VisRing: A Display-Extended Smartring for Nano Visualizations

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Figure 1: *VisRing* is a smartring integrated with sensors, a bendable display, and an accompanying firmware library. (a) An exploded view of the smartring. (b) *VisRing* integrates sensors and a bendable display into a compact ring form factor, enabling nano visualizations such as message delivery, time display, and health monitoring.

Abstract

We introduce VisRing, the first smartring incorporating a bendable 160 × 32 4-bit grayscale organic light-emitting diode display. VisRing stands out by displaying nano visualizations while maintaining a compact design and minimal weight of 6.6 g, with an overall cost of around $35. We exploit opportunities for a system-on-a-chip architecture to tightly integrate an inertial measurement unit, a photoplethysmograph sensor, a temperature sensor, Bluetooth, a microcontroller, and a display unit that spans 270° to 360°, depending

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on finger size. Our contributions include the hardware design and implementation of VisRing, along with a software library that supports visualizing various data types. A qualitative study with 12 participants demonstrated the comfort, likability, and social acceptance of VisRing's hardware and software. The participants liked the visualizations and found the ring lightweight, but also pointed out possible improvements. All materials are shared under an open-source license to enable the community to extend and improve VisRing.

CCS Concepts

• **Hardware** → **PCB design and layout**; • **Human-centered computing** → **Visualization toolkits**; **Mobile computing**.

Keywords

Smartring, Wearable, Sensor, Sensing Application, Micro Visualization, Nano Visualization, Usability Study

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1 Introduction

Wearable devices, such as smartwatches and smartbands, are increasing in popularity due to their size and unobtrusiveness. Even smaller smart devices are possible with the evolution of chips, flexible electronics, and displays. Unlike smartwatches, smartrings offer a more discreet and seamless experience. Adding a display to a smartring enables convenient visual access to information, while maintaining a discreet and compact form factor compared to larger devices like smartwatches or smartphones. Recent industry reports indicate that rings are emerging as the next natural wearable device to be enhanced with smart capabilities, as robust market forecasts [39, 84] and innovations from major tech players such as Samsung [21] and Oura [58] evidence. However, the majority of smartrings are designed for sensing applications, such as personal health and fitness data, which have to send data (e. g., heart-rate data, oxygen saturation, blood pressure, sleep data) [23, 47, 48, 71] to a smartphone for visualization. In contrast, smartrings featuring integrated displays are still rare [9, 16, 50, 67].

The few currently available commercial smartrings with displays are proprietary and offer only basic feedback that cannot visualize complex information, such as detailed health metrics, text-based notifications, or interactive interfaces. This limitation exists because they rely on light-emitting diodes (LEDs) or multi-segment liquid-crystal displays (LCDs) that can only represent simple digits or basic icons [9, 35, 43]. Darbar et al. [16] developed a smartring featuring an organic light-emitting diode (OLED) display, but they did not use a bendable display, resulting in an increase in size, compromising the smartring's wearability. In addition, most smartrings lack the functionality to depict visualizations. Most of the smartrings in academia focus on finger motion tracking (e. g., [10, 72, 87, 92, 95]) as well as health and fitness monitoring (e. g., [21, 53, 58, 67, 71, 95]). Up to date, no smartring exists that incorporates a bendable display capable of depicting common visualizations (e. g., bar charts, line charts, or progress charts). To address this research gap, we explore the design and fabrication of a smartring extended with an OLED display that enables the depiction of such standard visualization.

We identified three key challenges when designing such a smartring platform that integrates an OLED display: (i) The circuits of the smartring must accommodate a high-resolution bendable OLED display, multiple sensing units, a battery, and a microcontroller within an extremely compact form factor. (ii) Assembling a bendable OLED display, a flexible printed circuit board (FPCB), and a battery into a curved, miniaturized enclosure demands a precise and cost-effective fabrication process. (iii) Making the smartring customizable and extensible requires a programmable interface and efficient wireless communication, all while keeping the form factor minimal.

To validate *VisRing* in the context of displaying real-time health data as visualizations, we explore the design challenges of visualizing data on such small displays. Researchers have explored micro visualizations for smartwatches and fitness bands, providing insights into the miniaturization and glanceability of information visualizations [5, 40, 55]. However, the OLED display on the smartring allows us to visualize data in a discreet, unobtrusive, and compact way. For this, we have to consider the bendable nature and elongated shape of the display, the even smaller display size, and the potential of displaying data on the inside of the hand for privacy considerations. Therefore, we introduce the term *nano visualizations* to explore the specifics of visualizations on smartrings. In summary, our work makes the following contributions:

- We designed and fabricated *VisRing* (Figure 1), the first **display extended smartring**, integrating a 160×32 4-bit grayscale OLED display, multiple sensing units including IMU, PPG, and temperature sensors, and wireless communication. Depending on the finger size, the display ranges between 270° to 360°.

- We define **nano visualizations** and demonstrate the feasibility and readability of visualizations of real-time data on smartrings by extending the display's firmware and developing a visualization library.
- We conducted a **qualitative study** to validate comfort, likability, and acceptance of *VisRing*, as well as the use of nano visualization for health data while walking.
- We **open-source the hardware and software** of *VisRing* for the community to extend it with additional hardware capabilities and further nano visualization for diverse applications.

2 Related Work

This work is inspired by and builds upon prior work on smartrings and information visualizations on smartwatches called micro visualizations. The following sections embed our work in existing research and commercial products. First, we discuss previous smartrings and their input and output possibilities. We used two review papers [73, 88] as a reference, which identified in total over 356 publications related to smartrings, and further investigated commercial smartrings. Table 1 shows an overview of academic and commercial smartrings most related to our *VisRing*. Additionally, we introduce the current state of Organic User Interfaces (OUIs) and micro visualizations on smartwatches.

2.1 Input Modalities of Smartrings

One of the earliest developments of a ring used as input modality was by Fukumoto and Tonomura [24]. They attached ring-shaped sensors to each finger, enabling the input of commands or characters through finger-typing actions. Meanwhile, subsequent advancements in rings' input modalities have led to their use for a variety of applications, such as gesture recognition [42, 92], activity tracking [21, 58], contactless transactions [59], control of other (smart) devices [16, 45], (thermal) imaging [45, 93], touch-based interactions [4, 16, 31, 42], and more related to our work—measuring health and fitness data [21, 30, 48, 48, 53, 58, 65, 67, 71, 82, 94, 95].

Health and fitness data measurement encompasses a wide range of applications, including detection (e. g., fatigue, falls, disease, peri-menopausal depression) [25, 80, 83], prediction (e. g., labor onset, sleep quality) [22, 49], and feedback (e. g., quality of chest compressions) [46], as well as rings as assistive devices (e. g., for the elderly) [80], and monitoring (e. g., blood pressure, sleep, physical activity) [49, 71, 95].

Sel et al. [71] developed a smartring that introduces a ring-based bio-impedance sensor to continuously monitor cuff-less blood pressure. Magno et al. [48] developed a smartring that measures blood oxygen saturation (S_pO_2) and can charge itself through integrated solar panels. Another ring for healthcare is developed by Zhang et al. [94], which integrates a fluid sensor that detects a variety of hand-washing agents such as tap water, soap, and sanitizers. OmniRing [95] embeds IMU and PPG sensors for healthcare applications like activity detection, sports analytics, heart rate monitoring, blood pressure monitoring, and sleep sensing.

Overall, previous work on smartrings has mainly focused on sensors for data collection and exploring input modalities like gestures, while commercial smartrings like the Oura Ring [58] and the Samsung Galaxy Ring [21] offer health data monitoring.

