Application of an Intuitive, Glove-type Remote Control with Haptic Feedback to Quadcopters

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Abstract

Although remote controllers for drones, based upon a classic two-joystick architecture, are unwieldy, they still see widespread use. As a replacement, we propose a remote control with a glove-based architecture that utilizes haptic feedback from the quadcopter. The proposed controller should be far more intuitive, making drone flight easier and more intuitive. Additionally, since the pilot will have one hand free, he or she can use maps, electronics, and other aids much more straightforwardly than with a two-handed controller. While our technology is designed for drones, it also could see further usage in a wide variety of civilian and military applications, from entertainment to industry. This glove-based architecture with haptic feedback might well become a staple of the future.

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Introduction

“The Drone Age.” Emblazoned on the cover, the title of the special report rests against a backdrop of almost a thousand glowing drones, which together form the iconic logo of TIME magazine (Fitzpatrick, 2018). Indicative of the modern era, the heading calls to mind questions of control that only recently have grown from hypothetical to imminent. With an ever-growing constellation of multirotors tracing our skies, how can we minimize the number of crashes and the dangers that they present? Traditional remote controls, which use two bidirectional joysticks for the requisite four axes of input, have three main deficiencies in this regard: they are unintuitive, they require two hands to use, and they lack feedback from the drone to the user. Consequently, crashes are frequent (Domestic drone accidents, 2017), possible use cases are constrained, and pilots remain quite disconnected from their drones.

In response, we propose an intuitive, glove-type remote control for quadcopters, using the orientations of the hands and fingers to provide yaw, pitch, roll, and thrust inputs. By incorporating haptic feedback, we can improve the pilot’s mental connection with the drone, such that the pilot can intuitively “feel” the motion of the quadcopter, even at a distance. A visual prototype of our design is shown in Figure 1.

