LitPorts: On-demand Illuminated Ports to Facilitate Inter-device Connections in Low-light Conditions

TIFFANY E. TAYLOR, University of Portsmouth, United Kingdom
WOLFGANG STUERZLINGER, Simon Fraser University, Canada

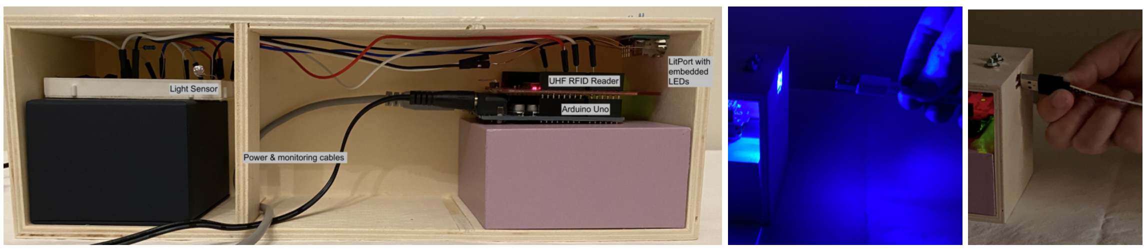

Fig. 1. LitPort prototype overview with labeled parts (LitPort on rightmost face of the device). In the presence of a matching plug in proximity, LitPorts are illuminated to facilitate establishing a connection in low-light conditions (middle). In the presence of a plug that does not match the receptacle LitPorts do not illuminate (right).

Plugging a cable or peripheral into a device is an integral aspect of daily use of computing devices for most users. Yet, in low-light or constrained-visibility conditions the simple act of finding the receptacle to connect a cable to can be challenging and lead to user frustration. To alleviate this frustration we present LitPorts, a technology that illuminates receptacles in low-light conditions when a compatible plug is in proximity, making plugging a cable in substantially easier and leading to a better all-around user experience. We also present user feedback from our prototype testing demonstrating the broad appeal and applicability of LitPorts.

CCS Concepts: • **Hardware** → Electro-mechanical devices; • **Human-centered computing** → **Mobile devices**; **HCI theory, concepts and models**.

Additional Key Words and Phrases: Receptacles, ports, illumination, NFC, computing devices, user experience

ACM Reference Format:
Tiffany E. Taylor and Wolfgang Stuerzlinger. 2022. LitPorts: On-demand Illuminated Ports to Facilitate Inter-device Connections in Low-light Conditions. In *OzCHI '22: connected creativity, 29 November – 2 December, Canberra, ACT*. ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/00000000.00000000

1 INTRODUCTION

We live in a computerized society. Phones, televisions, computers, and even cars are common devices in most households, and the list does not stop there [14, 35]. Recent research has shown that when such common technologies are difficult or otherwise frustrating for the user to interact with, users feel negatively towards the technology [38]. As technology that is frustrating to use is less likely to be adopted, the pervasiveness of technology has been supported by a wealth of work focused on improving the user experience in the user's interactions with technology [33]. Such work has focused

Manuscript submitted to ACM

primarily on user interaction with the device to make the use of device more user friendly or navigable while the area of device connectivity appears to be under-explored.

Device connectivity is an important aspect of device use. No matter what type of device is being used, at some point during the routine use of that device the user will likely need to connect either a second device or cable for input/output or charging [14, 35]. In certain conditions (e.g., low-light, constrained spaces, or other instances that create reduced visibility) this seemingly simple task can be difficult to achieve, as anyone who has ever tried to plug in a cable in a dimly lit situation knows. A recent study on user's experiences with technology found that a significant proportion of users find establishing such connections to be frustrating [38]. Building off of work on charging and sensing technologies and device illumination, *LitPorts* eases this frustration by illuminating the receptacle that the user is trying to connect to as a way to guide the user. Light has long been proven to be an effective means of guidance and a stationary light you are headed towards is more effective than a moving light source that you use to search with.

Our primary contributions benefit all users of devices regardless of their levels of expertise. These contributions include: Introducing receptacles that illuminate when the appropriate plug comes in proximity to make it much easier for user to hone in on the correct port and where the illumination ends when connection is made; reducing user frustration and thereby improving the user experience in situations that are (somewhat) challenging to deal with; and addressing this gap in the user experience through little additional hardware.

