Comfort Controller Design for Improved Computer Video Gaming

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Term Project Report

Abstract

Although the video gaming industry appeals to a vastly diverse audience, common input devices are often standardized to fit an average hand size. Users with hand sizes beyond this specific range can experience discomfort or even injury as they adapt their movements to achieve the same performance as those with average-sized hands. To investigate the role of hand size in computer gaming, we interviewed an avid gamer who experiences difficulty reaching inputs on a keyboard with some digits. From this data, we constructed a framework for the design of the Comfort Controller, a gaming device with adjustable and customizable inputs. Using this testbed, we aim to study the effects of input orientations on reaction time to examine our hypothesis that adjustable input orientations will improve accessibility to controls during urgent computing tasks. These results would signal the value of designing input devices informed by all human bodies.

I. Introduction

The advent of COVID-19 in early 2020 led to a shift from office-based work to home-based work in order to suppress viral spread through self-isolation, lockdown, and quarantine [1]. Prior to the pandemic, only 7.9% of the workforce worked from home, but during the pandemic, 81% of workers experienced a workplace closure, many of which were forced to transition to working from home [2], [3]. These world-wide closures have significantly increased individuals' free time and have led to large upticks in digital entertainment usage such as video gaming, which alone has grown by 75% [4]. This rapid shift in behavior presents a higher risk of musculoskeletal disorders due to the sudden and heavy increase in tool usage [5], [6]. To compound this issue, common devices are designed to fit average-sized bodies, so those who fall outside of this range often experience discomfort while using them. Therefore, developing ergonomic and customizable tools has the potential to improve physical outcomes, which is especially important during this unique period, for the sizable population that spends a large percentage of time working from home and playing video games.

A. Background

Previous work around computer interaction tools involve a variety of customizable input methods. Zheng, et al. explored multiple input functions for a single key, depending on the finger used and posture of the hand [7]. Pressing the same key with different fingers or the same finger, but different hand postures eliminated the need for modifier keys such as 'ctrl,' 'alt,' and 'shift,' and could map more functionality to the limited number of existing inputs. In addition, it enabled keyboard customization on a software level by and for each individual user, allowing those with different hand functionality to tailor their keyboard to best conform to their actions and needs. This study showed such a device was relatively easy to learn, and had a low error rate on the part of both the user and the computer. Another study by Lee, et al. utilized chording gloves to create a universal typing system without a physical keyboard that could be used by individuals with vision impairment [8]. The gloves were equipped with three contact pads along the palmar side of the fingers to detect combinations of thumb and finger contacts in different regions which generated respective letters, numbers, or Braille codes. A third group, Choi, et al., studied improved virtual keyboard design based on physical QWERTY keyboards by pre-allocating vertical columns of key inputs to each finger [9]. Higher error rates in typing were measured between adjacent keys in the same horizontal row and correlations between finger movements were observed between fingers in contact with inputs and the remaining fingers not in contact. These studies emphasize the value of input customization as a design factor in the development of accessible keyboards for all.

In addition to customizing input functions, much work has been done in optimizing overall device design for a variety of body sizes and postural preferences. Several of these studies focus on kinematic analysis of the body during interaction with a device to understand best practices in ergonomic design. Nelson, et al. studied wrist and finger motions during a typing task to determine how unique keyboard designs impact the finger and hand biomechanics [10]. They found that with greater wrist extension, finger joints flex more to compensate, and flatter keyboards induce more biomechanical stress via tendon travel. Baker, et al. aimed to quantify the angles, angular velocities, and angular accelerations of the MCP and PIP joints during word processing tasks [11]. This study introduced a new metric in the form of hand-wrist displacement, to measure how much a subject's hand moves laterally during these actions. While hand anthropometrics were measured, no correlations or relationships between them and keyboard use were assessed. Accordingly, Magno, et al. sought to quantify the anthropormetric hand model and correlate it with the hand sizes needed to reach various keys and combinations on a computer keyboard comfortably [12]. Common keyboard shortcuts on the extreme end of required distance were found to only be reachable by the 95th (left hand) or 99th (right hand) percentile and above while keeping the hand relaxed, with that barrier lowering to 25th and 75th percentile respectively when the hand is extended. Beyond hand kinematics alone, Chung, et al. assessed upper body musculoskeletal discomfort in computer operators for a wide range of body sizes, noting that those with body sizes outside of the average range reported higher discomfort compared to those in the average range [13]. We can speculate that the standard workstation setup may not be the best fit for all users due to variable body sizes and as such, adjustability or customization should be considered. This collection of work further highlights the shortcomings of classical keyboard design with regards to long-term comfort, especially when used by those with body sizes outside of the average range.

