The Ultimate Wearable: Connecting Prosthetic Limbs to the IoPH

Rhys James Williams
University College London
UCL Interaction Centre
Gower Street, London, UK
Rhys-james.williams.11@ucl.ac.uk

Catherine Holloway
University College London
UCL Interaction Centre
Gower Street, London, UK
c.holloway@ucl.ac.uk

Mark Miodownik
University College London
Institute of Making
Gower Street, London, UK
m.miodownik@ucl.ac.uk

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Abstract

A new wearable device called the 'Ubi-Sleeve' is currently being developed that enables prosthesis wearers and other stakeholders to review temperature, humidity and prosthesis slippage behavior during everyday prosthesis wear. A combination of custom 3D printed strain sensors and off the shelf temperature and humidity sensors will be integrated into an unobtrusive sleeve to create a device that enables a deeper level of understanding of heat and sweat issues. To create the device, a series of experiments are in progress that will quantify changes in heat, humidity and slippage that negatively affect the prosthesis experience. Interviews and focus groups are also being conducted to gain a deeper understanding of the human side of prosthesis wear and to also ensure that data are presented in a way that is effective, useful and easy to understand.

Author Keywords

Prosthetics; disability; data visualization; data physicalization; ubiquitous computing; Internet of Things; Internet of Personal Health.

ACM Classification Keywords

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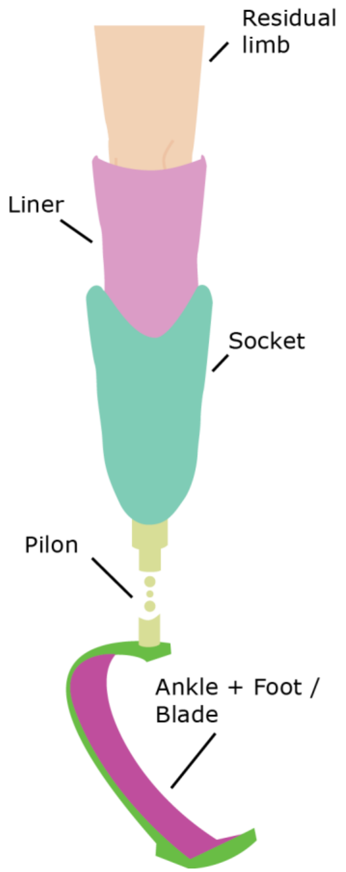

Figure 1: A typical prosthesis is made up of an elastomeric liner that directly contacts the skin, a hard, load bearing socket, a metal pilon (plus connectors) and an ankle and foot combination of some kind.

Introduction

Traditionally, computing has mainly been used to improve prosthetic function via microprocessor powered knees or ankles, rather than as a tool to understand how prosthetics are (or are not) used. Sensor based technologies have been adopted, but only to assess quantities such as pressure and shear forces and gait profile, with no understanding of how these affect the prosthesis wearing experience. This research aims to go beyond this and create a co-designed wearable device with integrated heat, humidity and strain sensors. At present, modern lower-limb prosthetic devices are typically made up of a foot, ankle, pilon, socket and silicone liner (figure 1). The liner component provides a coupling from skin to the prosthesis. Unfortunately, most liners are made out of impermeable materials that have low thermal transfer coefficients. As a result, the amputated limb cannot effectively transfer heat away from the body; and light physical exertion that causes small temperature changes in the total body system results in amplified rises in the amputated limb temperature [15]. This leads to sweating, which as a complaint is reported more frequently than instances of pain by prosthetic users. Sweating is also linked to a lower quality of life and is the most frequent reason to not use an upper-limb prosthesis [3]. A small amount of sweat weakens skin and increases friction between skin and the liner [5], which can lead to blistering and infection as the prosthesis slips during everyday use. The Ubi-Sleeve project aims to be the first demonstrator of how sensor technologies can be co-designed and integrated into prosthetics so they benefit multiple stakeholders.

The lack of understanding of amputee life

Prosthetic research was borne out of medical necessity and research is typically approached from a highly clinical perspective. As a result, the field has been criticised due to an over reliance on clinical outcome indicators which disregard important human and social outcomes and depict a narrow, simplistic representation of what life is actually like whilst wearing a prosthesis [7]. This is exemplified by the reliance on hours of prosthesis wear, or frequency of wear as a common representation of prosthesis 'success' [10] and a focus on laboratory experiments that are too controlled to provide any valid insights into real-world amputee life [4].