2 PREVIOUS WORK

2.1 Device Connectivity

While many types of connections are optional, such as headphones or keyboards, one connection that is necessity-based is charging. For many common devices (e.g., phones, laptops) if the device has no charge it will not work. Thus, device charging is a form of device connectivity that most users experience on a daily basis [35]. Establishing that physical connection requires the user to locate the charging port or receptacle on the device and connect the charging cable. Research on device charging can be divided into two categories, wired, which utilizes physical interconnection with a power cord to transmit electricity, and wireless, which transmits the electricity through an air gap [29]. Findings and developments in charging connections are easily transferable to other types of device connectivity as this connection process is also used for data transfer or connecting different peripheral devices for input or output needs.

Two significant developments in charging technology have been the introduction of both wireless charging and magnetic connections. Wireless charging utilizes a fully enclosed transmitter that relays the electricity to a receiver embedded in the device [20, 29] requiring a precise alignment of the transmitter and receiver with very limited physical separation between the two [20]. Such precise placement can be difficult for users to achieve, especially in scenarios without good visibility of the location where the device needs to be placed. Magnetic connections use magnetic attraction for the last few millimeters to connect the device to the charger. Apple introduced the MagSafe power adapter [2] for their laptops in 2006, which used a magnet as a means of securing the connection of the power cable to the charging port. Magnetic connections are also used for wireless charging such as with the Apple Watch [3] and Oral-B iO electric toothbrush [6]. However, the use of magnets may not be safe for all users, for example those with implanted cardiac devices [37], and is warned against in user guides [2, 3, 6].

2.2 Sensing Technologies

Sensing technologies can make device interaction more convenient [8] and have been used to aid the user in chaining devices [31], to facilitate data transmission between devices [9, 31], for touch or gesture recognition [7, 8, 23–25, 31, 34], power management [1], and otherwise recognizing human activity [8] but our review of the literature did not yield evidence of the use of sensing technologies to aid in a user establishing a physical connection to a device. For example, proxemics can be helpful in the area of device interaction if applied to the space a device occupies to determine when another device is in proximity. This has been demonstrated with display devices that provide on-screen graphical notifications indicating the presence of an additional display in the proximate area [31]. Capacitive proximity sensing relies on sensors [1, 23–25] that measure the electric field generated by a conductive object, such as the human body [7, 8, 34], and is not well suited for applications in which multiple different sensors are located in a small area [7, 8]. Wireless communication technologies such as Bluetooth and WLAN have been used for device binding when multiple devices are in proximity [26, 30] but are only effective when both parts have networking capabilities and, typically, plugs and cables are not networked. Most promising is Near Field Communication (NFC) which enables an NFC-enabled device to communicate with a proximate NFC tag to communicate information from the tag to the device to either retrieve data or perform an action [9].

2.3 Device Illumination

The use of light as a means to communicate information about a device is not new but is largely under-utilized in products [18], one notable exception being electronic keypad locks. These are becoming more commonplace and research has identified that, in low-light conditions, users of these locks significantly prefer the keypad to illuminate for use [38]. Researchers have explored the use of illuminated cables and receptacles in various ways including illumination as a means of conveying information about the active electrical load of a cable [12, 16] or outlet [19] as well as information about the status of the connected device [11, 22, 32]. The use of illumination as a means of locating a receptacle port has been explored by introducing touch-activated illumination of the housing of the male connector [10, 17] or of the surrounding area of a port or outlet [4, 11, 21, 43], either once the cable is connected [11, 21], or constantly [43], or for ports or outlets with a covering door such as the charging port of an electric vehicle, when the cover is opened [22]. Such cords and plugs are not necessarily that helpful in locating the desired receptacle in low light conditions as the light source is being controlled by the user and they still must first search for the port. Cord illumination requires the cord be powered, which is not true for many input/external devices, e.g., headphones, [32]. Outlets and receptacles that have the surrounding housing rather than the port illuminated are also not necessarily effective for aiding in precise device connectivity as many portable devices have a number of different ports clustered together in very constrained spaces, see Figure 2. Such an arrangement does not leave space to illuminate the area surrounding each individual port. An abandoned patent application from 2010 shows an initial foray into port illumination but, while being very narrowly focused to only USB ports, discussed such a wide variety of potential options for port illumination that no specific methods or implementation resulted and the patent was not granted [36].

3 LITPORTS

Building on the these prior works we present a method to make it easier to plug in devices in low-light conditions. The core idea of *LitPorts* is to illuminate a receptacle when:

- Nothing is currently plugged into the port,

Fig. 2. Left and middle: Example for devices where there are multiple different receptacles clustered together in a constrained space. Right: Ports in the center console of a vehicle photographed in late afternoon on a sunny day. Note that even though there is a lot of light, the ports are not that easily visible.

- the environmental illumination is low,
- and there is a matching plug in proximity.