One existing ergonomic input solution currently on the market today is the vertical mouse design as an alternative to the standard flatter computer mouse, which may increase risk of musculoskeletal disorders such as carpal tunnel syndrome [14]. Quemelo and Vieira studied performance biomechanics between the two devices, concluding that the vertical mouse shows reduction in pronation and wrist extensor muscle activity, diminishing the risk of musculoskeletal disorders [15]. Similarly, Odell and Johnson evaluated wrist postures resulting from the use of variable angled computer mice. They also reported the fully vertical mouse reduced pronation compared to the traditional flat mouse and a partially angled mouse [16]. These works underscore the benefits of reducing pronation in wrist posture during computing tasks, but this has yet to be translated into the keyboarding-type input component of the computing workspace.

B. Overview

Given the prior work on novel computer input designs as well as kinematic assessments of manual computer interaction, it follows that existing standard computer input devices fail to accommodate for a wide range of hand morphologies. These shortcomings are especially apparent and can become increasingly frustrating when faced with urgent and pressing computing tasks, such video gaming. Therefore, we hypothesize that adjustable input functions and positioning for variable hand sizes will improve comfort and accessibility during time-dependent actions.

Through a contextual inquiry with a computer video gamer who has smaller hands, we identified critical user needs and values that supported our hypothesis, as outlined in Section II. In Section III, these needs were evaluated then translated into design factors, informing the resulting testbed and enabling us to study the efficacy of our design on ergonomic comfort and in fast-paced gaming situation. The results of this study could change the way product designers and engineers develop adjustable, inclusive tools specific to the human body, as described in Section IV. Finally, the appeal of these results and our intended open-access will enable widened accessibility for all users of the greater video gaming community, as discussed in Section V.

II. Preliminary Results

We conducted a virtual interview over Zoom with an individual who experiences difficulty in non-prehensile keyboarding tasks due to smaller hand size than the average range that many devices are designed to fit. Through the method of contextual inquiry with this interviewee, we learned that they spend a significant amount of time at their computer, often playing video games that require time-sensitive actions on a computer keyboard. The importance of swift input control necessitated by these situations exposes the shortcomings of input reachability in generally designed products. To gain a deeper understanding of the user's needs related to computer interactions, we adopted a Master/Apprentice technique to conduct a contextual inquiry, allowing the interviewee to teach and show us the different ways they interact with their computer on a daily basis. From this interview, we identified the most critical needs of the user, presented in Table 1.

As a result of these inquiry methods, we learned that video games are a major component of the individual's daily routine, but there are multiple ways they interact with their computer to play these games. They introduced us to a variety of tools they use to play video games at their computer, including a keyboard and mouse setup, and two different external, handheld controllers. The tools had some overlapping use cases, such as compatibility across multiple devices, and we used these cases to improve our understanding of both the most desirable and limiting factors of each of those existing designs and the individual's interactions.

Since the contextual inquiry was conducted over Zoom, the interviewee demonstrated how they use each of the tools. When using the keyboard and mouse setup, we observed an unusual compensatory strategy they developed to reach augmentation keys such as 'ctrl' and 'shift' when playing a game. Typically, their left hand controls character movement by utilizing digits 2-4 to control the 'A,' 'S,' and 'D' keys, with digit 3 switching between the 'S' key and the 'W' key above it. Inputs such as the 'ctrl' or 'shift' keys on the left-hand side of the keyboard are often used in combination with other keys to augment or perform additional actions. While many users utilize the 5th digit to press these keys, the individual we interviewed struggles to reach these keys with their 5th digit due to smaller hand size and alternatively contorts their hand so that their thumb flexes under the palm to reach these inputs instead. This unconventional technique reiterates the findings of Magno et al., reaffirming the importance of an inclusive device design for a wider range of hand sizes [12].