Prescribing and designing for, not with

Prescription has a massive effect on the success of a prosthetic device, so clinicians must be aware of all of the needs of the wearer when prescribing [11]. However, amputees often do not have an active role in selecting their prosthesis. This 'prescribing-for-not-with' process can result in greater rates of device abandonment [13]. Manufacturers have also stated that communication between themselves and prosthesis wearers is difficult, often causing change to be slow [12]. Prescription and design present situations where real-world sensor data can be collected and relayed to clinicians and manufacturers to improve relevant prescriptions and design solutions. This data also presents an opportunity for prosthesis wearer empowerment- a body of evidence that can be presented at prosthetist appointments could help wearers easily articulate their problems. Sullivan stated that "facts known only by physicians need to be supplemented by values only known by patients" [17]. An interpretation of this statement is that patient

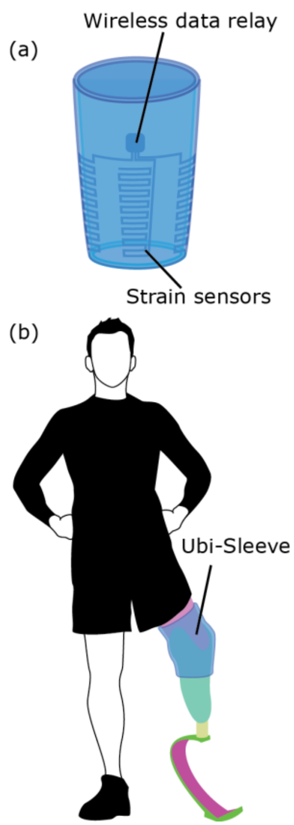

Figure 2: Temperature and humidity sensors will be in direct contact with the skin, underneath the liner. The Ubi-Sleeve will have integrated strain sensors to quantify prosthesis displacement and will be placed over the socket. All sensors will wirelessly relay data to a central processing unit and data will be presented.

knowledge, whilst important, is simply supplemental. If patient values were backed up with patient data, they would become patient facts. This presents an opportunity to shift to a non-hierarchical structure, where patient and physician facts can influence prosthesis design and prescription equally.

Concept

To facilitate this change, the Ubi-Sleeve (figure 2) will be a sensing device that enables 'in the wild' research into amputee life. The value of this data will be to quantify the levels of temperature and humidity change that results in increased of prosthesis slippage and a negative prosthesis experience. This will assist in identifying problems with an amputee's current prosthesis. It will also provide real-time and historic data in a meaningful and easy to understand way. For prosthesis wearers, this device can facilitate a deeper understanding of the issues they face during daily living and provide clinicians information that may improve prescriptions. For prosthesis manufacturers, this information will aid in the design of future prosthetic devices that are tailored to prevent heat and sweat issues occurring.

Manufacturing

A custom 3D printer is being developed that can print exclusively in gel and paste materials, including silicone rubber and hydrogels. The printer's design uses a combination of soft-sensor manufacturing techniques described by Muth et al. [14] and suspended 3D printing techniques of Bhattacharjee et al. [1]. Using this combined approach, we will be able to print unconstrained three dimensional soft strain sensors, as well as the necessary conductive tracking to integrate other sensors into the sleeve.

Methods

A multiphase mixed method approach will be used to facilitate explanatory and exploratory research. Wearable sensor and pervasive health monitoring frameworks [6,18] will be implemented in studies that quantify heat, sweat and displacement changes that result in a negative experience for prosthesis wearers. Experience sampling methods will be employed in tandem to asses the frequency and degree of negative experience [8]. In addition, face to face semi-structured interviews are being conducted with amputees to explore the topics of daily wear of prosthetic limbs, with a specific focus on heat and sweat issues. This data will be analyzed using a theoretical thematic analysis approach [2] and will help inform the ideation process for different ways to present data and possible ways prosthesis wearers and prosthetists could interact with the data.

Data Redundancy

A preliminary study is currently in progress that uses a network of 16 temperature and 4 humidity sensors located in contact with the skin and the prosthesis. This will provide an insight into the temperature and humidity profiles over the entire limb for 5 lower limb prosthesis wearers in a contrived climate controlled laboratory setting and 'in the wild'. In the lab, participants will walk on a treadmill to simulate light physical exertion and in the wild setting, participants will be free to conduct their normal daily routine. Once acquired, the individual sensor data will be compared against the average network sensor reading. This many sensors would be difficult to discretely integrate into a device such as the Ubi-Sleeve. With this in mind, sensor positions that best track the average behaviour of the residual limb will be used to reduce the total number of sensors that are integrated into the Ubi-Sleeve.

Data visualization and physicalization

An emerging theme from patient interviews has been the importance of heat and sweating changes at different times (both daily and seasonal) and locations. Different ways to visualize this data will be trialed with focus groups. Rather than rely on software based visualization, the possibility of presenting data change via a physical device (e.g. change in shape, movement, light) will be explored, with the designs being initially inspired by work by Posavec & Quick [16] and Houben et al. [9]. One amputee suggested that there must be multiple levels of visualization and include "at a glance", detailed "non expert" and detailed "expert" display options. This acknowledges the multi-stakeholder nature of prosthetics and the effect of situational context and technical confidence within the prosthesis wearer community.

Conclusion

Connecting prosthetic limbs to the Internet of Personal Health will benefit multiple stakeholders. The approach described in this paper will ensure the Ubi-Sleeve is useable and useful for multiple stakeholders and will act as an exemplar of how HCI techniques and sensor technologies can be applied to medical problems to effectuate and facilitate change that benefits users, clinicians and manufacturers.

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