Once all of these conditions are met, the receptacle is illuminated. For an illustration, see Figure 1.

Determining port availability and environmental illumination is relatively easy. Generally, a system knows when a port is occupied and environmental illumination normally requires just a photodiode and thresholding mechanism. Detecting if there is an object close enough to be potentially plugged into the receptacle can be achieved through some form of passive proximity-sensing technology, such as an inductive, ultrasonic, or capacitive proximity sensors, or some other electromagnetic or electrostatic method. A good option, and the core premise of *LitPorts*, is a strategically placed LED in the receptacle and an appropriately shielded RFID/NFC sensing coil near the receptacle as well as embedding a generic RFID/NFC tag in all potential plugs. Such a solution allows for identification of a matching plug in proximity to the port, and triggers the receptacle to illuminate, thus creating a *LitPort*.

An important distinction of *LitPorts* is that it is the receptacle itself that is illuminated and not a surrounding ring or area. There is existing technology, e.g., in electric vehicles, that features an illuminated ring around the receptacle but this necessitates a larger receptacle assembly area. This is undesirable in many circumstances, especially for mobile devices where space is at a premium as shown in Figure 2. By illuminating the port itself, *LitPorts* does not require additional surrounding space which makes it a more desirable solution for constrained spaces, such as in portable devices.

3.1 Prototyping a LitPort

We used an Arduino Uno with a SparkFun Simultaneous RFID Reader - M6E Nano to prototype *LitPorts*. To sense the ambient lighting condition, we connected a light sensor (a photocell) and the micro LEDs embedded in the USB-A plug to light up the receptacle, via a standard breadboard to the Arduino. The built-in UHF antenna of the RFID Reader enables the reliable detection of UHF RFID tags at 10 cm distance (initial experiments with standard HF RFID readers did not support reliable enough detection at this range). We used an AD-160u7 tag, as this can be directly attached onto the wire of a USB cable. The software running on the Arduino lights up the LEDs as long as the following conditions are met: the RFID reader reports the presence of a matching tag, the environmental illumination is below a predefined, heuristically determined threshold, and there is nothing connected to the plug.

Illuminating LitPorts: There are multiple options for illuminating a port. One of the simplest options is to place a light at an appropriate location inside the receptacle, which is a core premise of *LitPorts*. Today, Ethernet plugs and receptacles are often already made from clear plastic materials, which makes it trivial to illuminate them. Other receptacles have often various plastic components that can be replaced with a translucent version, which then can be illuminated by a strategically placed LED. By illuminating the port itself, *LitPorts* presents a more desirable solution for constrained spaces, see Figure 2. Some examples for existing ports that can easily be illuminated by replacing opaque plastic with translucent or clear material are shown in Figure 3.

Fig. 3. Illustration of several receptacles with some of the most salient parts that can be illuminated by replacing plastic components with translucent versions highlighted in red to create *LitPorts*. *LitPorts* illuminate only the receptacle not the surrounding area. From left to right: USB-A 3.0, Micro USB, USB-B 2.0, USB-C, VGA, HDMI, RJ45/Ethernet. Receptacles not to scale.

Matching LitPorts: A novel feature of *LitPorts* is that they illuminate only if a matching plug is in proximity. For example, an Ethernet port lights up only in the presence of an Ethernet plug, but not when a USB cable is near. To detect which type of plug is near we used an appropriately shielded NFC coil placed around the receptacle and a corresponding (unpowered) tag on the plug. With this technology a receptacle can then sense not only the proximity of the plug (RFID/NFC readers typically can read tags that are within a few centimeters), but also verify if it is the correct type of plug. See Figure 1.

We recruited student, staff, and faculty volunteers from the local university population and, following institutional ethics processes, 12 male and 3 female participants ranging in age from 20's to 50's provided informed consent to participate in the study. After completing a demographic pre-questionnaire all participants were asked to sit at a table that had a desktop computer and prototype USB-A *LitPort*. Then, to simulate nighttime conditions, the overhead room lights were dimmed to the lowest setting, creating a nearly dark environment. Immediately after dimming the lights, participants were asked to first plug in a USB-A cable into a normal USB-A port and then into the *LitPort*. No further prompting was given. As participants were not given the time to dark-adapt, i.e., they were still limited to photopic vision, this simulated the experience of plugging in a cable in a very dimly lit environment, where it was difficult (for most) to see the positions of the ports.