Alternatively, the external controllers offer the interviewee more intuitive hand positioning that enables easy access to all of the necessary inputs. While the user experiences no discomfort due to digit reachability challenges, these controllers rely primarily on the thumbs for input control, which often require leaving one input to access another. Digits 3-5 on each hand support the grasp of the controller, but do not interact with any inputs. Furthermore, we observed that moving the hands off and back onto the external controllers to perform out-of-game tasks such as using a cellphone or eating a snack, resulted in far fewer hand positioning errors than the same set of actions with a keyboard, where the user commonly returned their left hand to the wrong set of keys. This experience particularly concerned the interviewee due to the time-sensitive nature of their video games, informing the intended goal for our device design.

TABLE I: Critical User Needs Chart

1. Compatible with user's anatomy Inputs should be easily reachable with all digits Hand positioning should be intuitive and natural	**3. Efficient finger-to-input mapping** Inputs should utilize many digits and be tailored to their respective dexterity
2. Highly customizable Inputs should be customizable to user's intended functions Inputs should be adjustable to accommodate hand anatomy	**4. Broad versatility** Capable of a variety of normal computing tasks Easily integratable into an existing setup

These interview findings led to a strong emphasis on reachable and intuitive inputs in our design process. We aimed our design efforts toward creating a device that could be adjusted to fit any hand size and allow for customizable input functions, without compromising the dexterity needed to perform time-dependent computer tasks. Additionally, we aimed to utilize all of the fingers to improve dexterous control without introducing added complexity to an existing setup.

III. Methods

A. Testbed

Considering the prior art and findings from our contextual inquiry, we developed a controller for the left hand, to accompany right-handed mousing during computer-based video games (Figure 2). The controller body was designed with ergonomic comfort in mind, featuring a vertical shape modeled after the existing Logitech MX Vertical mouse [17], contoured to the left hand to reduce wrist pronation. During the interview, we learned that options for multiple control methods was a desirable trait. Thus, one side of the controller features a bank of keys for use by digits 2-5, while the other side features an analog thumbstick (Figure 1). We also observed how the interviewee struggles to hit certain key combinations comfortably due to "one-size-fits-all" keyboards failing to accommodate different hand sizes. Therefore, our testbed introduces adjustable key orientations; each bank of keys is attached to a slider, which can be moved forward and backward to best fit the user's hand (Figures 3, 4).

Additionally, the interviewee noted that they often misalign their hand when placing it on the keyboard, similar to the finding by Choi, et al. [9]. To address this concern, we limited the number of available keys

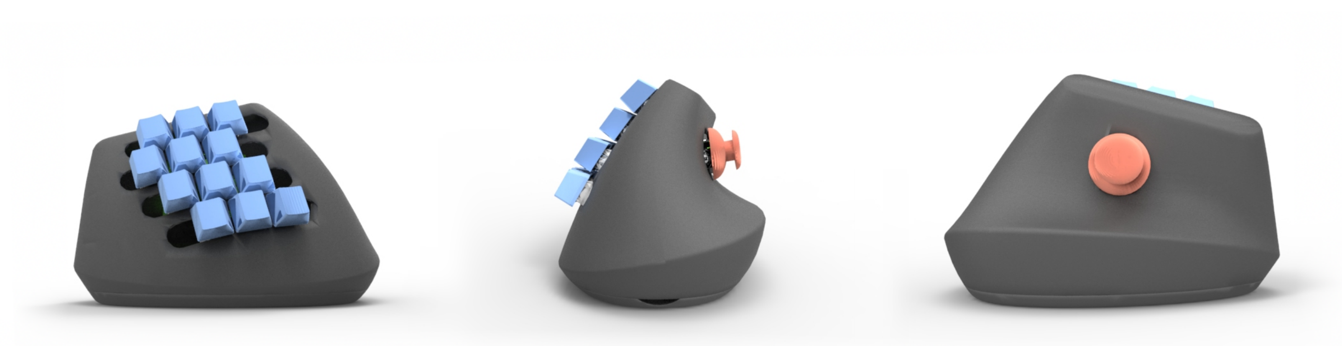

Fig. 1: Left, front, and right view renders of device.