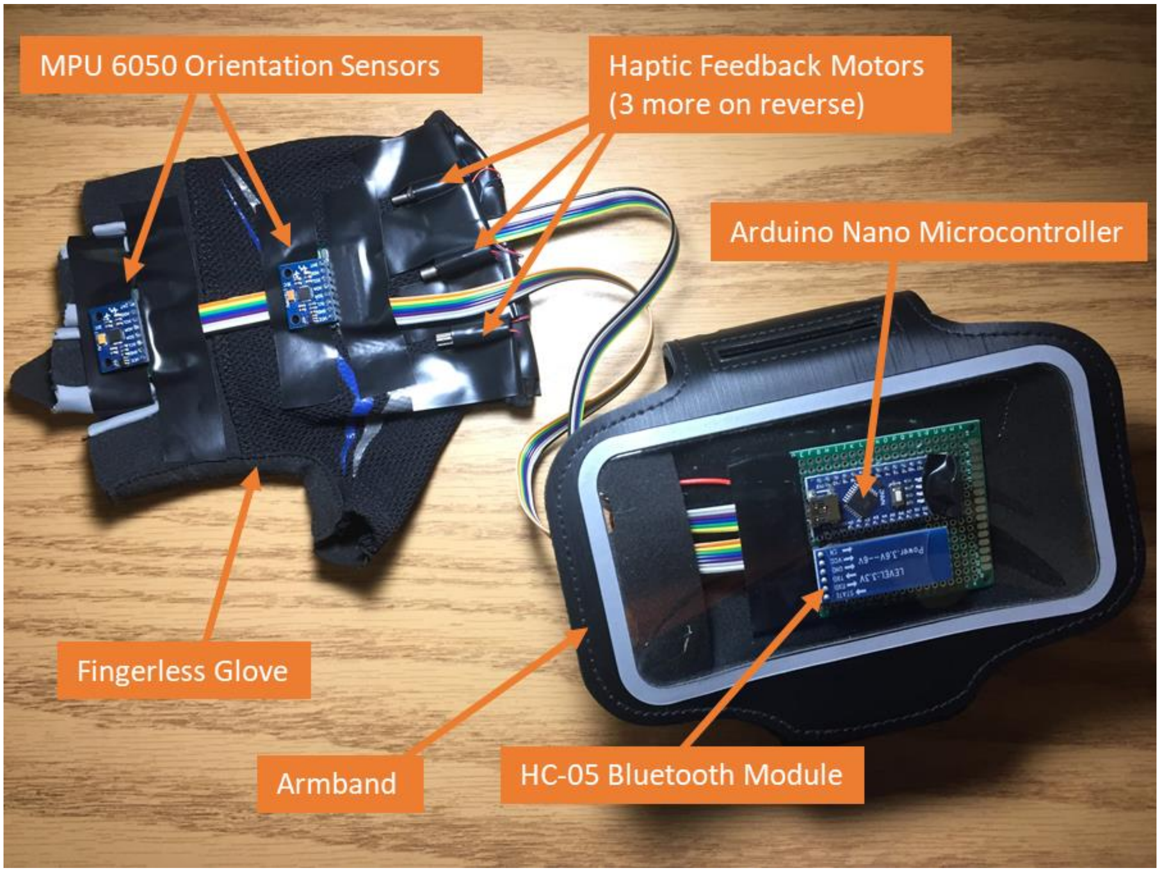

Figure 1. Visual prototype of design.

By using this controller, we believe that pilots will be able to improve the proportion of successful flights and keep the skies safer. As an added benefit, the pilot will no longer be constrained to use both hands, allowing for phone or map usage alongside drone flight, with appropriate caution. This technology helps signal a new generation of quadcopter controls that closely integrate the pilot and the craft.

Prototype Design

Especially since the proposed solution differs greatly from common controls, it is important to explain exactly what comprises the new control. Broadly, the remote controller has all the components that we would expect from a typical remote, namely, a mechanical structure, electric circuit, microcontroller, sensors, and a communication link, with the addition of haptic feedback. Understanding each of these components will contribute to a full knowledge of the solution.

Mechanical Structure

As the solution is physical in nature, it must necessarily include a mechanical design. These mechanical components provide the structure on which the electronic components rest. Given the wearable nature of this technology, the mechanical components should be reasonably comfortable, even for the prototype.

The mechanical structure can be divided into two main components, in order to remove unnecessary electronics from the glove. First, of course, is the glove itself. A fingerless glove helps the user remain cool, at no functional cost. The glove should fit the user reasonably well, especially at the wrist, where the system applies haptic feedback. Second, an armband on the same arm as the glove can house the microcontroller and power system, an allocation that saves space and weight on the glove.

Other than these general components, there are no major mechanical components in this design. Fortunately, calculations on the mechanical system are wholly unnecessary at this stage in development. This reflects the fact that the complexity in the solution lies in the electronics and coding.

Electric Circuitry

The electric circuitry provides power to each of the electronic components in the design, and it carries signals to and from the microcontroller. The entire circuit runs off a

6V source, converted down to 5V on our microcontroller board. Ribbon cables provide pluggable connections between distant components. The full circuit schematic, generated in NI Multisim, is shown in Figure 2.