Subsequently, participants were asked to fill out a questionnaire about their experience. The individual measurement items Perceived Usefulness (PU) and Perceived Ease of Usefulness (PEU) [13, 39, 41], Confirmation Expectancy (CONF) and User Satisfaction (SAT) [5], Perceived Usability (USAB) [15, 28], User Enjoyment (ENJ) [27], and Self Efficacy (SELF) [40] were adapted from the existing literature.

The constructs were measured using a seven-point Likert scale ranging from "strongly disagree" (1) to "strongly agree" (7), except for SAT2 which asked about the users overall experience with the *LitPort*, where the scale ranged from "absolutely terrible" (1) to "absolutely delighted" (7), for both scales (4) was "neutral". Finally, participants were asked about their thoughts and observations for *LitPorts*.

4 RESULTS

Even though participants were exposed to *LitPorts* for the first time, all were immediately able to use it on their first attempt and the majority (n=11 or 73.3%) found the connection easier to establish in the illuminated condition while 2 found no difference and 2 said the non-illuminated condition was easier. Overall, the response to *LitPorts* was very positive, with average ratings in the range 5.7 to 6.5, i.e., "agree" for most measures, or a rating of 6.0, i.e., "delighted" for SAT2. The only exception was for confirmation, which elicited a rating of 5.3, i.e., "somewhat agree" response which, in retrospect, makes sense as the participants were introduced to *LitPorts* for the first time and had no prior expectation of performance, so confirmation cannot be expected. For the summary statistics see table 1.

Table 1. Questionnaire Results

Construct	Item	Mean	SD	Construct	Item	Mean	SD
Perceived Usefulness (PU)	PU1	5.9	1.0	User Satisfaction (SAT)	SAT1	5.8	1.2
	PU2	6.2	0.9		SAT2	6.0	1.0
	PU3	5.9	1.5	Perceived Usability (USAB)	USAB1	5.9	1.2
	PU4	5.7	1.1		USAB2	6.0	1.0
Perceived Ease of Use (PEU)	PEU1	6.0	0.9	Perceived Enjoyment (ENJ)	ENJ1	6.0	1.0
	PEU2	6.3	1.0	Self Efficacy (SELF)	SELF1	6.5	0.8
Confirmation (CONF)	CONF1	5.3	1.1		SELF2	6.1	0.8

Participants immediately saw the utility and benefits of *LitPorts* demonstrated by comments such as *"It was very intuitive as soon as it was illuminated"* [P11], *"A little light to help with the problem of plugging it in"* [P8], *"Having the guidance is great"* [P7], *"Good for users in dark environments"* [P3], *"This is great for at night, on plane, any place with low light conditions"* [P6], *"Useful not just on desktop but in other forms. For example I live in an old house where the electrical outlets and power bars are often in dark spots"* [P5], and *"The lighted port enhanced the experience"* [P7]. One participant directly identified one of the benefits of *LitPorts'* design when they stated that the light it provides *"Does not destroy your night vision"* [P11] while another wondered *"Why does not everyone have this?"* [P14].

Comments such as *"I scratched up my iPad around the plug by searching for the plug [in the dark]"* [P8], *"Nice that it lights up when you get near, some of the difficulty of plugging a cable in is taken out"* [P6], *"useful to plug in phone at night - I always fumble around"* [P15] identified areas of user frustration that *LitPorts* would be helpful in reducing. Additionally, some participants [P8, P12, P15] mentioned using the phone screen or flashlight to provide some illumination for plugging in a smartphone to charge but that it was an imperfect solution as light from these sources are directed *away* from the receptacle. Other comments discussed how *LitPorts* would help with the challenge of accessing receptacles at the back of equipment as it would be *"Most useful for plugging in a computer monitor or anything at the back of a desktop"* [P4] and *"Addresses the challenge of accessing port, I know the general area [of the receptacle], but some areas are so tight, helps narrow down the location. Still have to feel precise location"* [P7], as well as the benefit for broader populations saying *LitPorts* are *"great for new users AND new devices"* [P14], *"Useful for cable management in music stuff/industry"* [P5], *"Great for older people, my mom would enjoy this!"* [P6], and *"for people over certain age, [such as my] father with shaking hands, light guidance will be helpful, as will physical guidance"* [P9].

5 DISCUSSION

The limitations of previous work as discussed above point to an apparent void in the technology as there appears to be no existing inter-device connectivity method that enables ease of connection in low-light settings where the user is guided towards the receptacle. *LitPorts*, an illuminated receptacle that serves as a beacon for the user who is searching for the appropriate port, fills that void and is unique in doing so as only the receptacle itself is illuminated and not a surrounding ring or area.