Fig. 2: Intended usage of the device in conjunction with a computer mouse.

on our device, compared to those featured on a standard keyboard: the Comfort Controller features four banks of keys, corresponding to each digit 2-5. Each bank consists of three keys, one located centrally serving as the "rest position" key, as well as one proximal and distal key, all oriented linearly along the bank. The four central keys feature a homing bump, similar to those found on the 'F' and 'J' keys on a standard QWERTY keyboard. The combination of homing bumps and limited inputs guides the hand to a single natural horizontal position, making it extremely difficult to misalign the hand when placing it on the device, even without visual cues.

Following the incorporation of primary user needs identified in the interview, we introduced additional features to the Comfort Controller corresponding to some of the secondary needs distilled from the interview. For instance, the interviewee mentioned how different input methods are more suitable for different situations, with some games benefitting from the precision of an analog controller, and other games benefiting from the flexibility of many keys. We chose to provide the user with the best of both worlds: including a thumbstick in the device allows the user to choose between analog and digital inputs, depending on whatever is best in the moment. Customizable device firmware allows the digital inputs to be mapped to any key on the keyboard, and the analog inputs of the thumbstick to be mapped to any axis on a standard controller (Figure 5). Swappable, standardized keycaps allow the user to adjust them to best fit their needs, whether that involves different lettering, different keycap shapes, or even a fully

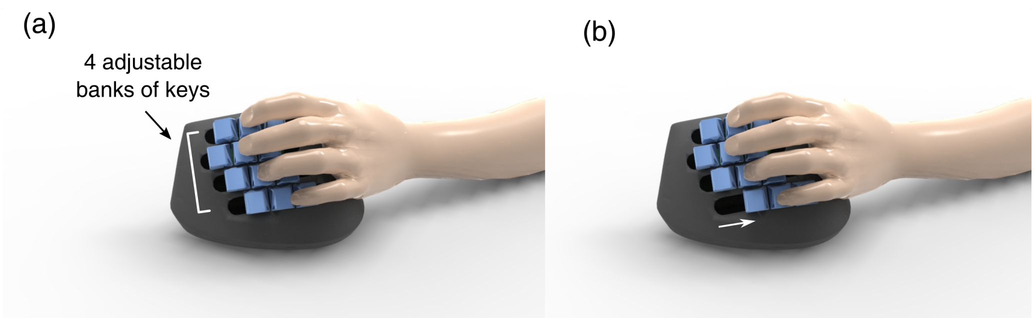

Fig. 3: (a) The device features four adjustable banks of keys. (b) Each bank can be individually moved to best fit the user's hand. In this case, the bank allocated to digit 5 is moved proximally for better reachability.

