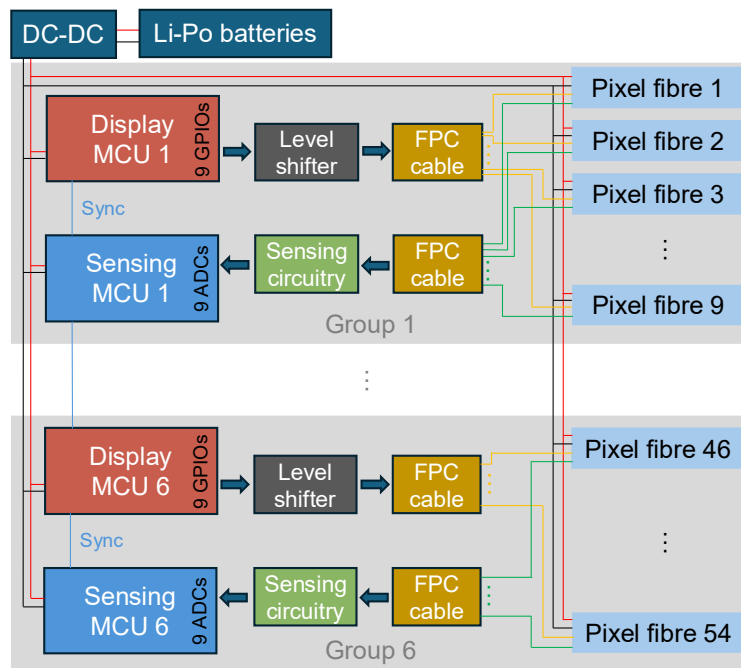
Supplementary Figure 27 | False activation under forearm-supported contact conditions.



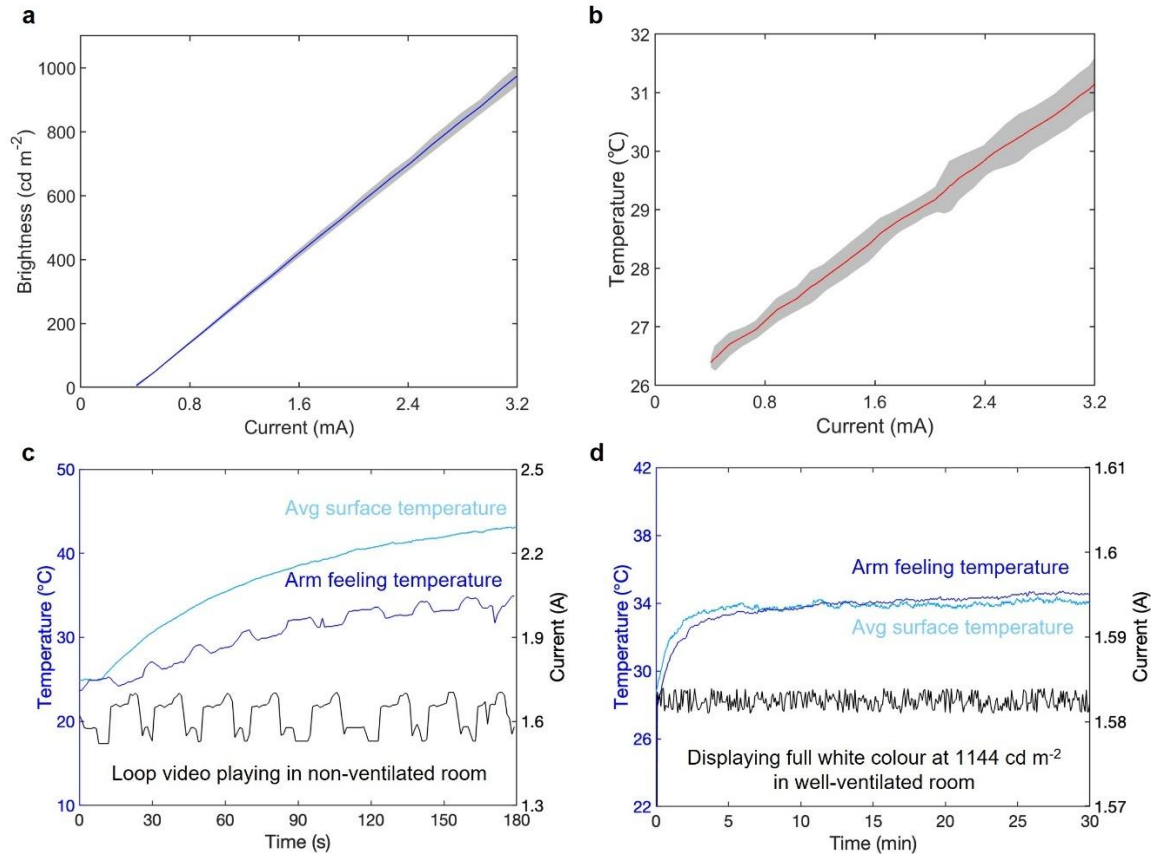
Supplementary Figure 28 | LED cascading limit for 800 kHz SW-RZ protocol. a, Duration for a single LED intercepting and forwarding the SW-RZ data. **b,** Characterisation of the ESP32-U4WDH encoding delay with the number of cascaded LEDs increasing.