As identified in the participant feedback, *LitPorts* benefit not just low-light conditions but potentially also vision-constrained settings and people who struggle with precision alignment tasks without visual guidance, thereby making technology more accessible to all demographics of the population. By improving this one aspect, physical connections to the device, the overall user experience will improve making *LitPorts* an attractive development for device makers as the adoption of technology is ubiquitous and there is a sizeable aging population. Discussing the concept of *LitPorts* with various non-participant device users also resulted in highly favourable responses and user interest.

While our current prototype involved only a dedicated device, *LitPorts* have broad potential applicability. Study participants were easily able to see uses for *LitPorts* in areas ranging from charging their mobile devices at night to connecting computer components and even cable management. In such situations it may be fairly easy to get somewhat close to the receptacle but locating the correct receptacle and aligning the plug and receptacle with the required precision to establish a connection can be frustrating for users [38]. *LitPorts* eases this frustration by illuminating the receptacle that the user is trying to connect to as a way to guide the user.

For example, research into battery usage and charging habits of cellphone users shows that most charging happens in the evening and at night [14, 35], with users frequently connecting to their chargers between 1:00am – 2:00am [14]. Evenings and nighttime are typically times of reduced light and performing a precision task, such as connecting a cable plug to its matching port, can be difficult to achieve easily in low-light settings. With *LitPorts*, the user only needs to grasp the cord or plug and maneuver it towards the device and the port will softly illuminate to show the user where to connect the plug, without impacting their drowsy state or night vision. For wireless chargers, including magnetic chargers, *LitPorts* could be implemented on the charging surface so the user could maneuver their device towards the charging pad which would then softly illuminate to assist with the precise placement of the device onto the charging pad. The fact that *LitPorts* illumination turns off when a successful connection is made then also informs the user that their device is properly connected for charging.

Large, non-portable devices such as big-screen TVs or desktop computers typically require a permanent installation in the space they occupy, and typically have their receptacles at the back of the equipment, where locating the proper port can be quite challenging, regardless of the level of room illumination. A further constraint in locating ports on such devices is that the devices themselves are frequently dark in colour to provide a sleek or cool aesthetic. When a user plugs in a peripheral device they must establish the connection in, typically, a constrained physical space with limited visibility. This can result in a seemingly simple task such as plugging an HDMI cord into a wall-mounted TV or a monitor to a desktop computer a time-consuming and frustrating task, as the user must try to search for a port they cannot establish an easy line of sight to. Using *LitPorts* to illuminate the port on the back of the TV or computer will simplify the task by guiding the user towards the port they otherwise are unable to see.

Our work also applies to the ports in the cabin of a vehicle for connecting USB devices, audio input, or other auxiliary devices. Such receptacles are commonly located in parts of the cabin that are less directly accessible or poorly lit, even when the surrounding illumination is high, see, e.g., Figure 2. When a vehicle is operated at night this issue is typically worse. If the port gently illuminates as the plug nears it, this connection can be easily established without risk of serious distraction by the driver.

We acknowledge that our prototype implementation is not without limitations and does not yet directly match how *LitPorts* would be integrated into computing hardware to fulfill its potential. For example, the RFID reader and the tags can likely be optimized in terms of size and/or placement. The layout of the testing space may have been a contributing factor for the 2 participants who did not find *LitPorts* easier to use as, depending on the positioning of the participant, the *LitPort* was at a greater distance that required a longer reach. Another approach may combine different proximity sensing and identification technologies. However, exploration of such combinations exceeds the scope of our current work.

A potential limitation of *LitPorts* is that they require replacing existing opaque plastic components of receptacles with translucent versions to allow the light to transmit through the port. However, there are already transparent versions of some plugs (RJ-45) that are mechanically sufficiently stable, ameliorating this concern. Also, surface-mounted LEDs are already very small and very bright [18] and most receptacles already have power connections. For receptacles with very small features (USB-C) finding the right place in the construction of the receptacle for the LED to light the translucent plastic piece may pose challenges, but light pipe technologies, such as Printed Optics, demonstrate solutions [42].

Finally, while implementing *LitPorts* would require changes to all plugs and ports, this does not negate the value of *LitPorts* as users typically replace their systems every 3-5 years[1]. This continuous renewal of hardware makes it easier to introduce *LitPorts* into the marketplace, as vendors could present the innovative feature of *LitPorts* as added value to customers. However, an international standard would need to be created to assign unique IDs to different types of plugs.