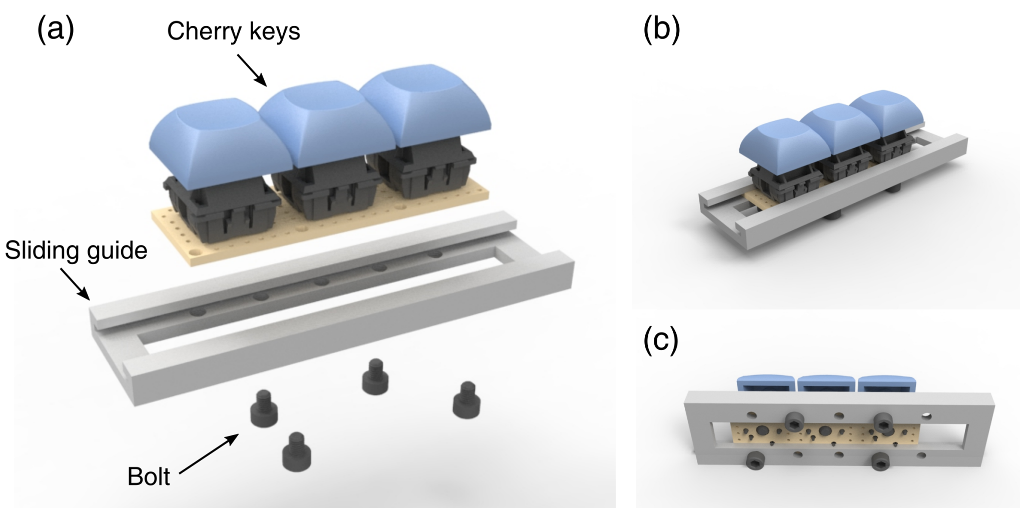

Fig. 4: (a) Exploded view of sliding mechanism. (b) Each bank slides as a single unit, but separately from other banks. (c) Mounting holes on the bottom of the mechanism allow it to be secured to a skeleton inside the device.

custom 3D-printed solution. Similarly, the flexibility of the hardware allows the user to take full control of the shape of the controller itself, including 3D-printing a shell that perfectly molds to their hand, or possibly even adding or removing banks of keys if the user has more or less than five digits.

Our prototype electronic implementation also includes specific benefits that would be integrated into a finalized device. For instance, our use of Cherry MX Blue keyswitches provides the user with both tactile and auditory feedback whenever a key is actuated. In addition, our choice of an Arduino Leonardo as the microcontroller, which can natively emulate USB devices, means the user does not need to install any additional software to use the device. A deeper dive into the hardware details can be found in Appendix A.

B. *Proposed Study*

The Comfort Controller will be tested on human subjects to measure the speed at which a user can execute common video game input combinations for different input locations. We aim to recruit participants of many different hand sizes and observe the differences in speed of key presses for inputs located at the two extreme orientations on the Comfort Controller (all inputs closest to the palm and all inputs furthest from the palm), as well as a customized input orientation of the participant's choosing. Input accuracy and speed, or successful actions per minute, will additionally be measured during prehensile homing; we aim to minimize errors when returning digits to the home input positions from off the device. Following the conclusion of the experiment, we will also survey the participants to learn how they would rate the comfort of each input orientation as well as any comments about the device design itself. This initial study deliberately focuses solely on input actuation instead of performance in video gaming sessions to prevent the results being confounded by muscle memory of experienced gamers. In future studies, we plan to incorporate the video gaming aspects into our analysis of device effectiveness.

IV. Intellectual Merit

The development of the Comfort Controller introduces many key design principles that will inform the creation of better devices for computer interaction. Adjustable sliding mechanisms on our testbed add a new dimension to ergonomic design techniques for computer input devices, beyond the standard

