The Logitech M705: A Wireless Mouse Teardown

By Bill S. Preston, Esquire

for

ECEN 0000: A Cool Course

on

Friday, December 2, 2016

Introduction

Along with the interfaces built into computers, the devices humans use to interact with those interfaces have evolved quickly. Punch cards and tape were the first widely-used method to provide information to a computer. They operated by feeding cards and tape with an array of holes punched in them into the computer, which read the locations of the holes as instructions. One of the next leaps came with the introduction of the system called the computer terminal. This consisted of a screen with a keyboard to input commands. Once user interfaces had moved beyond simple text entry, pointing devices were invented to allow more fluid computer use. Modern technology heavily uses touch screens as well as other methods like gesture tracking and voice recognition, but keyboards and mice are still the most common input devices.

The M705

The M705 is a wireless mouse developed by Logitech. It was released in early 2010, and it is still on shelves through 2016. It sported many improvements over traditional mice for home use, and it added many features that were selling points for power-users. It uses a laser sensor for higher precision and use on a wide variety of surfaces that are off limits for optical mice. Along with the sensor, Logitech added a thumb button and side scrolling to the traditional left, right, middle, forward and back buttons. It also was the first affordable mouse with Logitech's Hyper-fast scrolling, which is activated by the press of a button.[1] The Logitech M705 fulfills the niche of the higher end home mouse, and it has done so for the last 6 years. It continues to be a highly-reviewed and successful product for Logitech.[2]

The M705's Predecessors

While the mouse and keyboard are the most common devices to allow human interaction with computers, there have been plenty of other solutions. An early device that allowed humans to directly interact with the data on a computer's screen was the light pen. The light pen, used in conjunction with a keyboard, allowed the user to perform some tasks more intuitively by pointing the device at the screen. The graphics card could tell where the pen was pointing due to the CRT monitor's method of painting the screen in sequence. When the light pen's view changed, that corresponded to the last area changed on the screen. The joystick was the next peripheral to be developed, and this device allowed the user to be further from the screen, even though the precision of the instrument was significantly lower. Variations on the joystick involved the user manipulating the device with hands, knees, and feet.[3] The mouse, however, proved to be the most user-friendly and agile device, allowing it to outlast its competitors.

Mice have used many tracking methods in the past. The first mice used two perpendicular wheels that were attached to potentiometers. The resistance of each potentiometer translated to the x and y locations of the curser. The next mice used a rubber ball that was in contact with the desk surface. When the ball spun, two rotary encoders read the rotation and translated that to movement of the curser. The next innovation in mice was developed in 1981. These mice used cameras to track the surface under the mouse. They rapidly took photos of the surface, which was usually illuminated by a red LED, and interpreted movement from the location changes of objects in the image.[3] Laser mice, like the M705, use the same concepts as optical mice, only they use an infrared laser to illuminate the underlying surface. Laser sensors offer higher resolution on more types of surfaces than optical sensors, but they are more expensive and are slightly less precise.[4]

---

[1] Logitech Product Description Page, http://www.logitech.com/en-us/product/marathon-mouse-m705

[2] Product Review by PCMag.com, http://www.pcmag.com/article2/0,2817,2370577,00.asp

[3] "History of Computer Pointing Input Devices" by Lorenzo Garbani, http://students.asl.ethz.ch/upl_pdf/358-report.pdf

[4] Logitech Techbrief Covering Laser Mice, http://www.logitech.com/lang/pdf/laser_techbrief-04.pdf

The M705's Market

The computer peripheral market is a well-defined, competitive market with many firms selling similar products. Logitech's main competitor in the market for keyboards and mice is Microsoft, a much larger company, with more resources and faster development cycles.[5] Logitech must stay on the bleeding edge of the technology to stay competitive. There are many different sub-markets for mice, and Logitech is competitive in the markets for home, professional, enterprise, and gaming, which each require vastly different products. The M705 competes in the market for home pointing devices, which is declining due to the growing popularity of touch screens for casual computer usage.