6 CONCLUSION

In this paper we presented *LitPorts*, a novel technology to reduce user frustration and improve the user experience with inter-device connectivity by illuminating a receptacle when a matching plug comes into proximity. The most common scenario anticipated is connecting a device to charge at night, thus we introduced *LitPorts* through that lens. However, *LitPorts* could easily be expanded to non-charging connections and usage scenarios such as Ethernet, USB cables or drives, HDMI, input devices, headphones, and more which will be explored in subsequent work. As discussed above, illuminating a receptacle will make it easier for users to connect their devices in low-light/low-visibility situations. Given that prior research has found device connectivity is frustrating for users and device illumination is enjoyed by users [38], *LitPorts* would reduce user frustration and improve the all-around user experience. By illuminating what a user is trying to find, the item becomes easier to locate. By improving this one aspect, physical connections to the device, the overall user experience improves, making *LitPorts* an attractive development.

The strength in the idea of a *LitPort* is that it is an answer to the limitations of other technologies. Magnets are not discriminate, in scenarios where multiple ports are in close proximity, see Figure 2, they cannot guide the user to only the intended port, and illuminated cables are not beacons. *LitPorts* is both of these things and additionally is proximity-activated. Given that technology that is easy to use is more likely to be adopted [33], and one common action that device users face, regardless of whether they are novice or expert, is connecting their device to either another device or a power source [14, 35], we suggest that one simple technology that can be applied to a myriad of different devices, thereby improving the overall user experience, would be an important contribution to the user experience. *LitPorts* is such a technology.

ACKNOWLEDGMENTS

We acknowledge help from kt for keeping things "lit".

REFERENCES

[1] Rachid M. Alameh and Aaron L. Dietrich. 2013. Method for Adapting a Pulse Frequency Mode of a Proximity Sensor. Patent No. US8519322B2, Filed Aug. 6th, 2012, Issued Aug. 27th, 2013.
[2] Apple. 2020. MagSafe 2 Power Adapter. https://manuals.info.apple.com/MANUALS/1000/MA1986/en_US/apple-magsafe-2-power-adapter-UA03404138-ug.pdf
[3] Apple. nd. Important safety information for Apple Watch. https://support.apple.com/en-ca/guide/watch/apdcf2ff54e9/watchos

[1]https://www.officedepot.com/cm/article/stretching-device-life

[4] Ron Aviv, Tomer Rider, Yair Giwnewer, and Kiveisha Yevgeniy. 2017. Illuminated Socket. Patent No. US9711913B2, Filed Sep. 28th, 2013. Issued Jul 18th, 2017.

[5] Anol Bhattacherjee and Arash Barfar. 2011. Information Technology Continuance Research: Current State and Future Directions. *Asia Pacific Journal of Information Systems* 21, 2 (2011), 1–18. https://www.koreascience.or.kr/article/JAKO201124359107106.page

[6] Braun. nd. Oral-B iO. https://www.service.braun.com/line/OC/O3758/O3758_2_NA.pdf

[7] Andreas Braun and Pascal Hamisu. 2011. Designing a Multi-Purpose Capacitive Proximity Sensing Input Device. In *Proceedings of the 4th International Conference on Pervasive Technologies Related to Assistive Environments (PETRA '11)*. 1–8. https://doi.org/10.1145/2141622.2141641

[8] Andreas Braun, Reiner Wichert, Arjan Kuijper, and Dieter W Fellner. 2015. Capacitive Proximity Sensing in Smart Environments. *Journal of Ambient Intelligence and Smart Environments* 7, 4 (Jul 2015), 483–510. https://doi.org/10.3233/AIS-150324

[9] Gregor Broll, Wolfgang Reithmeier, Paul Holleis, and Matthias Wagner. 2011. Design and Evaluation of Techniques for Mobile Interaction with Dynamic NFC-Displays. In *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '11)*. 205–212. https://doi.org/10.1145/1935701.1935743

[10] Irvine Edward Bushnell and Marcelo Blalock. 2015. Illuminated Electrical Cords and Outlets. Patent No. US9022605B2, Filed Sep. 7th, 2013. Issued May 5th, 2015.

[11] Bala S. Chander, Bruce Carvell Blakemore, Jenny Brzozowski, Dale Gilman, and Duane M. Grider. 2011. Plug-in Vehicle Having a Recharging Port With a State of Charge Indicator. Patent No. US7999665B2, Filed Jun. 10th, 2010, Issued Aug. 16th, 2011.

[12] Robert M. Currie and Jonas J. Robertson. 2006. Illuminated Electrical Cords and Outlets. Patent No. US7121707B2, Filed Sep. 24th, 2004. Issued Oct. 17th, 2006.