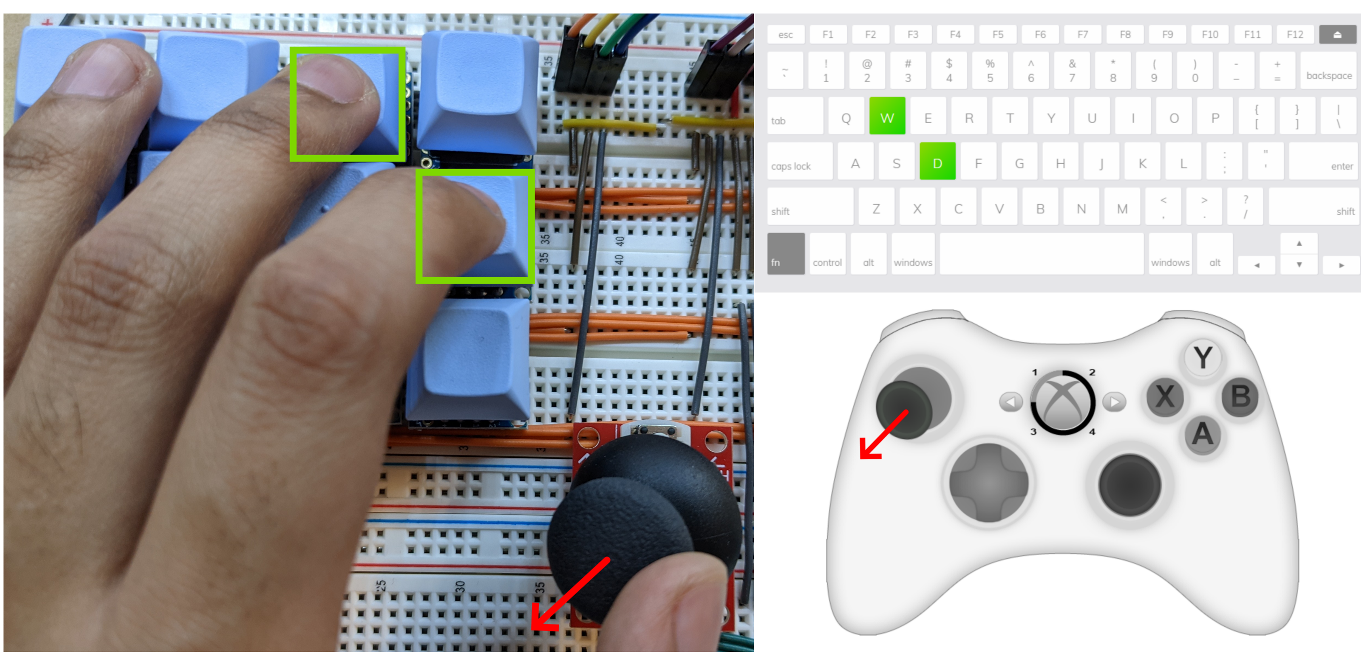

Fig. 5: Prototype functionality showing mapped inputs to those found on common devices.

methods of static geometries seen in commercial mice and keyboards. Such customizability ensures better fit between tools to the hand, which has long been an ergonomic concern, but yet to be addressed in the context of video gaming. Furthermore, our design process highlights the importance of the number of inputs in a gaming setup. While more inputs may have the advantage of many distinct input functions, the ideal number of inputs for time-dependent tasks should be refined and designed with the appropriate digits in mind to reduce input errors. Taken together, these attributes emphasize the importance of designing comfortable and effective devices for the human body.

V. Broader Impact

With the extraordinary expansion of the video game industry, companies have relied heavily on mass production of input devices which has left little room for user customization. The breadth of the video gaming audience naturally lends itself to a wide range of hand sizes, which have yet to be addressed by major suppliers. With open access to all of the resources necessary to build the Comfort Controller, individuals with all hand morphologies can use and create modifications to best fit their needs. Utilizing the novel universal design factors we developed in this work promotes inclusivity within a single device for a wider range of users. The Comfort Controller has the potential to improve gaming accessibility to include a wider audience, thereby democratizing digital entertainment.

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APPENDIX A
INVESTIGATIONAL DEVICE DETAILS

Our prototype features twelve Cherry MX Blue keyswitches as digital inputs, plus an additional thirteenth digital input corresponding to depressing the thumbstick. These inputs are connected to an Arduino Leonardo through its internal pullup resistors (Figures 6, 7). The advanced design of the Cherry MX series ensures that there is no debounce circuit needed for the twelve main digital inputs, however, the thirteenth "joystick depress" input would benefit from its own debounce circuit in a future iteration of this device.

The two potentiometers of the joystick are connected to the analog pins of a second Arduino Leonardo. While the ability of the Leonardo to natively emulate a USB device makes it ideal for this project, unfortunately due to driver-level limitations, it is impossible for the Leonardo to emulate two devices at the same time. Hence, our solution is simply to have two separate microcontrollers. One, connected to all the digital inputs, emulates an HID keyboard, while the second, connected to the joystick, emulates an XInput controller. These two microcontrollers are connected via a common ground, and are simply wired up to a USB hub to allow the user to only require a single connection. Notably, this is basically the same solution that most modern high-end keyboards use, which often emulate multiple different keyboards within the same device in order to overcome key "rollover" limitations.