The year the M705 was released, Logitech made $1,966,748,000 in net sales, $528,236,000 (26.9%) of that was made in the pointing devices market, which mainly consists of mice and trackballs. It was one of the first devices to use their Unifying protocol, and it boasted a laser sensor. Logitech's total R&D costs for 2010 reached $135,813,000 and their marketing costs reached $304,788,000.[6] Assuming the ratio for sales holds true for R&D and marketing, Logitech spent $36,477,000 on R&D and $81,861,000 on marketing for mice and trackballs in 2010. Products like the M705 yield wider profits than newer products due to their long product cycles. Logitech also makes larger profits on the higher-end devices due to higher selling costs and similar manufacturing costs compared to cheaper options. Many of the electronics inside the mice are the same across all price-points, and only slight differences move a product from the home market to the professional market.

Regulations

All wireless devices are subject to FCC regulations in the US. The M705 falls under the category of low-power, non-licensed transmitters because it outputs low amounts of power and users do not require a license to operate it. These devices must have antennas that are either non-replaceable or have unique connectors, so the user cannot easily use a higher-gain antenna. Devices in the 2.4GHz band cannot have an output power of more than 1W. Every device in this category must be certified by the FCC to be eligible for sale in the US.[7] The EU equivalent to the FCC is the European Commission, which has similar rules. The laser sensor on the M705 is also subject to regulation. ANSI has outlined regulations for lasers in their Z136 document. The laser in the M705 is classified as class I, which means it is incapable of producing harmful radiation levels.[8]

The electronics inside of the M705, like all other electronics, are tightly regulated in some areas when it comes to disposal, due to the heavy metals and other hazardous materials they contain. In Boulder, for example, it is illegal to dispose of electronics in landfills, so they must be taken to specialized recyclers instead. These companies separate the harmful materials from the trash. These are reused or disposed of differently than the rest of the non-harmful materials.[9]

Design Considerations

The M705 has many competitors, so it was designed to stand out from other mice. One choice the designers made was to suit the mouse only for use by right hands. By doing this, they made the mouse much more comfortable to use, even though it eliminated some possible buyers. They also chose to pack many functions into the device that some users will never use, like the thumb button and alternative

---

[5] Logitech Quarterly Fiscal Report: Second Quarter 2016, http://d1lge852tjjqow.cloudfront.net/CIK-0001032975/690d1372-bb05-449e-bfe6-ee8abcec4759.pdf

[6] Logitech Yearly Fiscal Report: 2010, http://s21.q4cdn.com/947125427/files/doc_financials/annual_reports/2010/2009AR.pdf

[7] "Understanding the FCC Regulations for Low-Power, Non-Licensed Transmitters" https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet63/oet63rev.pdf

[8] "American National Standard for Safe Use of Lasers" https://www.lia.org/PDF/Z136_1_s.pdf

[9] Boulder County Electronic & Computer Waste, http://www.bouldercounty.org/env/recycle/pages/ewaste.aspx

scrolling mode. This was done to increase the list of possible buyers to power-users. When designing the electronics, the engineers chose to use 2.4GHz over the more popular FastRF, which operates at 27MHz. 2.4GHz is a frequency that is used my many modern systems, including Bluetooth and WiFi. This results in a band that is packed with interference. However, 2.4GHz offers some advantages over 27MHz. According to Logitech's tests, 2.4GHz allows for many more devices per area than FastRF, and 2.4Ghz has better range in modern construction.[10]

How the M705 and Its Receiver Work

The Logitech M705 consists of two separate systems, the mouse and receiver. The mouse uses a laser sensor to track movement, which is combined with an infrared LED and sensor for the scroll wheel and an array of buttons for various other functions. There are a total of nine buttons on this particular mouse that the user uses to interact with the computer and one switch that controls power. It uses a microcontroller to interpret and encode the buttons and sensor, and another chip to send the encoded data to the receiver over the 2.4GHz band. The receiver has one chip that receives the data from mouse, decodes it, and sends it to the computer over USB. Each receiver can pair with up to six devices using Logitech's Unifying protocol. These systems work together to allow the user to easily interact with their computer.

The mouse is loosely divided into multiple systems: power, sensors, the microcontroller, and the transmitter. Power is provided to the mouse by two AA batteries connected in parallel. This provides 1.5V and about 5Ah of capacity.[11] This is regulated up to 2V, which is used as the main voltage for the microprocessor and transmitter. There is a status LED that draws 14mA when it is on, but it does not stay on for very long. The mouse draws 1mA when transmitting, but after five seconds of no change, it stops transmitting and lowers its power draw down to 0.8mA. The mouse has power regulation that stretches the two batteries to a rated three years of use.