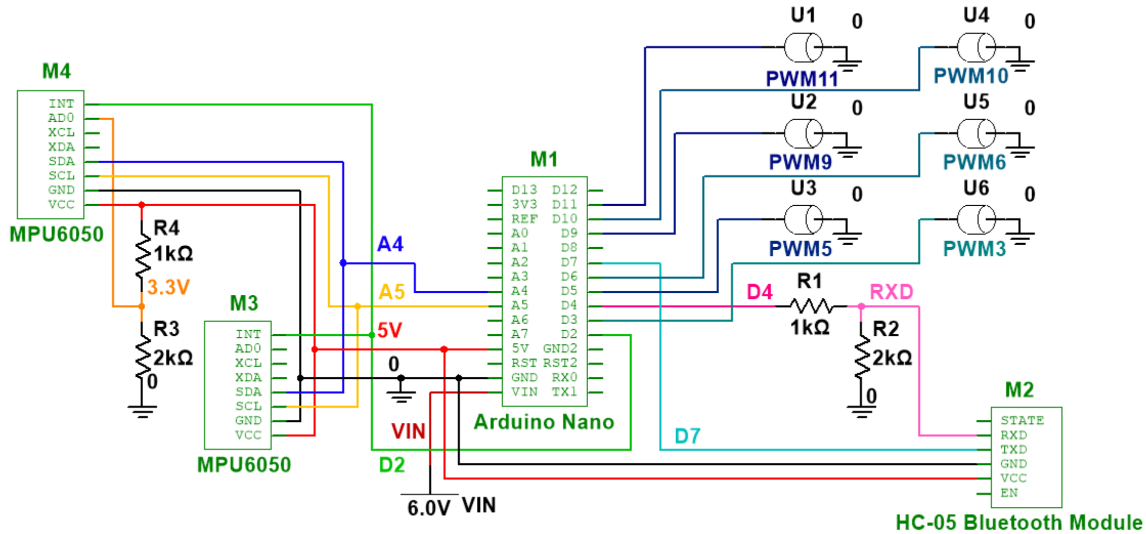

Figure 2. Full prototype circuit schematic.

Microcontroller

For our microcontroller board, we chose an economical Arduino Nano clone. This board provides thirty pins, including six capable of pulse-width modulated output (Arduino, 2019a). Fortunately, processing speed is not an important variable in our application, as the likely bottlenecks in our program are the sensors or the communication connection. The Arduino Nano has a clock speed of 16MHz, which is more than adequate. Additionally, the support base for Arduino-based boards is quite extensive, increasing its attractiveness for proof-of-concept projects, such as ours.

Sensors

To detect the orientation of the hand and fingers, we utilized two tilt and rotation sensors. We chose the popular MPU6050 boards. Each board reports the acceleration vector and angular velocities that it experienced, allowing the microcontroller to compute the current orientation of the board with the 2-argument arctangent and complementary filters.

The MPU6050's communicate with the microcontroller using the I^2C protocol. They are designed to respond to one of two I^2C addresses, depending on whether their AD0 pins are set to 3.3V. A voltage divider at one sensor easily lets us lock its AD0 pin to this voltage, so we can differentiate between sensors (Arduino, 2019b).

We place one sensor on the back of the hand of the glove, to provide steering information to the drone. Let us name this *Sensor 1*. We place the other sensor, *Sensor 2*, across the first joints of the ring and middle fingers. When the user clenches his hand, the angle of orientation of *Sensor 2* shifts sharply downward. By measuring the difference in angle between *Sensor 1* and *Sensor 2*, the microcontroller determines how far the fingers are clenched. This, in turn, drives the throttle.

Haptic Feedback

The incorporation of haptic feedback is integral to the uniqueness of this design. Amazingly, the human body can learn to accept haptic input in a manner similar to a new sense, using touch as an avenue of input to the brain (Eagleman, 2015). This should enable the user to feel the motion of the drone much more intuitively than in popular, current designs. Particularly, it seems to make sense to feed back the velocity of the drone to the user.

With six PWM outputs on the Arduino Nano, we can control six small vibrating motors. Activated, each of these provides a sensory input to the user, with magnitude proportional to the width of the voltage pulse applied. A simple solution would be to connect the six motors around the wrist, then set each motor to denote a particular direction of motion: up, down, forward, backward, left, or right. The degree to which the motor vibrates then correlates to the magnitude of the velocity in that direction. Notably, the choice of motor and direction association may be arbitrary, since the brain should theoretically perceive the pattern on a subconscious level. Still, for ease of learning, it may help to place the feedback for opposite directions opposite each other on the ring of motors. Thus, the motor denoting forward motion should be opposite that denoting backward motion, and so on. In the particular case of upward and downward motion, it may also be helpful to activate the top and bottom of the wrist particularly, again, to make the feedback as intuitive as possible.