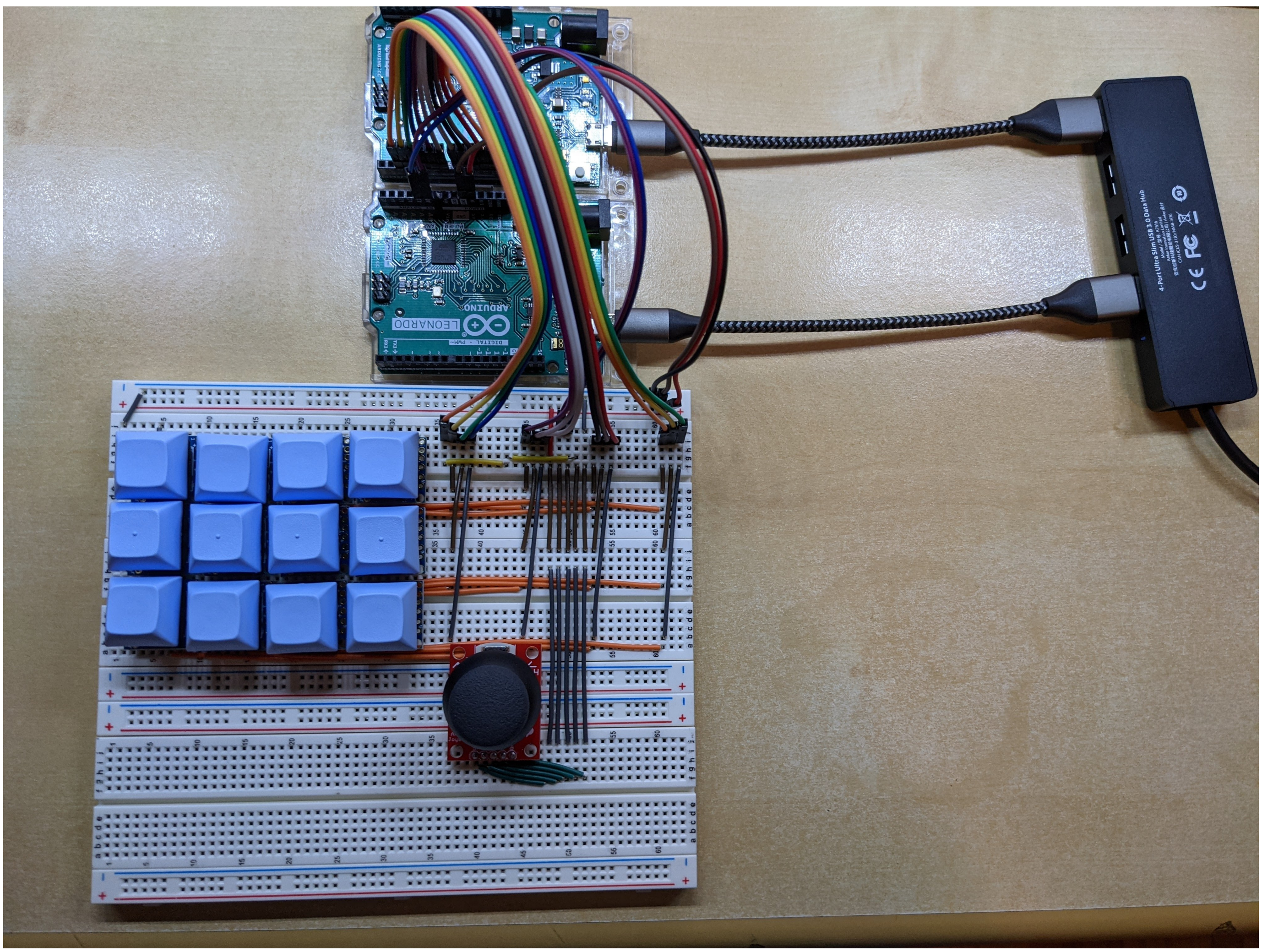

Fig. 6: Fully-functional electronics prototype.