[13] Fred D Davis. 1989. Perceived Usefulness, Perceived Ease of use, and User Acceptance of Information Technology. *MIS Quarterly* 13, 3 (Sep 1989), 319–340. https://doi.org/10.2307/249008

[14] Denzil Ferreira, Anind K Dey, and Vassilis Kostakos. 2011. Understanding Human-Smartphone Concerns: A Study of Battery Life. In *International Conference on Pervasive Computing*. 19–33. https://doi.org/10.1007/978-3-642-21726-5_2

[15] Carlos Flavián, Miguel Guinalíu, and Raquel Gurrea. 2006. The Role Played by Perceived Usability, Satisfaction, and Consumer Trust on Website Loyalty. *Information & Management* 43, 1 (Jan 2006), 1–14. https://doi.org/10.1016/j.im.2005.01.002

[16] Anton Gustafsson and Magnus Gyllenswärd. 2005. The Power-Aware Cord: Energy Awareness through Ambient Information Display. In *CHI'05 extended abstracts on Human factors in computing systems (CHI 2005)*. 1423–1426. https://doi.org/10.1145/1056808.1056932

[17] Michael Peter Hardy. 2014. Connector Plug Having an LED Activated by a User's Touch. Patent No. US8740640B2, Filed Oct 15th, 2012, Issued Jun 3rd, 2014.

[18] Chris Harrison, John Horstman, Gary Hsieh, and Scott Hudson. 2012. Unlocking the Expressivity of Point Lights. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 1683–1692. https://doi.org/10.1145/2207676.2208296

[19] Florian Heller and Jan Borchers. 2012. Physical Prototyping of an On-Outlet Power-Consumption Display. *Interactions* 19, 1 (Jan 2012), 14–17. https://doi.org/10.1145/2065327.2065332

[20] Siu Lau Ho, Junhua Wang, WN Fu, and Mingui Sun. 2011. A Comparative Study Between Novel Witricity and Traditional Inductive Magnetic Coupling in Wireless Charging. *IEEE Transactions on Magnetics* 47, 5 (May 2011), 1522–1525. https://doi.org/10.1109/TMAG.2010.2091495

[21] Richard R. Hook and David A. Dingman. 2014. Charge Port Illumination System for Electric Vehicle. Patent No. US8628225B2, Filed Nov. 26th, 2012, Issued Jan, 14th, 2014.

[22] Richard R. Hook and David A. Dingman. 2019. Charge Port Illumination System for Electric Vehicle. Patent No. US10406970B2, Filed May 19th, 2017, Issued Sep, 10th, 2019.

[23] Steve P. Hotelling, Brian Q. Huppi, Joshua A. Strickton, Duncan Robert Kerr, Imran Chaudhri, Greg Christie, Jonathan P. Ive, Peter J. Kennedy, Anthony M. Fadell, and Jeffrey L. Robbin. 2018. Proximity Detector in Handheld Device. Patent No. US10042418B2, Filed Nov. 14th, 2014, Issued Aug. 7th, 2018.

[24] Steve P. Hotelling, Brian Q. Huppi, Joshua A. Strickton, Duncan Robert Kerr, Bas Ording, Imran Chaudhri, Greg Christie, Jonathan P. Ive, Peter J. Kennedy, Anthony M. Fadell, and Jeffrey L. Robbin. 2006. Proximity Detector in Handheld Device. Patent No. US20060161870A1, Filed Sep. 30th, 2005, Issued Jul. 20th, 2006.

[25] Steve P. Hotelling, Duncan Robert Kerr, Bas Ording, Jonathan P. Ive, Peter J. Kennedy, Anthony M. Fadell, and Jeffrey L. Robbin. 2006. Proximity Detector in Handheld Device. Patent No. US20060161871A1, Filed Sep. 30th, 2005, Issued Jul. 20th, 2006.

[26] Tero Jokela, Ming Ki Chong, Andrés Lucero, and Hans Gellersen. 2015. Connecting Devices for Collaborative Interactions. *Interactions* 22, 4 (Jul 2015), 39–43. https://doi.org/10.1145/2776887

[27] Chieh-Peng Lin and Anol Bhattacherjee. 2008. Elucidating Individual Intention to Use Interactive Information Technologies: The Role of Network Externalities. *International Journal of Electronic Commerce* 13, 1 (Sep 2008), 85–108. https://doi.org/10.2753/jec1086-4415130103

[28] Han X Lin, Yee-Ying Choong, and Gavriel Salvandy. 1997. A Proposed Index of Usability: A Method for Comparing the Relative Usability of Different Software Systems. *Behaviour & Information Technology* 16, 4-5 (Jan 1997), 267–277. https://doi.org/10.1080/014492997119833