2.2 Output Modalities of Smartrings

In contrast to input, smartring's output capabilities are far more limited. Prior works explore using thermal feedback [96], friction force [27], vibrotactile feedback [13, 42, 62], and more related to our smartring—visual feedback, like LEDs [13, 42, 62, 94], and non-bendable displays [16] for output. Regarding visual output, there exist some rings that use LEDs to give the wearer feedback, such as Pradana et al. [62] and Choi et al. [13], which use an LED with vibration for simple non-verbal communication accompanying text messages. Ringly [63, 66], a smart gemstone ring, can alert the wearer about phone events, by vibrations and changes in the color of the ring. Similar to that, Ketabdar et al. [42] present Pingu, a ring that provides feedback for gestures through vibration and a red-green-blue (RGB) LED. The *Wave for Work* [35] smartring uses a 9×5 LED matrix to provide feedback about the made gesture used to control various applications, such as adjusting the volume on Spotify.

In addition to smartrings with LEDs, there are also some with segment LCD displays, such as the Casio CRW-001-1ER [9] with the look and features of a typical wristwatch or the Rogbid SR08 Ultra [67] that features a 7-segment LCD to display digits (e. g., time, step count, heart rate, and sleep duration), and separate small displays for a heart and a step count icon. However, based on their type of display, they are limited to visualizing only simple information such as digits.

To visualize more complex data, displays with higher pixel counts are required. NailDisplay [77] presents a nail-mounted display, which can be used to reveal what is occluded under the finger while interacting with another device with a (small) screen. However, the NailDisplay is not designed as a ring and therefore lacks the specific requirements—such as size and shape—needed for use as a ring. RingIoT [16] mounts an infrared (IR) transmitter, an IMU sensor, a capacitive touch sensor, and a rigid OLED display to a finger-worn device with a connection to an Arduino board on the wrist, enabling interaction with other internet-of-things (IoT) devices. However, RingIoT requires larger electronics mounted on the wearer's wrist, which are

Table 1: Summary of related work with output modalities and comparison to *VisRing*. Legend: Inertial Measurement Unit (IMU) with n degrees of freedom (n-IMU), Photoplethysmograph (PPG), Electrocardiography (ECG), Temperature (TMP), n-Segment liquid-crystal display (n-Seg. LCD), open-source (OS) and Wireless (WLS).

System	Year	Sensors	Application	OS	WLS	Output
Ketabdar et al. [42]	2012	9-IMU, proximity	Interaction, gestures	✗	✓	Vibration, LED
Pradana et al. [62]	2014	Pressure	Interaction	✗	✓	Vibration, LED
Ringly [66]	2015	N/A	Interaction, health	✗	✓	Vibration, colored light
Han et al. [27]	2017	Proximity, hall	Interaction	✗	✗	Haptic feedback
Wave for Work [35]	2018	6-IMU, motion	Interaction	✗	✓	9×5 LEDs
Darbar et al. [16]	2019	6-IMU, touch	IoT interaction, gestures	✗	✗	Rigid OLED, Infrafred
Zhu et al. [96]	2019	N/A	Present information	✗	✗	Thermal
Zhang et al. [94]	2019	Fluid	Hand hygiene	✗	✓	LED
Rogbid SR08 [67]	2024	N/A	Health	✗	✓	7-Seg. LCD
Casio Ring [9]	2024	N/A	Timer	✗	✓	7-Seg. LCD
***VisRing* (ours)**	**2025**	**9-IMU, PPG, TMP**	**Visualization**	✓	✓	**Bendable 160×32 OLED**

connected to the smartring. Therefore, it is still far from being miniaturized into an actual smartring. This limitation restricts natural hand and arm movements, whereas our *VisRing* demonstrates better performance. In contrast to previous works, we propose *VisRing*, the first fully self-contained smartring equipped with a bendable OLED display and multiple sensors that follow the curve of the ring.

2.3 Organic User Interfaces

As interest in Organic User Interfaces (OUIs) continues to grow in the field of Human-Computer Interaction (HCI) [64, 76, 85, 86], recent advances in flexible electronics have made it increasingly feasible to create interfaces that are both physically deformable and interactive. Strohmeier et al. [76] presented how different display sizes on a cylindrical, wrap-around smartwatch affect user performance in scrolling tasks, highlighting the impact of curved display dimensions on interaction efficiency. Priyadarshana et al. [64] introduced MagicWand, a handheld cylindrical device composed of two flexible OLED displays. They investigated how a curved physical form factor influences interaction compared to traditional flat smartphones. Among these advances, flexible displays play a central role in enabling intuitive, co-located input and output on non-planar surfaces. In parallel, a rapidly growing industry has emerged around shape-deformable displays, such as the Samsung Galaxy Fold [20], the triple-folding phone Huawei Mate XT [33], the rollable OLED TV by LG [19], and stretchable technologies [44], which are seen as key enablers of the next generation of user interface designs. However, prior research on OUIs has primarily focused on wrist-worn or handheld devices, such as smartwatches and smartphones. To extend this paradigm to a more compact and body-integrated form factor, we present *VisRing*, a finger-worn device that embeds a flexible OLED display to explore the feasibility of OUIs at the scale of a smart ring.

2.4 Micro Visualizations

Micro visualizations—small-scale visualizations that are commonly used with wearable devices—are part of a growing field of research, especially in the context of smartwatches [5, 40, 55]. The goal of micro visualizations on smartwatches is to be read "at a glance" [6], which is about 5 seconds [5, 61]. The original definition of micro visualizations by Isenberg [40] explicitly states that "[...] we apply the word *micro* primarily to the perceived small display space but not the number of dimensions or data points and expand the application context beyond text." [40, p. 2] and she "focus[es] on small data representations that can be read *in eye span*." [40, p. 2]. The author even gives examples of pixel-sized indicators ("very small data displays, in the range of a few to several millimeters" [40, p. 3]) and smartwatches ("typically around 3–4 cm wide or high" [40, p. 4]). Researchers have developed and evaluated such micro visualizations for different data types (heart-rate data [26, 54, 56], sleep data [41], back pain data [78], stock prices [11], as well as heel strikes and forefoot strikes while running [69]) but also for different visual representations (bar charts [6, 11, 26, 41], line charts [54, 56], donut charts [6], radial bar charts [6], hypnograms [41], and time spirals [69]). Many of the works visualize the respective data using most of the available screen space (e. g., [6, 26, 41, 56]). However, some works also use complications—a term from horology that describes graphical features on watches that represent information other than time [90]—which are even smaller (1 cm × 1 cm, 90 × 90 pixels) in size [7]. Few visualizations (bar charts and

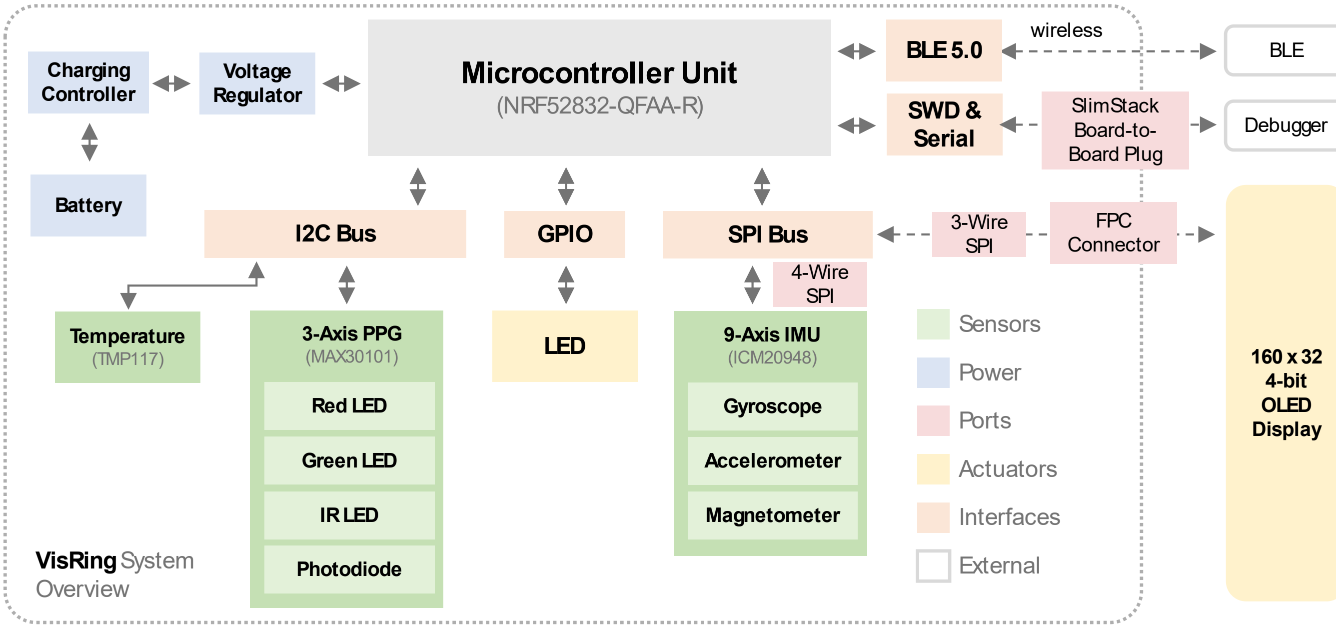


Figure 2: Overview of the *VisRing* system architecture. The microcontroller unit is the central hub that communicates with the sensors, actuators, and display.