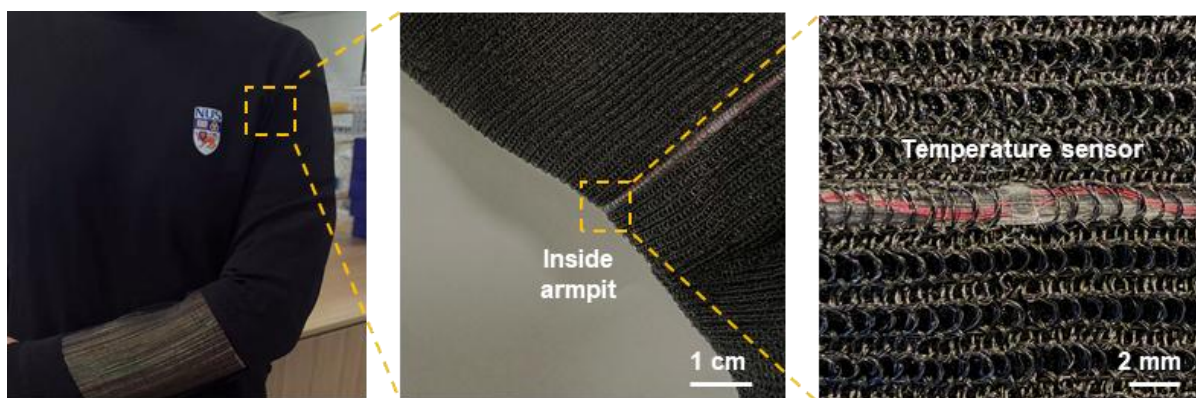
Supplementary Figure 29 | Appearance of the fabric screen at different viewing angles. **a**, Normalized emission spectra measured at 30°, 45°, and 60° relative to the normal (perpendicular) surface, compared with the spectrum recorded at 90° incidence (perpendicular viewing, borderless curve). **b-e**, Photographs of the fabric screen viewed at **(b)** 90°, **(c)** 60°, **(d)** 45° and **(e)** 30°, respectively, showing angle-dependent colour shift.



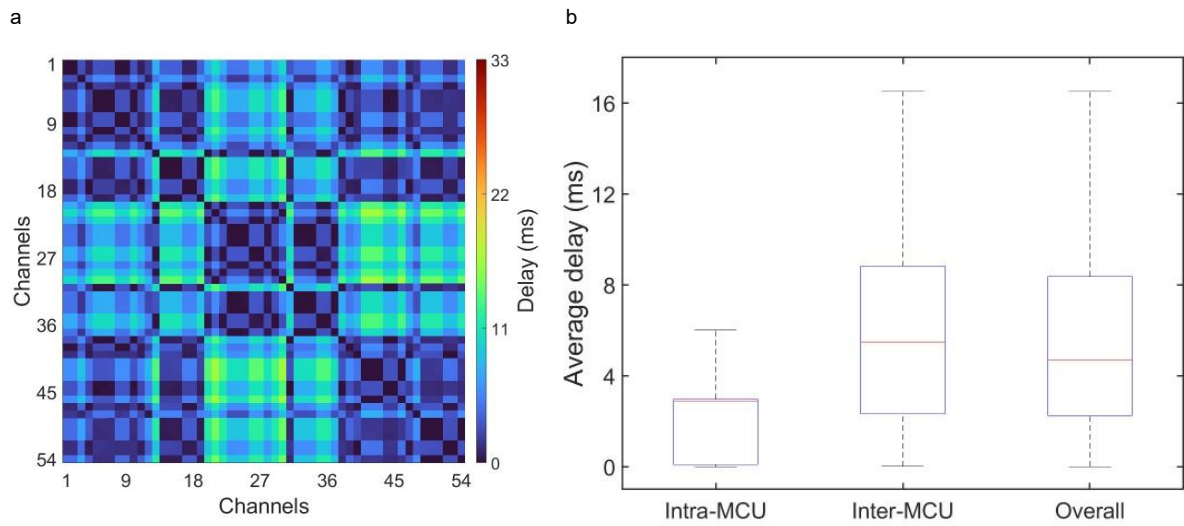
Supplementary Figure 30 | Garment GUI system connection schematic.