Communication

When deployed, the remote control will have to wirelessly communicate with a quadcopter. For short-range quadcopters, Bluetooth communication is a popular choice. We chose to deploy our prototype with an HC-05 Bluetooth module, which implements Bluetooth V2.0+EDR. This limits our typical operation range to less than 100m (HC-05 Bluetooth Module), although this is not an issue for our prototype. Notably, other communications systems are quite possible to use in place of Bluetooth on our design, should the user require increased range and/or data rates.

Implementation

To implement the design, it is necessary to assemble the prototype and create the software. Both steps can bring to light deficiencies in the original design, contributing to the iterative nature of research and development. Also, it is important to test the prototype constantly during the implementation phase to verify that it continues to function properly.

Assembly

The assembly of the device poses no major challenges, though it can take significant time. Many solder connections are necessary for a permanent circuit, and the speed at which one can finish these is highly dependent upon former soldering experience. Fortunately, all of the components with pin headers fit nicely upon standard through-hole prototyping boards, simplifying the implementation process considerably. A crimp tool may also be necessary to create the custom ribbon connectors, but these connections pay off in their ease of plug-and-play adaptability.

Software

The creation of the software poses the biggest challenges for the project. Particularly, the two-way communication over a serial connection (e.g., Bluetooth) is fraught with potential for error. If bytes become unsynchronized due to data corruption, it is quite possible that the receiver will begin interpreting pitch commands as roll commands, for example. To disallow this, we designed our communication system with one reserved byte, 0xFE (254), which we use to denote the start of a new communication stream. Whenever the receiver captures a byte of value 0xFE, it restarts its collection. By placing this byte only between cycles of data transmission, the system seeks to avoid synchronization errors.

Completed, the software follows a predictable outline that can be summarized easily in a flowchart (Figure 3) or the following pseudocode.

```
Setup()
     Initialize Values
     Begin Bluetooth Communication
     Activate Sensors
Loop()
     Obtain data from Sensor 1
     Obtain data from Sensor 2
     Orient Sensor 1 with complementary filter
     Orient Sensor 2 with complementary filter
     Compute thrust from difference in orientation
     Compute direction from orientation of Sensor 1
     Transmit thrust
     Transmit direction
     Transmit stop byte (0xFE)
     Receive feedback from quadcopter
     Provide haptic feedback to user
```