hypnograms) were also tested on fitness bands, which have a smaller form factor than smartwatches [41]. These works are more relevant to our endeavor to create nano visualizations that can be read on a smartring because we only have about 32 pixels for one side of the visualizations. Blascheck et al. [7] tested bar and radial bar charts compared to text representations as complications and found that both bar and radial bar charts can be read faster than text if multiple complications are shown. However, the complications had a size of 90 pixels, leaving the question of whether even smaller visualizations can be read "at a glance."

3 VisRing

The prototype of *VisRing*[1], featuring an OLED display, enables wearers to visualize real-time health data in an unobtrusive, wearable suitable for daily use without disrupting regular activities. We identified six design goals for creating such a display-extended smartring.

3.1 Design Goals

When developing *VisRing*, our main objective was to provide an extensible OLED smartring platform for the research community that allows us to explore state-of-the-art sensing and nano visualization capabilities on smartrings with a minimal form factor. The following considerations guided us during the design and development process.

Choice of Display. When choosing a display for *VisRing*, we considered several factors, including size, resolution, power consumption, viewability, and durability to ensure optimal functionality and user experience. (i) Size and resolution must be carefully balanced. The display should be large enough to be functional while fitting within the constrained space of the smartring. (ii) The display must facilitate depiction of nano visualizations while minimizing power usage. (iii) Viewability under various lighting conditions, including direct sunlight and wide viewing angles, is important for readability. (iv) The display must be flexible enough to be bent into a ring shape without damage. Therefore, *VisRing* is designed with a display for optimal performance, offering high resolution, viewability, and flexibility.

Comfortable Wear. When designing a wearable smartring with an integrated display, it is important to carefully optimize its size, weight, and form factor to achieve the ideal balance between functionality, user comfort, and aesthetic appeal. The smartring must be sufficiently compact to fit comfortably on a finger without feeling bulky, while the display should deliver crisp information with a high resolution within the limited space available. Using lightweight materials such as thermoplastic polyurethane (TPU) is essential to minimize weight, ensuring the smartring can be worn comfortably for extended periods. Integrating all necessary electronic components, including sensors, a battery, and a display, demands careful planning to optimize weight

[1]Hardware library: https://github.com/TaitingLu/VisRing

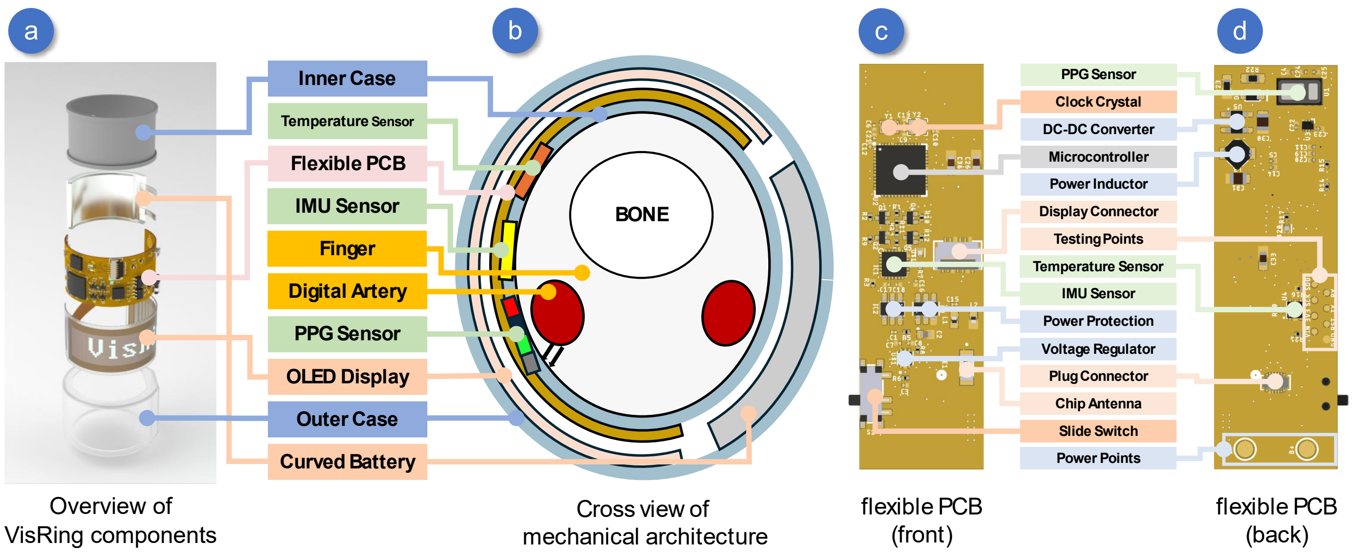


Figure 3: (a) Explosion rendering of *VisRing* depicting an overview of the components. (b) The mechanical structure of *VisRing*, illustrating the position and arrangement of various sensors (IMU, PPG, temperature), the OLED display, and the curved battery. (c) The top of the FPCB board contains the computing, sensing, and display connector. (d) The bottom of the FPCB board contains the PPG, temperature sensor, and SWD programming interface.

distribution and space usage. *VisRing* is designed to be a lightweight, comfortable smartring with a compact form factor, while effectively providing nano visualization.

Mobility. *VisRing* should support wireless communication to enable real-time synchronization and seamless data transfer between the smartring and a smartphone. This connectivity could allow the smartring to display notifications, messages, and alerts from the smartphone directly on the smartring's display, providing wearers with immediate access to important information without needing to check their smartphone. Bluetooth Low Energy (BLE) is particularly suited for this purpose due to its low power consumption, which is critical for maintaining battery life in the compact form factor of a smartring.

Support a Wide Range of Functionalities. We want to support a wide range of functionality (e. g. real-time health data visualizations, notification delivery, and time display), *VisRing* features an OLED display and multiple sensing units. While an OLED display provides opportunities for nano visualizations, multiple sensing units not only enable motion analytics applications like finger motion tracking [43, 60, 72, 95], but also a diverse range of health applications like heart-rate monitoring, activity tracking, and sleep supervision [58, 67, 71].

Extensibility. *VisRing*'s hardware and software platform should be extensible by the research community. *VisRing* should have a Serial Wire Debug (SWD) programming interface, allowing for straightforward connection to development tools. Researchers can use standard programming environments such as Arduino [3] or Segger Studio [70] and software development kits (SDKs) to write and upload code. Using familiar development platforms and interfaces ensures that researchers can implement firmware updates as well as debug and test new functionalities.

Manufacturability and Cost-Effectiveness. It is essential to select materials that balance cost-efficiency and durability to enhance the accessibility and affordability of *VisRing* for the research community. For the housing cases, we used 3D-printed materials to simplify the manufacturing process. The platform incorporates commercial off-the-shelf electronic components, known for their cost-effectiveness and wide availability. These components are integrated into a custom-designed 4-layer PCB, strategically engineered to minimize PCB manufacturing costs.

