The Peppermill: A Human-Powered User Interface Device

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ABSTRACT
A human-powered user interface device sources its power from the physical effort required to operate it. This paper describes a technique by which a geared DC motor and a simple circuit can be used to enable interaction-powered rotary input devices. When turned, the circuit provides a temporary power source for an embedded device, and doubles as a sensor that provides information about the direction and rate of input. As a proof of concept, we have developed a general-purpose wireless input device – called the Peppermill – and illustrate its capabilities by using it as a remote control for a multimedia-browsing application.

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Human-powered devices, power harvesting, user interface devices, remote control

ACM Classification Keywords
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General Terms
Design, Human Factors

INTRODUCTION

Providing a suitable power source is one of the fundamental considerations in the design of embedded and interactive devices. Batteries are a practical power source for mobile devices, but they must be changed, recycled or recharged. Eliminating the need to use a battery is clearly desirable from economic, ecological and perspectives.

The work presented in this paper is an exploration into the design space of user interface devices that are able to source their power from the physical effort involved in interacting with them, and thereby operate without the need for batteries. We refer to this kind of user interface device as being human-powered.

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The salient characteristic of a human-powered user interface device is that the transducers that sense the intent of the user double as sources of power for its operation. Through the process of interacting with the device and manipulating its controls, the user generates enough electricity to power its internal electronics. In this sense, human-powered user interface devices are examples of human-powered electronics [4], with the specific feature that interaction and power generation are intrinsically linked.

Figure 1. The Peppermill remote is an example of an *interaction-powered* interface device, which supports rotary input as the primary method of interaction.

The concrete contributions made in this paper are: the use of a simple circuit to enable interaction-powered devices that support *rotary input* as the primary interaction technique; a design for a generic wireless interface device based on this circuit, which we call the Peppermill controller (shown in Figure 1); a multimedia browsing and playback application, which we have developed to illustrate the capabilities of the Peppermill; and a discussion where we consider possible extensions of this and future work, as well as the wider design space for human-powered devices.

BACKGROUND

In 1955, the Zenith Corporation developed the Space Commander: a wireless and battery-less remote controller. Pressing buttons on the device would cause a set of miniature mechanical hammers to strike at aluminium rods inside the remote, emitting high-frequency sounds. These ultrasonic signals would be picked up by a microphone inside a TV set, decoded by analogue circuitry and used to turn the set on and off, change the channel or adjust the volume. Alternative designs used a whistle to generate the ultrasonic signal, which was powered by the airflow generated through squeezing the remote.

Figure 2. The Zenith Space Commander (1956). Image courtesy of Bill DeRouchey.

The Space Commander is an analogue version of an interaction-powered user interface device, and a perfect illustration of the principle: the act of physically manipulating the remote (by pressing one of its buttons) provides the power that generates the ultrasonic signal.

There exist a number of wind-up consumer devices (such as radios and flashlights [2]) that can be manually recharged by turning a crank or shaken to actuate a charging device. The generated power is stored in a rechargeable battery for later use. Although relevant from a technical perspective, the concept of wind-up appliances is different to that of human-powered devices. In the first case, the act of turning the crank generates power the appliance serves to generate and store power for later use; in the second, power-generation and user interaction are intrinsically linked and happen simultaneously.

The idea of powering devices through user interaction is expressed in Starner and Paradiso's comprehensive overview of the state-of-the art (2004) of human-power generation for mobile electronics [4]:

"One can imagine [on-body] input devices communicating wirelessly using power scavenged from the user's actions. For example, a finger or wrist-mounted trackball could be "self-powered." Moving the trackball would turn the wheel encoders inside the device, both registering the movement and powering the device."

The above work is primarily focused on the generation of electricity through body-worn power-harvesting systems, with the aim of supporting relatively complex (and power-hungry) devices such as mobile phones and portable computers. In a similar vein, a more recent study focused on providing a quantitative analysis of power-harvesting from human movement [5]. Our own interest is centered on providing power to user interface devices – such as handheld controllers or appliance remotes – which can wirelessly communicate a user's intention to a mains-powered system or interactive environment. These kinds of devices do not need to maintain a charge, as they only need to remain powered for the duration of the interaction that they facilitate.

An interesting example of an interaction-powered controller is the MIT Wireless Self-Powered Button, developed by Paradiso et al. and described in [3]. The MIT Button uses a piezoelectric element in the form of a switch that – when clicked by a user – generates enough power to wirelessly transmit a digital RF code. More recently, a commercial system based on this principle has become available [1].

Given the prevalence of buttons in user interface equipment, the MIT Button provides a useful building-block for the design of a wide variety of human-powered devices. However, the Button is limited to transmitting only binary and momentary interaction events – since power is generated on the downward stroke, it is only able to transmit a signal when the button is pressed, and not when it is released. Motivated by these limitations, we became interested in considering alternative circuits which would support richer interaction techniques, and which, like the MIT Button, act as generic building blocks for the design of interaction-powered interface devices.