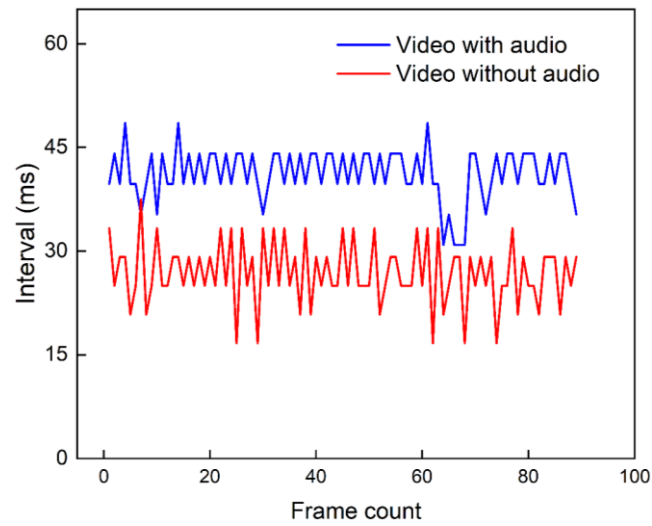
Supplementary Figure 31 | Current consumption and thermal behaviour characterisation. **a**, Brightness and current relation of a single LED working at 5 V, with grey shaded area representing error band. **b**, Temperature and current relation of a single LED working at 5 V, with grey shaded area representing error band. **c**, Temperature and current consumption performance of Garment GUI loop-playing 30 fps video in a non-ventilated indoor space with 7.4 V voltage supply. **d**, Temperature and current consumption performance of Garment GUI displaying full white colour at 1144 cd m^{-2} in a well-ventilated indoor space with 7.4 V voltage supply.



Supplementary Figure 32 | Garment GUI with an integrated temperature-sensing fibre. Temperature-sensing fibre integrated into the underarm region of the garment.



Supplementary Figure 33 | Characterisation of propagation delay across 54-pixel fibre signal channels. a, Heat map of the average delay across 54 channels. **b,** Box plot of the average delay in different categories.



Supplementary Figure 34 | Frame-interval comparison with and without audio. Frame-to-frame interval as a function of frame count for videos recorded with audio and without audio, showing differences in frame-rate stability and temporal jitter.

Supplementary Table 1 | Comparison of conventional yarns and the pixel fibre in terms of composition and typical applications.

Yarn type	Composition	Typical applications
Wax-coated PU yarn	100% polyurethane (PU), wax-coated	Leathercraft stitching, decorative cords, waterproof laces, wearable accessories
Cotton yarn	100% cotton	Knitted garments, T-shirts, socks, household textiles
Jute yarn	100% jute	Ropes, sacks, packaging materials, carpets, handicrafts
PVC–polyester yarn	35% polyvinyl chloride (PVC), 65% polyester	Outdoor textiles, mesh fabrics, tarpaulins, industrial straps, weather-resistant products
Pixel fibre	ECOC, CPE, SK6805 LED chips, 90 µm enamelled wire	Garment GUI

Supplementary Table 2 | Comparison of representative commercial fabrics and the fabric used in this work.

Fabric type	Fibre Composition (%)	Use case
Polyester–spandex fabric	70% polyester, 30% spandex	Sportswear, yoga wear, fitted apparel
Polyester–cotton fabric	50% polyester, 50% cotton	Casual wear, uniforms, workwear
Cotton–linen fabric	55% cotton, 45% linen	Home textiles, decorative fabrics
Nylon fabric	100% Nylon	Computer bag shoulder strap webbing / bag webbing
This work	50%cotton, 50% nylon, pixel fibre	Garment GUI

Supplementary Videos

Supplementary Video 1 | Solder micro-dispensing

Demonstration of automated solder micro-dispensing: LED dies are placed into recessed cavities with defined spacing and orientation, followed by automated micro-dispensing of solder paste onto the chip pads.

Supplementary Video 2 | Programmable de-insulation

Programmable laser de-insulation of magnet wires: A programmable laser selectively removes the enamel coating at locations precisely matched to the pad dimensions, exposing only the intended copper segments.

Supplementary Video 3 | Touch-activated LED feedback

Demonstration of touch-activated LED feedback: Direct tactile-to-optical interaction is enabled without planar electrodes or two-dimensional scanning architectures. Pressing different axial locations on the pixel fibre (single-point or dual-point touch) produces distinct ADC readings, which activate the corresponding LED region.

Supplementary Video 4 | Thermal drawing of pixel fibre

Demonstration of thermal drawing process: A single addressable LED strip is continuously fed from an overhead spool and passively pulled into the furnace by tractor-roller tension. With a stable draw ratio, the LED strip is smoothly encapsulated within the softened ECOC cladding as the CPE layer forms the sensing region, and the LEDs remain stably operational throughout continuous fibre production.

Supplementary Video 5 | Pixel fibre waterproof test

Demonstration of pixel fibre waterproof operation: The fibre remains continuously operational and stable while fully submerged in water, demonstrating its waterproof performance.

Supplementary Video 6 | Garment GUI applications

Demonstration of garment GUI functions. The wearable textile interface features a two-page menu system, showing calculator, body-temperature sensing, image display, stable video playback (30 fps without audio; 25 fps with audio), compass readout, voice-triggered control, BLE wireless transfer, and adaptive display features such as autorotation and automatic brightness adjustment.