3.2 Platform Design

In this section, we discuss the selection of sensing modalities used for *VisRing*, covering aspects such as form factor and circuit configuration, programming interface, how to assemble *VisRing*, as well as firmware and smartphone connection, along with a comprehensive analysis of the manufacturing costs associated with *VisRing*.

Choice of Sensing Modality. As depicted in Figure 2, we harness diverse sensors, including an IMU, a PPG sensor,

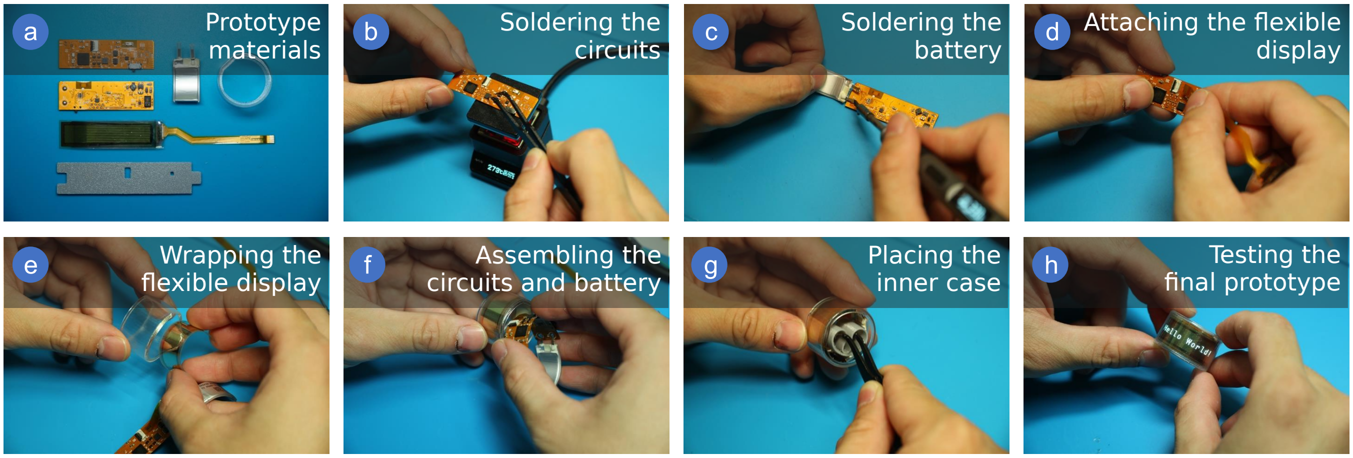


Figure 4: Images of how to assemble *VisRing*: Soldering all electronic components (a) of the circuit using a mini hot plate pre-heater (b), soldering the curved battery using a soldering iron (c), assembling the cable of the bendable OLED display on the circuit (d), wrapping the bendable OLED display inside the outer case (e), assembling the flexible circuit board and battery to the outer case (f), using tweezers to align the inner case inside the housing (g), and testing the final prototype with the text "Hello World!" (h).

and a temperature sensor to provide wearers with real-time data through an OLED display and support a wide range of applications. The IMU module is an ICM20948 [38] by TDK InvenSense, which incorporates an accelerometer (3-axis), a gyroscope (3-axis), and a magnetometer (3-axis). The PPG module is a MAX30101 [37] by Maxim Integrated, which integrates three-channel LEDs, including a green LED (527 nm), a red LED (660 nm), and an infrared LED (880 nm). The temperature sensor is a TMP117 [36] by Texas Instruments, which can provide digital temperature data. Incorporating various sensors improves *VisRing* by delivering a comprehensive set of health and fitness data to the wearer, thereby enabling personalized visualizations.

Form Factor Design. Our goal is to design a lightweight and comfortable smartring, as described in Section 3.1, with a display that allows wearers to quickly access health and fitness data from their fingers while embedding various electronic components within a limited space. Figure 3a and Figure 6 depict the form factor design of *VisRing*. We exploit opportunities including circuit design, mechanical design, and 3D printing technology to minimize the form factor while satisfying comfort and functionality for the wearer to integrate various components within a limited space in a smartring. (i) We design a 4-layer FPCB to integrate a high-resolution OLED display, multiple sensors (IMU, PPG, temperature), a battery, and a microcontroller within an ultra-compact form factor. The arc-shaped battery is embedded within the smartring to power the device (Figure 4a and Figure 4f). (ii) Figure 3b shows the mechanical structure of *VisRing*. We strategically arrange the PPG and temperature sensors in close contact with the wearer's digital finger artery, optimizing data accuracy and comfort. (iii) We encase the hardware in a skin-friendly 3D printed housing ideal for prolonged wear as shown in Figure 4h. Specifically, we choose a transparent resin material crafted using Stereolithography (SLA) 3D printing technology. This choice was made to facilitate the visualization of data shown on the OLED display, ensuring optimal clarity. The inner case of the smartring is designed to conform to the dimensions of an individual wearer's finger. *VisRing* is manufactured using fused deposition modeling (FDM) technology, employing TPU materials selected for their inherent flexibility and ability to enable comfortable contact with the skin. *VisRing* weighs between 5.6 and 6.6 g, with the exact weight varying based on the ring's size, which is adjustable to accommodate different finger sizes. The ring has a thickness of 3.85 mm and a width of 18 mm.

Circuit Design. As depicted in Figure 3c and Figure 3d, we design a 4-layer FPCB to integrate the following hardware components to meet the design goals discussed in Section 3.1. All electronic components are carefully assembled into a single FPCB to fit the limited form factor as shown in Figure 4. The hardware architecture is depicted in Figure 2. We designed a circuit for the microcontroller based on the NRF52832 [57] by Nordic Semiconductor as our microcontroller unit (MCU) which supports multiple interfaces including Serial Peripheral Interface (SPI), Inter-Integrated Circuit (I2C), Universal Asynchronous Receiver/Transmitter (UART) and embeds a 2.4 GHz radio frequency (RF) transceiver for

BLE. The NRF52832 communicates with the IMU via SPI, the PPG via I2C, the temperature sensor also via I2C, and the OLED display via 3-wire SPI and transmits sending data to a smartphone if needed. The OLED display [15] by Crystalfontz provides 160×32 4-bit grayscale with 88 dots-per-inch (DPI). The display, measuring 14.94 mm in width and 50.6 mm in length, can be bent into an arc to fit inside the form factor of a smartring. The MCU, IMU, PPG, and temperature sensor require 3.3V and 1.8V, while the OLED display operates at 12V. To meet these power requirements, we design a power regulation circuit using the MIC5370 [79] dual low-dropout (LDO) voltage regulator from Microchip Technology to supply the MCU and sensing components, and the AP3012KTR [17] step-up DC-DC converter from Diodes Incorporated to boost the battery voltage to 12V for the display. Finally, we designed a battery management unit to protect the PCB and battery from overcharging and discharging. We employ a curved lithium battery with 60 mAh as the power supply for *VisRing*. When actively visualizing sensor data on the OLED display and simultaneously streaming data to a smartphone, the hardware's power consumption is approximately 29.5 mA at 3.7 V, equivalent to 109 mW. This allows for up to two hours of continuous display operation. We extend the usage time by implementing a function to automatically turn off the display after some time. The wearer can then use the IMU as an input to wake up the display.

Programming Interface. To fulfill our goal of extensibility as described in Section 3.1, *VisRing* needs to incorporate an SWD programming interface for ease of development. However, given the limited form factor of *VisRing*, we exploit the use of the board-to-board plug connector by Molex [52], as depicted in Figure 3d, to enable easy firmware programming while minimizing the space of the interface.

Assembling. Figure 4 illustrates the step-by-step assembly process of *VisRing*. It begins with preparing all components, including the flexible circuit, curved battery, and OLED display (Figure 4a). The electronic components are soldered (Figure 4b–c), followed by attaching and wrapping the bendable OLED display around the circuit (Figure 4d–e). The circuit and battery are then inserted into the outer case (Figure 4f), the inner case is aligned using tweezers (Figure 4g), and finally, the prototype is tested to confirm successful assembly (Figure 4h).