[29] Xiao Lu, Ping Wang, Dusit Niyato, Dong In Kim, and Zhu Han. 2016. Wireless Charging Technologies: Fundamentals, Standards, and Network Applications. *IEEE Communications Surveys & Tutorials* 18, 2 (2016), 1413–1452. https://doi.org/10.1109/COMST.2015.2499783

[30] Andrés Lucero, Tero Jokela, Arto Palin, Viljakaisa Aaltonen, and Jari Nikara. 2012. EasyGroups: Binding Mobile Devices for Collaborative Interactions. In *CHI'12 Extended Abstracts on Human Factors in Computing Systems*. 2189–2194. https://doi.org/10.1145/2212776.2223774

[31] Nicolai Marquardt, Till Ballendat, Sebastian Boring, Saul Greenberg, and Ken Hinckley. 2012. Gradual Engagement: Facilitating Information Exchange Between Digital Devices as a Function of Proximity. In *Proceedings of the 2012 ACM International Conference on Interactive Tabletops and Surfaces (ITS '12)*. 11–14. https://doi.org/10.1145/2396636.2396642

[32] Alex Olwal, Jon Moeller, Greg Priest-Dorman, Thad Starner, and Ben Carroll. 2018. I/O Braid: Scalable Touch-Sensitive Lighted Cords Using Spiraling, Repeating Sensing Textiles and Fiber Optics. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18)*. 485–497. https://doi.org/10.1145/3242587.3242638

[33] Francesco Pucillo and Gaetano Cascini. 2014. A Framework for User Experience, Needs and Affordances. *Design Studies* 35, 2 (Mar 2014), 160–179. https://doi.org/10.1016/j.destud.2013.10.001

[34] Munehiko Sato, Ivan Poupyrev, and Chris Harrison. 2012. Touché: Enhancing Touch Interaction on Humans, Screens, Liquids, and Everyday Objects. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. 483–492. https://doi.org/10.1145/2207676.2207743

[35] Saurabh Saxena, Gustavo Sanchez, and Michael Pecht. 2017. Batteries in Portable Electronic Devices: A User's Perspective. *IEEE Industrial Electronics Magazine* 11, 2 (Jun 2017), 35–44. https://doi.org/10.1109/MIE.2017.2688483

[36] Amy L. Schellenberg. 2011. Lighted Port. Patent No. US20110266980A1, Filed Apr. 30th, 2010. Abandoned Sep. 19th, 2015.

[37] Julie B. Shea, Martin Aguilar, William H. Sauer, and Usha Tedrow. 2020. Unintentional Magnet Reversion of an Implanted Cardiac Defibrillator by an Electronic Cigarette. *Heart Rhythm Case Reports* 6, 3 (Mar 2020), 121–123. https://doi.org/10.1016/j.hrcr.2020.01.013

[38] Tiffany E. Taylor. EasyChair, 2022. The User's Experience. Exploring the Impact our Interactions with Technology Have on Us. EasyChair Preprint no. 8590.

[39] James YL Thong, Se-Joon Hong, and Kar Yan Tam. 2006. The Effects of Post-adoption Beliefs on the Expectation-confirmation Model for Information Technology Continuance. *International Journal of Human-computer Studies* 64, 9 (Sep 2006), 799–810. https://doi.org/10.1016/j.ijhcs.2006.05.001

[40] Viswanath Venkatesh, Michael G Morris, Gordon B Davis, and Fred D Davis. 2003. User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly* 27, 3 (Sep 2003), 425–478. https://doi.org/10.2307/30036540

[41] Viswanath Venkatesh, James YL Thong, Frank KY Chan, Paul Jen-Hwa Hu, and Susan A Brown. 2011. Extending the Two-stage Information Systems Continuance Model; Incorporating UTAUT Predictors and the Role of Context. *Information Systems Journal* 21, 6 (Nov 2011), 527–555. https://doi.org/10.1111/j.1365-2575.2011.00373.x

[42] Karl Willis, Eric Brockmeyer, Scott Hudson, and Ivan Poupyrev. 2012. Printed Optics: 3D Printing of Embedded Optical Elements for Interactive Devices. In *Proceedings of the 25th annual ACM symposium on User interface software and technology*. 589–598. https://doi.org/10.1145/2380116.2380190

[43] Bryan Wyatt. 2003. Illuminated Electrical Outlet and Light Switch. Patent No. US7036948B1, Filed Aug. 11th, 2003, Issued May 2nd, 2006.