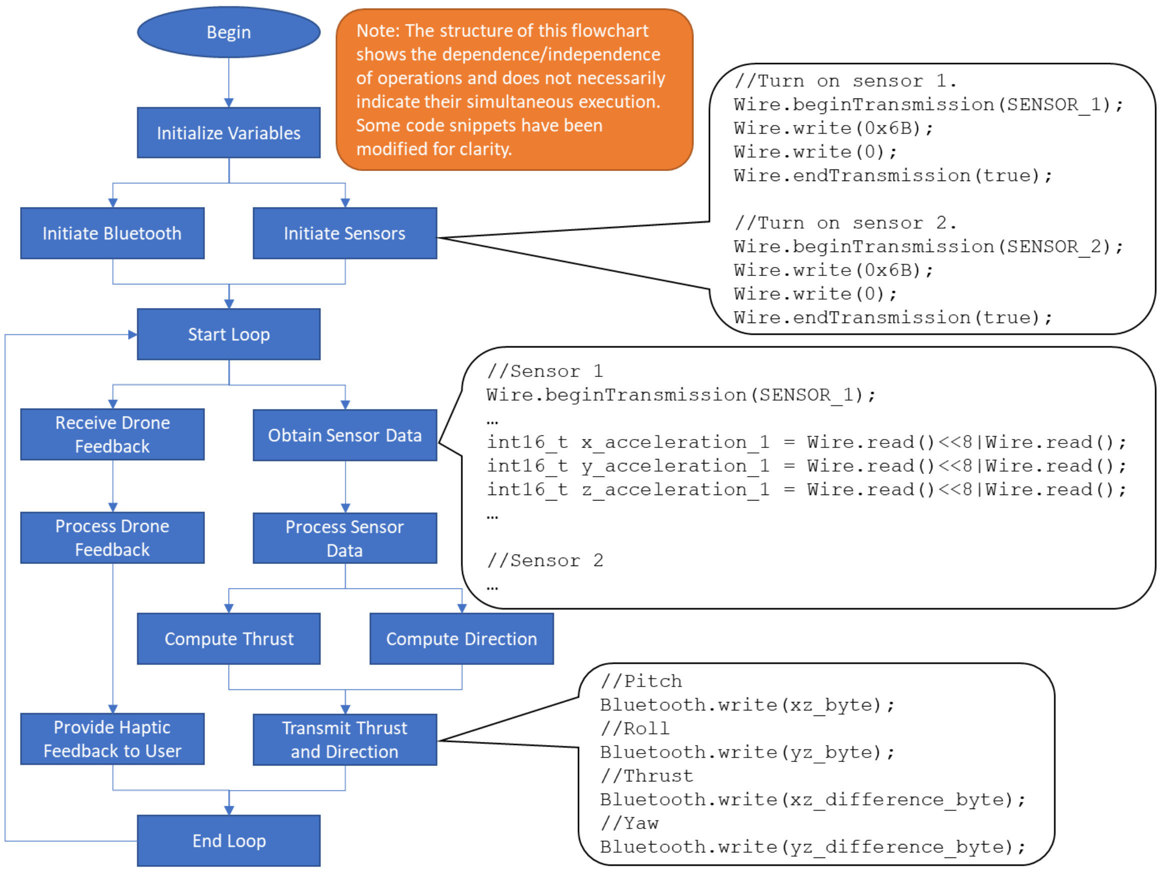

Figure 3. Flowchart of glove algorithm with key parts of code implementation.

Fleshing out this pseudocode takes significant effort and would be nearly impossible without steady access to the quadcopter or simulation with which the code was meant to interact. In our case, we use MATLAB to simulate the motion of a virtual quadcopter, using a simplified physics model that we developed. The precision of the physics is unimportant, as the primary goal is to create a realistic communication link.

Results

Research and design endeavors such as these often include significant speculation, describing what *should* work rather than, necessarily, what *does.* The risks involved are nontrivial, as the product may not work as intended, due to some oversight in design or deficiency in implementation. Fortunately, however, the results of this project were quite promising.

Goals Met

Using the MATLAB simulation, we confirmed that we could wirelessly communicate data back and forth from the remote control. Further, we observed that adjustments to the orientation of the sensors on the remote control produced noticeable, predictable changes in the output of the simulation, as expected. The simulation outputs two records, showing the x, y, and z positions as functions of time on a 2D graph and tracing out the path of the drone through space in a 3D graph. Unfortunately, we have not yet been able to connect the remote control to a graphical quadcopter simulation, such as Microsoft's AirSim. Another direction for further research would be to improve the reliability of the communication system, as bugs arise periodically during data transfer.

Observed Utility of Product

As a proof of concept, this project sought to show the efficacy of using intuitive sensors with haptic feedback. Already, in tests, it has become apparent that the tilt sensor is a much more intuitive means of data input than the traditional joystick. With haptic feedback, it seems quite possible that an intermediate user of this system could outperform an intermediate user of traditional controls. Also, the utility of having one hand free has been apparent while running simulations, as the free hand can interact with the computer. Transferring such an experience to real-world applications, we can confidently expect pilots with the glove system to fly drones more easily, especially when drone operations demand the use of other tools, e.g., cell phones, computers, or maps.