Price Breakdown. Table 2 summarizes each hardware component's retail and wholesale unit price. All firmware packages and programs used during development are free. The total cost to produce a single *VisRing* is as low as $35.62.

Table 2: Manufacturing cost breakdown of the VisRing prototype. All prices are per unit and in USD.

Component	Retail	Wholesale
MCU	5.03	2.39
PPG Sensor	11.21	6.43
IMU Sensor	8.32	4.61
OLED Display	37.52	16.94
Chip Antenna	0.59	0.23
Voltage Regulator ICs	1.94	0.94
Battery Protection ICs	0.32	0.18
Case	2.11	N/A
Arc Battery	4.90	3.90
Total	71.94	≈ 35.62

4 Implementation

We create the *VisRing* library[2] with proof-of-concept nano visualizations for various data types that can be used for many scenarios (Figure 5). We base our implementation on the open-source firmware of our hardware components [1, 2, 36, 74] to combine reading sensor data, using Bluetooth, and visualizing data. We provide the *VisRing* library as open-source software, and briefly describe its functionalities in the following. More details can be found in the repository.

4.1 Display Firmware Extension

The open-source firmware by SparkFun [75] implements the interface to control the display. It enables displaying grayscale images, while text, lines, circles, and other geometric primitives are limited to monochrome color. We overcome the underlying limitation and add variants of all functions that fully using the capability of the display to use 16 shades of gray. We release the updated firmware as a fork under an open-source license that aligns with the original.

4.2 VisRing Library

Based on the updated firmware, we present the *VisRing* C++ library for nano visualizations on smartrings. It provides tight integration and extendability by inheriting all functions from the display's firmware. It includes functions for all sensors of *VisRing*, establishing a BLE connection, and sending and receiving data over this connection via UART. Further, a set of functions is available to automatically turn off the display after some time and wake it up again through a double-tap on the smartring that the IMU detects.

Regarding visualizations, *VisRing* includes versatile functions for common visualizations like bar charts, line charts, progress charts, and text, but also to display notifications and

[2]Software library: https://github.com/ChristianKrauter/VisRing

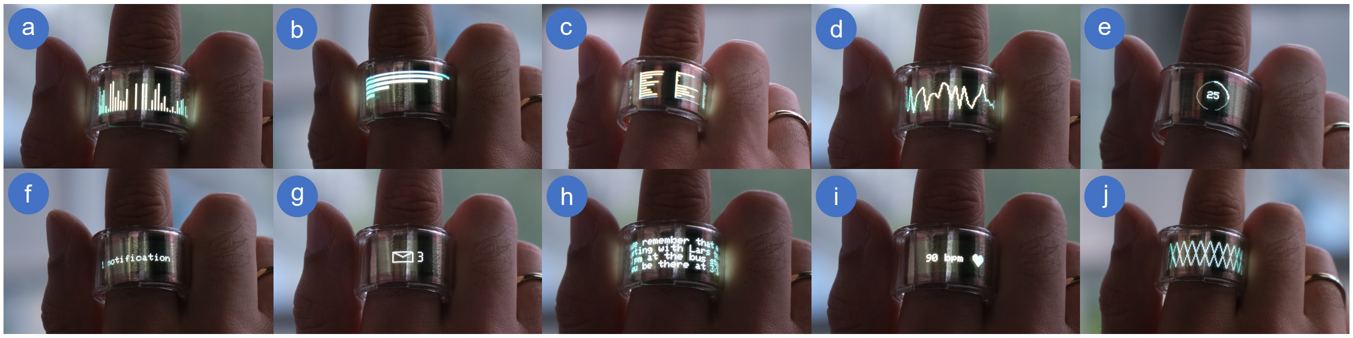


Figure 5: The visualizations provided in the *VisRing* library shown on a *VisRing* worn on the index finger: (a–c) horizontal, vertical, and small multiples bar charts, (d) a line chart, (e) a radial progress chart, number of notification with (f) a message, and (g) an icon, (h) a text, (i) the heart rate with an icon, and (j) one of three decorative patterns.

decorative patterns (see Figure 5). With these common micro visualizations [7, 12], many data types can be visualized, resulting in a wide range of possible applications, although health, fitness, time tracking, and notifications are likely the most useful for wearers.

Bar charts can be drawn horizontally (Figure 5a), vertically (Figure 5b), and as small multiples [81] (Figure 5c) to depict data from multiple days. These can be used to display data such as step count and sleep with up to seven vertical bar charts at once, each with a maximum of 16 values because we have a width of 32 pixels.

For horizontal **line charts** (Figure 5d), the limit for the value range is 160 (i. e., one pixel for each value). With such a chart, numerical data can be shown over time, such as heart rate or stock value.

Radial progress charts are popular on smartwatches to show progress, such as the minutes of daily activity, progress towards a step goal, or as a timer for a washing machine or the Pomodoro technique [91]. *VisRing* includes an implementation with eight 12.5% steps and the option to show the percentage inside the circle (Figure 5e).

We further provide two **notification** displays (Figure 5f–g), a clear usage scenario of smartrings, as well as a function to display **text** (Figure 5h).

For health and fitness data, another popular usage scenario, we implemented a basic visualization of the **heart-rate** and **heart-rate zone** (Figure 5i).

Finally, we present three different **decorative patterns** (e. g., Figure 5j), showcasing *VisRing*'s capability as a fashion accessory. The *VisRing* library further includes example Arduino sketches for all visualizations and functionalities, as well as one that shows the wearer's live heart rate and heart-rate zone, heart rate over time, the progress of a 2-minute timer, realistic step data, and notification information.

5 Nano Visualizations

Nano visualizations are ultra-compact data representations rendered on miniature, often non-planar screens integrated into wearable devices such as smartrings. Like micro visualizations [40], nano visualizations are designed to convey essential information at a glance and often support privacy-aware rendering strategies, for which sensitive or contextual data can be dynamically hidden or selectively disclosed.

We identify four design considerations that distinguish nano visualizations on smartrings from micro visualizations on smartwatches: (i) The small display of a smartring—in our case having a width 32 pixels—makes the visualizations even smaller than common micro visualizations (Google Pixel Watch 3: 456 pixels) or the complications found on smartwatch faces (around 90 pixels [7]). Here, we have the option of using small multiples instead of a full bar chart to use the available display space, or use arc or gauge charts that use only a half-circle, which allows more space for this type of visualization. (ii) They span a larger width and often have a curved display. Our display has 160 pixels in height and is bent around the finger, covering about 270° to 360° depending on finger size. (iii) Part of the display of a smartring, when placed on a finger, might be hidden from view. The fingers next to the finger wearing the smartring (e. g., when worn on the index or ring finger) cover a part of the display. Also, a part of the display might even be on the inside of the hand. In this case, a wearer can only see what is currently in the field of view and would have to rotate the smartring to see the rest of the display. We suggest the use of one-handed interactions for easy access to all parts of the ring (cf. Figure 8.4). (iv) The display of a smartring can support both private and public viewing by leveraging its partial visibility. Because part of the display is hidden from view on the inside of the hand, this unique feature supports privacy-aware rendering strategies, in which sensitive or contextual data (e. g.,

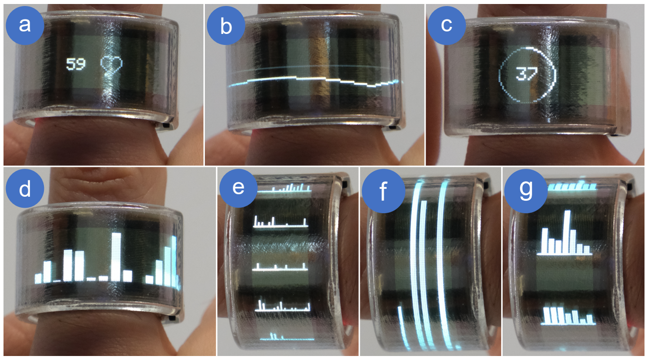


Figure 6: The visualizations used in the user study: (a) current real-time heart rate with heart-rate zone, (b) line chart of real-time heart rate, (c) progress chart, and bar charts showing step data of (d) 24 hours, (e) 7 days à 16 hours, (f) 7 days, and (g) 4 weeks à 7 days.

the current blood pressure, blood glucose level, or menstruation data) can be dynamically hidden or selectively disclosed (cf. Figure 8.3).