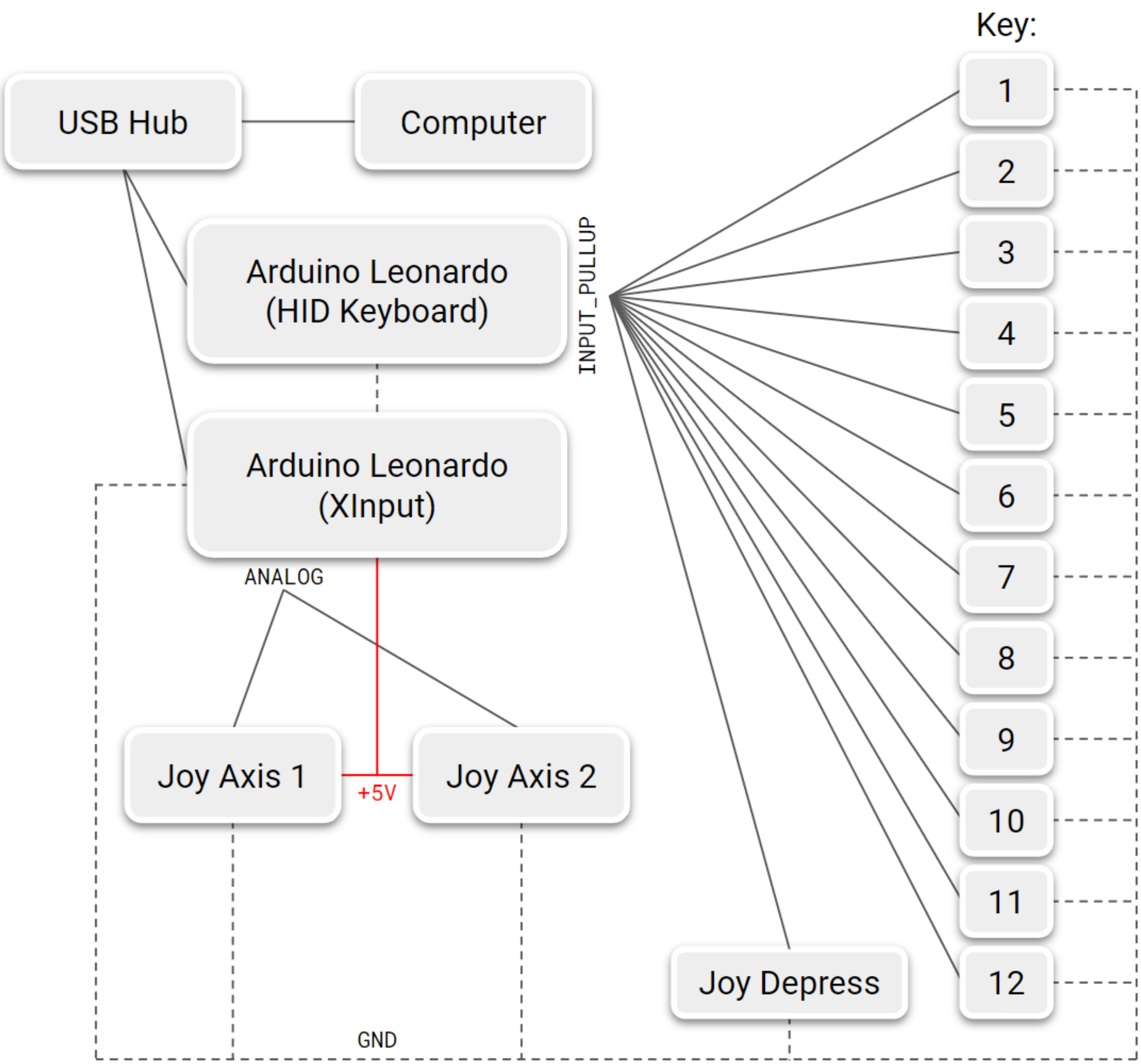

Fig. 7: Electronics block diagram.