Applications

Ultimately, the goal of any engineering design project centers around the applications of the new technology. From the beginning, this endeavor had in mind the final application of this product to real-life drones. However, it may also function well in other areas as a generic user input device, not unlike the two-joystick remote.

High Level Market Overview

Ours is not the first drone remote control that utilizes a glove architecture. Several commercial products, including the KD Aura Drone and the Goolsky 2.4G Glove Control Drone, offer the ability to pilot a drone from a glove with at least high-level control (Aura Drone, 2018). Also, at least one startup, MotionPilot, is developing a remote control with haptic feedback (MotionPilot, n.d.). However, to the author's knowledge, no products currently on the market offer both a glove-type controller and haptic feedback in one package, especially with low-level control of thrust, orientation, and lateral motion. With the drone market booming, it is entirely possible that the next wave of controllers will incorporate these features, as we seek to produce the safest, most intuitive system possible. Applications might well expand beyond hobbyists and into civilian employment, where the number of domestic drone pilots continues to increase (Kelly, 2017). Even beyond civil careers, and into the military, we find that the technology we use in practice must be, first, very useable and practical. Whether for surveillance or explosive detection, drones have many applications, but before they see widespread use, they must become relatively easy to use. This glove can raise the bar on straightforward, intuitive, control.

Further Uses of this Technology

While this technology was designed with drones in mind, it could see applications in many other realms. From entertainment to industry, intuitive controllers are an integral part of enjoyable, efficient operations.

In the entertainment realm, the glove could inspire a new generation of video game controllers, especially for racing games. Since each glove can handle three to four analog input channels, as opposed to the two of a single dual-axis joystick, it may be possible to create even more immersive video games than already exist.

Immersivity, of course, calls to mind virtual reality – another application where intuitive control is necessary. Since the user cannot see his or her hands when using VR, traditional remote controls can pose problems to those unfamiliar with them. Furthermore, VR often seeks the freedom of movement that wirelessly connected gloves offer, as opposed to the restraints of handheld controls. Imagine swimming through an ocean world, holding nothing in your gloved hands, but feeling the virtual water nonetheless; that is a very real potential of this technology.

Moving on from the entertainment realm, we might consider applications to industrial machines. While industrial robots require careful programming for continuous use, nonroutine jobs might well be easier to control with an intuitive glove. Specifically, robotic operations in emergencies may not afford the time necessary to reprogram an existing robot. Similarly, robots working in hazardous environments might require the fine control of a gloved hand.

Finally, in the distant future, it is possible that personal flight vehicles will become a commonplace reality. Already, multicopters can carry people significant distances (Ehang184, 2019). Some of these, however, act more like a taxi service than a car, in that the internal computer handles all flight operations (Trew, 2016). Yet, at some point, humans will probably want to regain hands-on control over the machines that they are using, even if only for operations on private property. When that day comes, we can surely hope that the controllers they use lead to far fewer crashes than common remote controls. Whether or not an intuitive, glove-type controller with haptic feedback will fill that market, only time will tell.

Conclusion

While they have served their purpose well, the currently commonplace remote control for drones, which uses two dual-axis joysticks, is unnecessarily difficult to use. As a result, countless drone crashes occur needlessly. We propose an intuitive remote control based on a glove architecture to combat this problem. By incorporating haptic feedback from the drone, we hope to increase the pilot’s awareness of what the drone experiences, allowing the pilot to fly better than ever before. Additionally, since the glove controller only uses one hand, the pilot can use the free hand for related tasks, such as mapping the route of the drone or interacting with video imagery on a smartphone. Upon deployment, we expect that this design will ease the process of learning to fly, decrease the number of drone crashes, and increase pilot productivity, while paving the way for a plethora of future technological applications.

As the headline of the TIME magazine article pointed out, “Drones are here to stay.” (Fitzpatrick, 2018). We might as well use the best available means to control them. With our design, we can navigate an unmapped technological future with the familiarity of the back of our hand.

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