Last, our current display features only 4-bit grayscale, which results in 16 shades of gray. For common visualization techniques found on smartwatches, this is enough, because commonly only a few colors need to be distinguishable (e. g., three heart-rate zones) [26]. However, we can also draw on research from e-ink displays, which use black-and-white textures for visualizations [29].

6 Qualitative Study

We conducted a qualitative study to evaluate the hardware of *VisRing* and the nano visualizations displayed on the ring. Our goal was to get feedback on the comfort, likability, and acceptance of the smartring itself, but also about the readability and usefulness of the nano visualizations. We wanted to gather the strengths and weaknesses of our current design to make future adjustments both to the hardware itself and to the nano visualizations. The participants experienced wearing our *VisRing* and seeing four visualization techniques on it while walking around indoors for two minutes each.

We tested seven visualizations depicting health data during the study: heart rate as text with their heart-rate zone as an empty, half-full, or full heart (Figure 6a), heart rate over time as a line chart (Figure 6b), a progress chart of a 2-minute timer (Figure 6c), and four versions of a bar chart (horizontal showing step data for 24 hours (Figure 6d), small multiples with 7 days à 16 hours (Figure 6e), vertical showing 7 days (Figure 6f), and small multiples with 4 weeks à 7 days (Figure 6g)). We used a within-subject study design, counterbalancing the order of visualizations with a balanced Latin square to eliminate learning and fatigue effects. The study took place in a bright, high-ceiling building to ensure comparable lighting conditions independent of time and sunlight. We took notes of participants' comments during the study, and after all four conditions, we conducted a semi-structured interview. After filling out a questionnaire about their use of wearable devices, if they would like to use the ring for the visualizations shown during the study, and demographic questions, they were remunerated $14 for their participation. We got the approval of the responsible ethics board at our university to carry out the study.

6.1 Participants

We recruited 12 participants through different university-related mailing lists and word-of-mouth. The demographics of our participants can be seen in Table 3. Half (6) of our participants had a vision deficit, and one wore no vision correction. One participant was left-handed, one ambidextrous, and the other 10 right-handed. While 7 participants indicated using smartwatches or smartbands and rings, only one participant mentioned using smartrings (see Figure 7a).

6.2 Results

Participants' answers to the question of whether they would like to use the four visualizations on *VisRing* can be seen in Figure 7b, clearly indicating an overall positive response to *VisRing* and its visualizations. The responses were also mainly positive when asked about using *VisRing* alone or around others, as can be seen in Figure 7c. The more insightful feedback comes from participants' comments during the study and the answers to the interview questions. We used the affinity diagram technique [32] to sort and group ideas into common themes. The following provides the aggregated feedback from participants grouped into these themes. We did not ask participants to make final judgments, but asked them about their opinions. Therefore, the numbers do not necessarily add up to 12. They merely indicate how many comments we received from participants for a specific theme.

Table 3: Demographic information for the 12 participants of our qualitative study.

(a)

Age Range	#
18–24	4
25–34	8

(b)

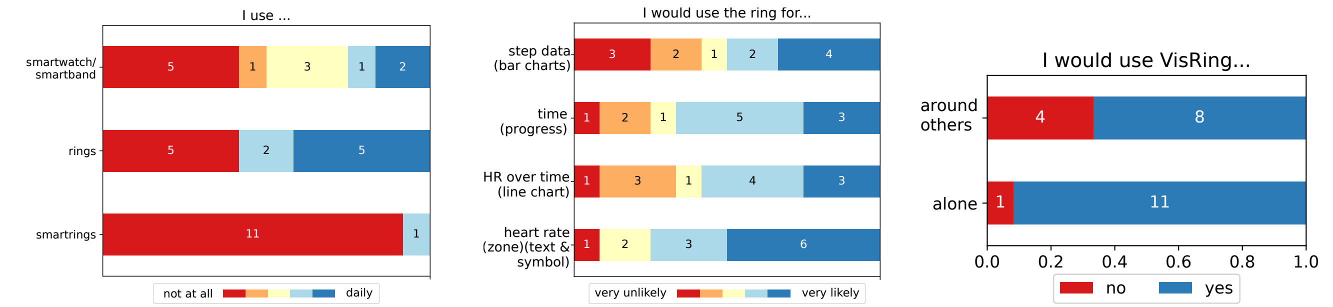
Gender	#
Woman/Female	6
Man/Male	6

(c)

Education Level	#
High school	2
Bachelor or equiv.	4
Master	6

(d)

Primary Occupation	#
Student	5
Ph. D. researcher	5
Other	2



(a) Use of wearables **(b) Use of visualizations** **(c) Usage context**

Figure 7: The aggregated responses of our qualitative study participants about (a) the frequency of using smartwatches/ smartbands, rings, and smartrings; (b) their interest in viewing visualizations and data on a smartring; and (c) their preferences for using *VisRing* alone or in social settings.

6.2.1 Visualizations. First, we discuss concrete feedback participants gave with respect to the visualization techniques. The number in parentheses counts how many comments we received for a given aspect. We only report on aspects that were mentioned multiple times. All detailed answers can be found in the supplemental material.

Heart-rate Icon. Participants mentioned that the heart rate depicted as a text and icon was cute and beautiful (4), easy to read (2), and overall good (3).

Heart Rate over Time Line Chart. Again, participants mentioned that the heart rate over time line chart was good (3) and readable (4). However, participants also mentioned that readability was difficult (8) (e. g., "*newest values least readable (positioning problem)*"). Participants indicated that they would like to have some reference lines for showing ranges (heart-rate zones) (3) (e. g., "*multiple lines to show desired range*"). Also, they wanted to see the current heart-rate value in text form (3) (e. g., "*add number of current value*").

Timer Progress-Chart. The progress chart was also mostly mentioned as being good (5) and readable (4). However, some participants found the progress chart hard to read and interpret (3) (e. g., "*in-between values harder to read*"). Additionally, participants mentioned changing the circular progress chart to a bar progress chart (3) (e. g. "*could be progress bar*").

Step-Count Bar-Charts. For the bar-chart visualizations, the results are mixed depending on the specific version. The 4 weeks à 7 days bar chart was mentioned positively (4), as well as the horizontal bar chart depicting step count data for 24 hours (3). Representing 7 days as a vertical bar chart got mixed statements: some mentioned it to be good (2), but most mentioned it was *"hard to read and confusing"* (5). The 7 days à 16 hours bar chart was the version that most participants disliked (4).

Some general comments about the readability of the bar charts mentioned that "*the axes changed between charts*" and "*bottom charts easier to read than top*" (in the small multiples representation), as well as "*can't tell time of peaks.*" Some improvements included to *"show total steps per day / week,"* "*show most important data, only the necessary, aggregate,*" or "*[use] comparative values / goal line.*"

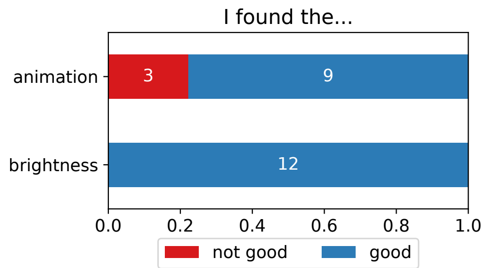
General. Further feedback about the visualizations included that participants liked that they were small, simple, and had a minimalistic design (4) (e. g, "s*imple and easy to read visualizations*"). However, some had a desire for more numbers instead of charts (3) (e. g., "*but [I] would prefer more numbers instead of graphs*").

6.2.2 Hardware. We asked participants specific questions about the hardware, such as about the smoothness of the animation, the brightness, readability, and likeability, including comfort and fit.