The M705's sensors provide multiple functions for the mouse to the user. The laser sensor sends image data to the processor, so the processor can judge the movement of the mouse. There are a total of nine buttons that serve various functions. three buttons are the standard left, right, and middle buttons. The mouse has forward and back buttons, as well as side to side scrolling buttons on the scroll wheel and a small button on the thumb pad. One button changes the feel of the scroll wheel. This button has a mechanical mechanism that then triggers an electrical function to tell the computer the enabled mode. The last interface sensor is an infrared LED paired with a sensor. The scroll wheel has slots allow the beam to pass through to the sensor, which sends a digital signal to the processor specifying if the beam is blocked. This allows the mouse to register the scrolling of the wheel.

The main microcontroller is an Atmel ATmega168PA, which runs an 8-bit AVR architecture.[12] The microprocessor reads in the digital values from all of the buttons, takes in the image data from the laser sensor, and reads the digital value from the scroll wheel sensor. It encodes this data into 8-bit packets, encrypts the packets, and sends them to the transmitter over SPI. The transmitter is an nRF24L01+ made by Nordic Semiconductor. This is a transceiver that is solely dedicated to communicating over 2.4GHz, and it mostly functions here as a transmitter. The Nordic chip sticks all packets into a circular buffer

---

[10] "2.4 GHz Wireless Technology: A Logitech White Paper" http://www.logitech.com/images/pdf/emea_business/2.4ghz_white_paper.pdf

[11] "1.5V AA Duracell Procell Alkaline Battery Tests" http://rightbattery.com/57-1-5v-aa-duracell-procell-alkaline-battery-tests/

[12] Atmel ATmega168PA Datasheet, http://www.atmel.com/Images/Atmel-42734-8-bit-AVR-Microcontroller-ATmega48PA-88PA-168PA_Datasheet.pdf

before sending them out over 2.4GHz. Nordic has their own system for acknowledgement and retransmission, which is configured on the nRF24L01+ itself.[13]

[13] Nordic Semiconductor nRF24L01+ Datasheet, https://www.nordicsemi.com/eng/content/download/2726/34069/file/nRF24L01P_Product_Specification_1_0.pdf

The receiver is a very small board that is mostly contained in the USB port. It receives 5V through USB, so there is no need for any other voltage regulation. It uses an nRF24LU1+, which is similar to the nRF24L01+ in the mouse, but this chip has a microcontroller, which runs Intel's 8051 architecture, integrated with the transceiver. The nRF24LU1+ has an integrated USB controller, so no other chips are needed to communicate with the computer. The receiver can communicate with up to six devices at a time, and the Nordic chip is the master of these communications. It coordinates timing and frequency for each paired device by taking advantage of the fact that it and the nRF24L01+ in each device are transceivers.[14] It senses interference and moves the affected device's communication to a different frequency. When it receives packets from connected packets, they immediately are loaded into a buffer. From that buffer, the device decrypts and decodes the packets before sending the information to the computer over USB.

The designers of the product drew knowledge from multiple fields of study to build the M705 and its receiver. At its base, the mouse uses many concepts from electrical engineering to build and design the chips and the board. The buttons and switches use mechanical connections that have been tuned to lengthen their lifetimes and reduce connection bounce. Both the mouse and receiver have transceivers in them which require precise frequencies and antennae. The antennae use many concepts of radio frequency design to reduce band pollution and noise. The chips employ different architectures and firmware which were designed by computer engineers. The firmware uses concepts from mathematics to interpret, encrypt, and decrypt data. Algorithms developed by computer scientists track the mouse's movement by comparing images. Other computer scientists and computer engineers designed the drivers and programs for varying operating systems. The electronics are housed in a case that took engineers specializing in human anatomy, user experiences, mechanical design, and machinery to design. The pieces were then fabricated and assembled by a mix of machines and humans, and the engineers needed to account for the constraints of the machines and the comfort and efficiency of human workers in their designs. The designs for the M705 and its receiver have likely been touched by thousands of people in dozens of different fields.