A CIRCUIT FOR ROTARY INPUT + POWER

Rotary controls are commonly to provide variable and directional control of a parameter. Here, we describe a simple circuit (shown in Figure 3) which uses a small DC motor as a rotary input sensor, whilst simultaneously generating a temporary 3.3V supply.

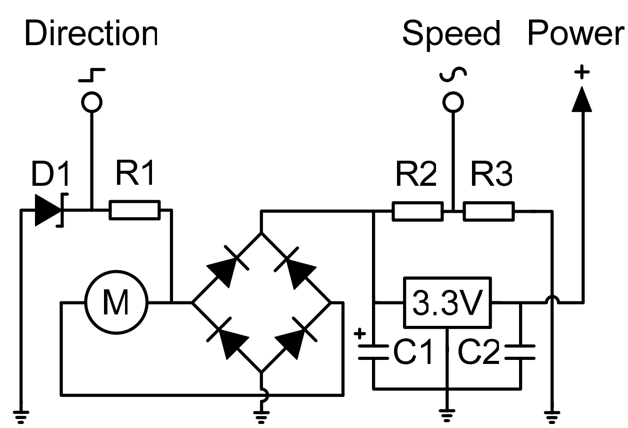

Figure 3. A simple circuit that enables human-powered *rotary input* devices.

The circuit is based on the fact that when axle of an electric motor is turned, a back-EMF is generated resulting in an electrical potential across its terminals. The output voltage is proportional to the rate of turn, and reversing the direction of turn reverses the polarity of the current.

The first stage of the circuit determines the *direction* of input (clockwise or anti-clockwise). A Zener diode (D1) with a reverse breakdown voltage of 3.3V is connected via a 100k current-limiting resistor (R1) to one of the motor terminals. This clamping circuit provides the microcontroller with a binary signal that indicates the direction of turn. The second stage of the circuit rectifies the output of the motor via a diode bridge, which provides a consistent polarity for the rest of the circuit regardless of the direction of turn.

The third stage of the circuit uses a pair of resistors (R2 and R3) as a voltage divider, reducing the variable output voltage to a level that can be directly sampled by an analog-to-digital convertor in a microcontroller. The exact values for R2 and R3 are dependent on the maximum power output of the motor, which is discussed below. In our prototype, we used values of 580K and 100K provided a sufficient reduction in voltage. This analog value acts as an indication of the *speed* of turn.

The final stage of the circuit uses a 3.3V low drop-out regulator to stabilize the variable voltage to a level that is readily usable by a microcontroller. A 100uF electrolytic capacitor (C1) smoothes ripples in the supply line. The second capacitor is required by the regulator to operate.

The amount of power that a motor can provide is limited by how quickly a user is able to manually turn its axle. A gearbox can be used to gain mechanical advantage and increase the rate of turn in exchange for an increase in input torque. We tested a wide variety of motors and gear-ratios, and found that a motor rated for 6V, equipped with a 104:1 planetary gearbox, provide a suitable compromise. The resulting torque is comparable to that needed to turn a standard rotary input control intended for this purpose and intended for manual operation.

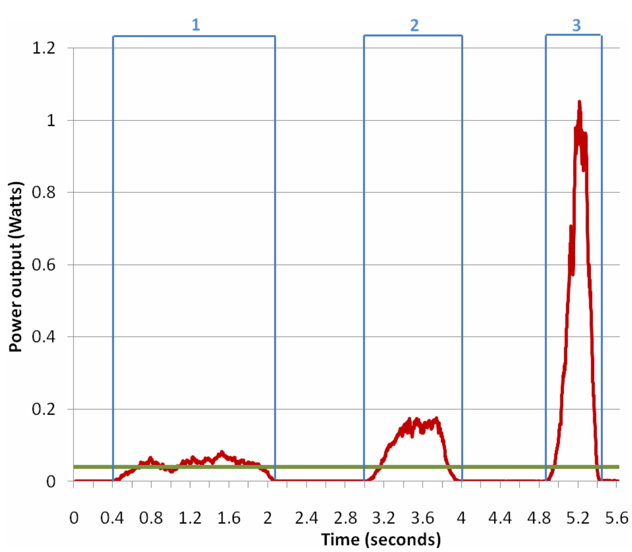

Figure 4. Power output of a 104:1 geared DC motor driving a 220R load. Periods 1, 2 and 3 show increasing speeds of turn.

The power output of our preferred configuration is shown in Figure 4. In this test, the motor was used to drive a 220R load, and a 5cm-diameter knob was used to turn the gearbox's output axle. The period delimited by (1) is the result of turning the knob slowly – completing a half-turn in about 1.5 seconds. Period (2) is a faster turn, where a half-turn is completed in about 1 second. Period (3) shows the power generated by a fast half-turn executed in close to 0.5 seconds. The horizontal green line demarcates a power level of 0.04 Watts, which is the power needed to drive the microcontroller and radio transmitter used in our prototype. Since we did not invest any effort in optimizing our initial prototype for low-power operation, we consider this amount a conservative estimate for the power requirements of simple wireless devices.