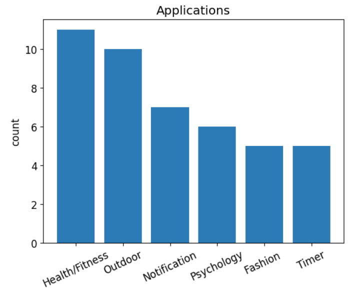
Participants rated the smoothness of the animation of the line chart (Figure 8a, top). Additional comments included that participants did not find it important (4) or did not even notice (3). All participants found the brightness good (Figure 8a bottom), but some mentioned concerns about how sunlight would affect the readability (4). When asked about readability in general, we had comments that the display was "*nice and clean without clutter*" (3). However, some comments mentioned not being able to see all the data at once for some of the visualizations (4). Regarding the likeability and comfort of our *VisRing* prototype, the ring was mentioned to be lightweight (4). However, participants also commented that the ring did not fit their (preferred) finger (8), that the ring is too thick (5), and generally uncomfortable or sweaty (5).

When asked about features the ring would need so participants would use it, comments included statements about interaction (7), tracking of time, fitness, or sleep data (5), and wanting to see the time and date (5).

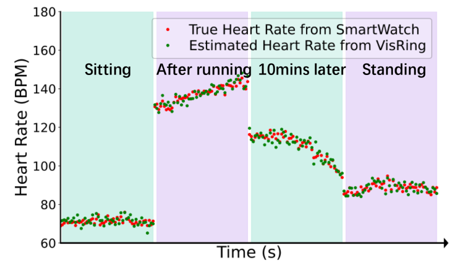
For possible improvements to the ring, comfort, size, and wearability were the themes that got many statements (17).



(a) Rating of display brightness and animation smoothness of *VisRing*.



(b) Future application ideas for smartrings of our participants.



(c) Heart rate comparison with a smartwatch.

Figure 8: User evaluation and heart rate sensing performance validation of *VisRing*.

Also, improvements to the hardware and material in general received a number of statements (9). Additionally, comments contained wanting a color display (3), adjustable brightness (3), and a waterproof ring (2).

6.2.3 Potential Application Ideas. To evaluate the perceived value and potential of *VisRing*, we asked participants to suggest additional applications for the smartring beyond those we demonstrated. As shown in Figure 8b, the most common themes were Health/Fitness, Outdoor, and Notification usage scenarios. Participants also mentioned ideas in Psychology, Fashion, and Timer applications, highlighting the ring's versatility. These insights suggest a strong interest in both practical and creative uses, supporting *VisRing*'s potential for broader visualization.

7 Quantitative Sensor Evaluation

We conducted a quantitative study to assess the accuracy of the PPG, acceleration, and temperature readings by comparing them to a state-of-the-art commercial smart watch [68]. To validate the PPG data, we conducted a preliminary heart rate monitoring study in which participants performed simple activities (i. e., sitting, standing, running, and standing again) while we collected PPG signals to estimate heart rate. We estimated heart rates while participants remained stationary following each activity, and as shown in Figure 8c, *VisRing* provides heart rate estimates that closely align with the reference measurements. Figure 9a presents an example of PPG data after applying a band-pass filter. Key biometric features—such as systolic and diastolic peaks, as well as inter-beat intervals (IBI)—are highlighted and can be used to monitor heart rate.

To assess the accuracy of *VisRing*s acceleration and temperature readings, we recorded data during controlled activities to ensure temporal alignment for comparison. As shown in Figure 9c and Figure 9b, the raw signals from *VisRing* closely resemble those from the smartwatch, validating the fidelity of our temperature and motion sensing modules.

8 Discussion

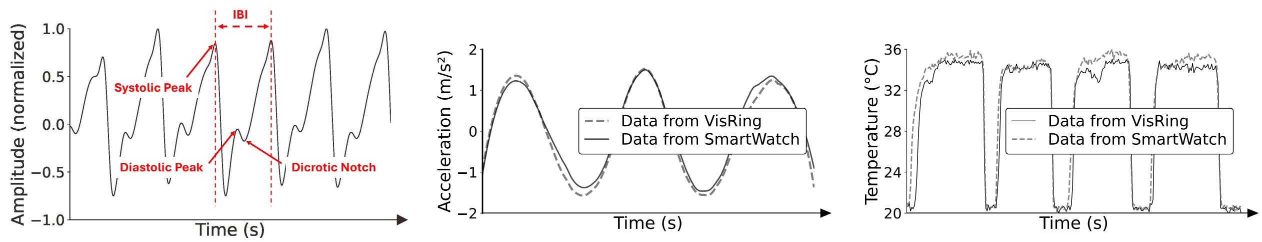
Based on our development of the *VisRing* hardware and software, as well as the qualitative study, we discuss our findings and potential use cases.

8.1 Reflectivity

Our goal with the paper is to show the feasibility of designing a smartring that integrates a bendable OLED display for showing nano visualization. However, we believe there is more work to be done before the smartring can be turned into a finished product. The mechanical design can be optimized. For example, currently our outer case for *VisRing* is made from a 3D-printed transparent resin material. Though this material reflects light, which reduces the visibility of *VisRing*'s screen, participants in the qualitative study found the smartring display to be bright enough and only one participant complained about the reflections. The non-reflective glass can be used to enhance screen visibility. However, non-reflective glass requires advanced manufacturing techniques such as chemical etching or multi-layer optical coatings and is much more expensive than 3D-printed resin material used for *VisRing*. The tradeoffs in reflectivity, manufacturing complexity, and material cost must be carefully considered.

8.2 Nano Visualizations

Creating visualizations is easier than ever with various software packages, libraries, and whole ecosystems available for free, like D3.js [8] or Matplotlib [34]. For *VisRing*, we are currently limited to pixel manipulation, having to implement even the most basic visualizations with primitives. Therefore, the flexibility of our implementations is limited. The qualitative study (Section 6.2) provided us with many ideas on how to improve the current nano visualizations, but also about which other types of nano visualizations to add (e. g., a progress bar chart).



(a) PPG data (green channel) after a bandpass filter. **(b) Raw acceleration data comparison with a smartwatch.** **(c) Raw temperature data comparison with a smartwatch.**

Figure 9: Sensor signal fidelity of *VisRing* compared to a commercial smartwatch.

8.3 Adaptive Privacy Display

A crucial aspect to consider is privacy—specifically, ensuring that private data is visible only to the person wearing the smartring. With smartwatches, sensitive information like a text message is typically displayed on a flat screen, making it visible to the wearer when they look at the display and potentially to people nearby. In contrast, our *VisRing* features a 270° to 360° display. As depicted in Figure 10, when a person wears *VisRing* on their index finger, the display is divided into two zones: a private area facing the palm and a public area facing outward. This allows the wearer to view sensitive information, such as heart rate, privately, while displaying non-sensitive data, like a timer, on the public-facing side. Depending on which finger the smartring is worn, different display sections are exposed to varying degrees. For instance, if the smartring is worn on the middle finger, the front and back of the display are visible, while adjacent fingers occlude the sides. In such cases, private data could be shown on the part of the display facing the palm (inner hand), while public data could be displayed on the outer side, addressing privacy concerns effectively. However, this solution may not be feasible if the smartring is worn on the thumb when all sides are potentially more exposed.

8.4 One-handed Interaction

A key difference between *VisRing* and smartwatches lies in their interaction modality. More specifically, wearing *VisRing* on a finger allows for single-handed interaction, enabling the user to use the thumb of the same hand to change the visualization content on the display, whereas smartwatches require two-handed interaction. This one-handed operability enables more seamless interactions in contexts where the other hand is occupied, such as during physical activity or commuting, and supports more discreet use in social settings. For example, when checking a message or notification, smartwatch users need their other hand to scroll or navigate, whereas *VisRing* allows users to perform the same action using just one hand. Figure 11 illustrates a wearer interacting with *VisRing* using only one hand, revealing the full sentence "The quick brown fox jumps over the lazy dog," a standard English pangram, to demonstrate one-handed interaction use case. By rotating the ring worn on the index finger with their thumb, the user can navigate and view messages directly on the curved display. The interface automatically rotates the content based on gyroscope readings.