Conclusion

The M705 has made a large impact on the wireless mouse market. It incorporates many functions that have become standard due in part to the M705. It is a popular mouse for home and professional use, and it has features that make it a good mouse for many people. This case study showed the applications of many of the topics covered in this course. The M705 and, by extension, other mice incorporate digital I/O, communication protocols, power management, and embedded design to make a product that many people use for a significant portion of every day. The course taught me enough that I could infer many of the workings of the device just by inspecting the circuit board. It taught me the skills necessary to sniff communication lines and decode protocols. Most of the chips had labels that led me to datasheets, which helped in understanding the specific workings of the device. The chips used for the RF communication are the same chips used by my group for the final project, which was extremely helpful. The M705 is an example of the need for embedded engineers across all fields and in many devices, which is comforting, if not inspiring. It shows the power of a well thought-out design for device longevity and adoption.

---

[14] Nordic Semiconductor nRF24LU1+ Datasheet, https://www.nordicsemi.com/eng/content/download/2724/34051/file/nRF24LU1P_Product_Spec_v1_1.pdf

Appendix

Figure 1: M705 and Receiver Block Diagram

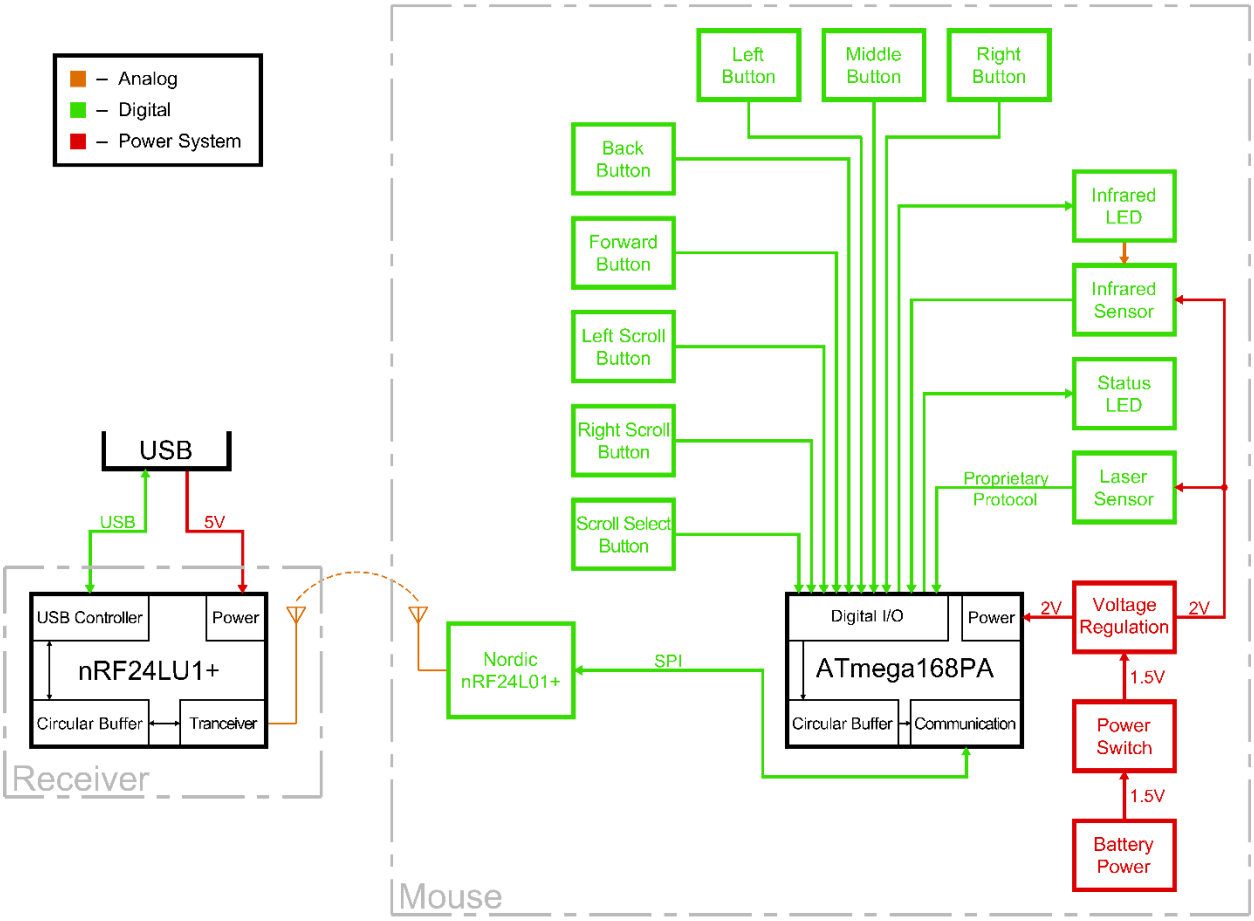

Figure 2: M705 Circuit Board

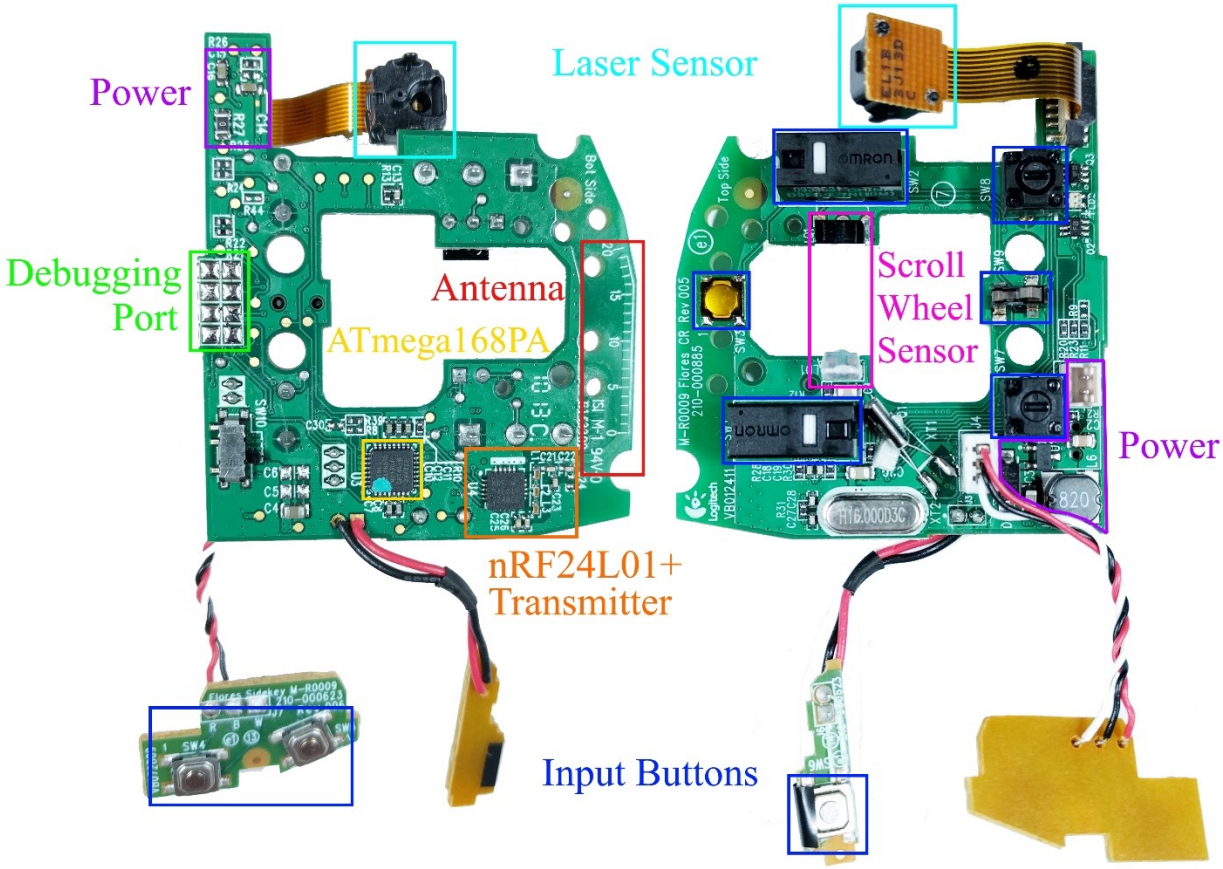

Figure 3: Receiver Circuit Board