This simple circuit, consisting entirely of common and low-cost components, not only provides a significant amount of power, but also captures a considerable amount of information about a user's interaction with the rotary control, making it possible to measure: 1) how *long* the user turns the control for; 2) how *quickly* the control is turned, and 3) in which *direction* the control is turned. In the next section, we describe a user interface device that uses this circuit as its primary interaction mechanism.

THE PEPPERMILL CONTROLLER

The Peppermill controller is designed as generic, wireless interface device for rotary input. It takes its name from its design and operation, which is reminiscent of a culinary pepper grinder. To operate it, the user holds the device in one hand and turns the rotary knob with the other. The knob can be freely turned clockwise or anti-clockwise (Figure 5, A). The handle of the device includes three pushbuttons, color-coded green, red and blue (Figure 5, B). These buttons can be pressed by the user *while* turning the knob and act as *modifiers* for the rotary action, resulting in a total of four input DOF.

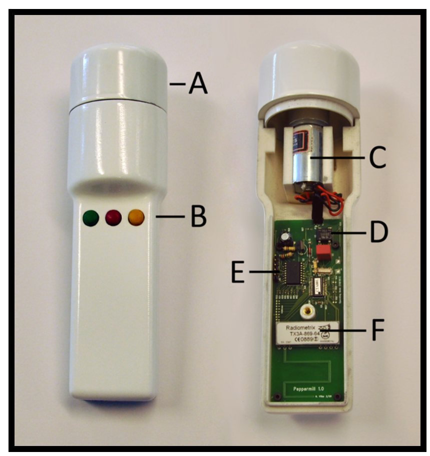

Figure 5. External and internal components of the Peppermill controller.

Internally, the Peppermill includes: a 6V motor with a 104:1 ration planetary gearbox (Figure 5, C); the circuit described in the previous section (Figure 5, D); a PIC16F microcontroller (Figure 5, E), and a Radiometrix 869MHz radio transmitter module (Figure 5, F). An accompanying radio receiver module with a USB serial interface (not shown) has been developed to receive and decode wireless packets from the Peppermill.

When the user turns the knob, the microcontroller powers up and samples the inputs from the supply circuit, as well as the state of the three additional buttons. It encodes and transmits the speed of turn, direction of turn and state of the buttons (pressed/released) as a single wireless packet. As long as enough power is being generated the microcontroller continually samples and transmits packets at 5ms intervals.

EXAMPLE APPLICATION: A VIDEO BROWSER

To demonstrate the application of the Peppermill to a concrete usage scenario, we have developed a simple video browsing and playback application. The Peppermill is used as a remote control that allows the user select from a number of video channels, presented as a scrolling carousel that is displayed on the screen whenever the knob is turned (Figure 6, top). By dwelling on a particular channel, the video becomes selected and is displayed full-screen.

Figure 6. Graphical interface of the Peppermill-controlled video browsing application.

By holding down the green modifier button while turning the knob, the user is able to display and adjust the volume level (Figure 6, bottom). The speed of turn controls the rate of movement of the carousel and volume level bar.

DISCUSSION AND FUTURE WORK

In informal testing of our prototype, we found that users would generally enjoy interacting with the Peppermill, and engaged with the interaction and 'feel' of using the device. In a number of cases, this positive response was manifested before users were made aware that the Peppermill was an human-powered device. Although purely anecdotal, we are encouraged by these initial reactions, as they inspire us to consider the real feasibility of designing devices that do not sacrifice quality of interaction for the sake of being battery-less.

We did observe that, in some cases, users would turn the knob too slowly to generate enough power for the device. However, on seeing no reaction from the system, the natural response seemed to be to gradually magnify the turning motion until a reaction was achieved. Once a minimum turning rate was established, users seemed to have no further problems using the device to accurately control the interface.

There are some interesting extensions to be made to the existing circuit design. For example, we have experimented with using the geared motor to provide haptic feedback to the user by generating dynamically-adjustable detents, which can be felt by the user as they turn the knob. Achieving this sort of force-feedback usually requires a considerable amount of power to be put *into* the system to counter the user's manipulation, an approach which is clearly out of the scope of our interaction-power design space. Instead, we have been able to achieve promising results by *braking* the motor through momentarily shorting its two terminals. The mechanical advantage gained by the high gear ratio means that, as long as the terminals are shorted, the resulting electro-magnetic braking makes it difficult for the user to turn the knob. By periodically and momentarily braking rotation in this manner, it becomes possible to dynamically generate a variety of interesting haptic effects without supplying additional power.

More broadly, future efforts in this area will consider how a wider variety of devices might be designed to reconcile the dual concerns of usability and power generation. For example, we are interested in the use of more gestural interaction techniques (for example, as enabled by the Nintendo Wii game controller). Gestural interaction techniques encourage users to perform actions that are rich in potential energy, and can also provide natural and enjoyable ways to interact. We believe that there are still rich opportunities and interesting research challenges in the development of new strategies for sensing and harvesting power for these kinds of user interface devices.

ACKNOLEDGEMENTS

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