9 Limitations and Future Work

Building on the current design and evaluation, this section explores several opportunities for future improvement and further development of *VisRing*.

9.1 Power Efficiency

While the OLED display enables visualizations of real-time data, it comes with trade-offs in energy efficiency. Given the importance of power efficiency in wearable devices, e-ink displays may offer a viable alternative in usage scenarios for which high refresh rates are not required. Compared to OLED displays, e-ink displays consume almost no power when the screen is not updated. However, the main drawback is their lower refresh rate. An example of a flexible e-ink display is the Waveshare [89], which has a similar size, pixel density, and price as our display for comparison. Its idle power consumption is nearly zero (5.2 µA) while updating a single frame consumes approximately 8 mA. Ignoring other power-consuming components, we estimate that an e-ink display could last around 7.5 hours with continuous updates at a 2-second refresh rate, producing approximately 13,500 frames. This is a significant improvement compared to our current 2-hour battery life. The battery life could extend to several days if the display is not updated continuously. However, we did not adopt an e-ink display in this prototype because its low refresh rate would limit our ability to support visualizations of real-time data that require more frequent updates. Therefore, a feature was implemented that automatically turns off the display to extend battery life. This technique can increase battery life by several additional hours, depending on how frequently the wearer interacts

Figure 10: Adaptive privacy with *VisRing*: The private zone (left) shows information like the heart rate to the user; the public zone (right) shows a timer to others.

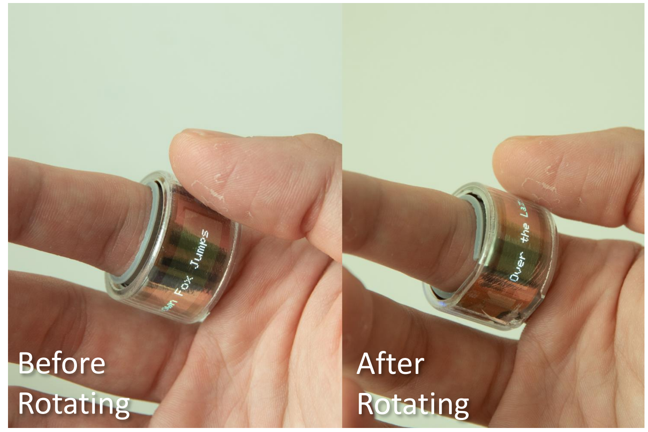


Figure 11: One-handed interaction with *VisRing*: The user rotates the ring with their thumb to view content on the other side of the ring.

with the ring. In the future, we also plan to explore ultra-low-power micro-controllers to extend usage time and enable longer continuous operation.

9.2 User and Real-World Evaluation

Our initial user study focuses on evaluating the feasibility of the hardware and nano-visualization design, with participants providing feedback on these aspects. However, additional user studies with contextualized benchmarks are needed to further assess usability and real-world performance. In future work, we will conduct real-world diary studies in which participants wear *VisRing* during everyday activities (e. g., running, cycling, attending meetings, and spending time outdoors). Participants will regularly log how they use the ring, the surrounding context, and their experience over time. To complement this, we will include in-the-wild think-aloud sessions, prompting users to verbalize their thoughts during actual use. This approach will help uncover usability issues and provide deeper qualitative insights, for example, evaluating the ring's display readability and screen reflections under direct sunlight.

As demonstrated in prior HCI research [14, 51], contextualized benchmarks could reveal subtle trade-offs and guide design improvements. In future work, we will compare *VisRing* with existing wearable devices (e. g. smart watch, clip-on display and LED smart ring) in terms of glance-recognition time, reading accuracy, and NASA-TLX workload[28] to better understand the differences and design trade-offs between *VisRing* and these alternatives. These comparisons will help improve future iterations of *VisRing* by highlighting strengths, limitations, and areas for usability enhancement in real-world contexts.

9.3 Display and Ring Size

While our current prototype may have appeared bulky to some participants, *VisRing* is still the most compact ring among existing devices that incorporate a display. This limitation is primarily an iterative engineering challenge rather than a scientific one. Achieving a smaller form factor would require custom-designed displays and batteries, which are beyond the scope of this paper. Nevertheless, our work lays the technical foundation for designing a compact ring with an integrated display and demonstrates the promising potential of this form factor. Our current prototype uses a 44.5 mm-wide display, which provides approximately 20% more screen area than typical wristbands or the Apple Watch. However, despite the larger size, the display's limited resolution, particularly the 32-pixel height, led to significant challenges. Many visualizations were truncated, and participants frequently expressed confusion with small-multiple bar charts. In future iterations, we plan to adopt a smaller 14.94 mm-wide display [18] to achieve a more compact and comfortable form factor. While this will reduce the physical display area, we aim to maintain visibility and expressiveness by upgrading to a higher-resolution screen. This can be achieved by integrating a more advanced display driver circuit with greater frame buffer capacity, at the cost of modest increases in power consumption and component cost. Additionally, we plan to improve user comfort by optimizing the ring's casing material. Using breathable materials, such as medical-grade silicone, can enhance airflow and reduce sweat accumulation during prolonged wear.

Moreover, our study is an exploratory proof-of-concept and does not compare *VisRing* to other smartrings, smartwatches, or other control conditions. Nonetheless, given its novelty, design, and use of nano visualizations, we believe the study clearly demonstrates the strong potential of *VisRing*.

9.4 Sensors and Input Capability

VisRing incorporates a bendable OLED display and multiple sensing units in the current *VisRing* design. While the bendable OLED display can be used in several applications in visualization, the sensing units can be used for activity tracking. However, we believe that we have only scratched the surface. Additional touch-sensing sensors can be incorporated to enhance usability. This would allow wearers to interact with the smartring through touch gestures, such as tapping or swiping. Wearers can even operate it with one hand, depending on the finger. For instance, if worn on the index finger, they could tap or swipe using their thumb on the same hand. This intuitive interaction would be convenient during activities like working or running, enabling people with only one hand to use the smartring—impossible with traditional smartwatches. In the future, we plan to explore a capacitive touch sensor, enabling an interactive display that supports basic touch-based input. This opens up new interaction possibilities, such as pinch interactions or triggering actions with simple gestures. We will also explore IMU-based interactions to enable intuitive applications, such as scrolling through notifications using subtle finger movements. Additionally, integrating a microphone can enable voice interaction. Voice control would be handy when someone cannot use their hands, such as when carrying something. While the space might be limited to include all sensors in one ring, we are currently exploring these tradeoffs, and we hope that the community can extend our platform to enable exciting new possibilities.

10 Conclusion

We introduced *VisRing*, the first smartring equipped with various sensors and a bendable OLED display that, depending on the finger size, covers 270° to 360° of the ring. Our *VisRing* prototype weighs a maximum of 6.6 g and costs around $35 to produce. We extended the display's firmware to support full grayscale and provide an open-source library to visualize data from the sensors. Due to the display's small size and unique form factor, we introduce the term *nano visualizations* to describe the specific opportunities and limitations associated with presenting data on such a tiny screen. By using our open-source design, fabrication techniques, and nano visualization library, researchers and experienced makers can create custom smartring interfaces integrating a bendable OLED display and a variety of sensors. We conducted a qualitative study to demonstrate the working principle of *VisRing* and get initial feedback about the comfort, likability, and acceptance of *VisRing* and visualizations of health data. Additionally, we explored challenges and opportunities for the hardware, visualizations, interaction, and privacy of a smartring featuring a bendable display. In the future, we aim to adapt our visualizations to work with lower frame rates, enabling an e-ink display and significantly extending battery life. Additionally, we plan to explore privacy aspects further in future iterations. This will involve developing strategies to ensure sensitive information remains confidential, regardless of how the smartring is worn or others view it.

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