Chapter 28O

Online Content: Toys in the Attic Sensors, Actuators and Gadgets

At this point in our university course we would list devices that we happened to have in the lab, hoping students might conceive new ways to use them. We don't know what you have in *your* lab, so it seems more useful to steer a reader toward the sort of supplier that we have found useful.

In addition, we've moved this section of Chapter 28 online so we can at least *try* to keep it up to date. Electronic technology moves at a dizzying pace and a neat part one month might be an obsolete one the next. (That is not to say some obsolete parts are not still fun. We designed a nifty project lab for one of our courses around the circa 1970 RCA Numitron tubes after Harvard blanched at our initial plan to use [even older] high-voltage nixie tubes: see Fig. 28O.1.[1])

28O.1 A few good sources of sensors, actuators and other devices

Here are some sites that we enjoy:

Adafruit A really good site founded by the serious and thoughtful electronics geek Limor "Ladyada" Fried who often integrates parts into helpful "breakout" boards that make the parts easy to wire. This aid is important because so many new parts are available in surface-mount packages only. The breakout boards permit breadboarding with such parts. Adafruit often provides code in addition to take advantage of programmable parts. The site initially leaned toward Arduino interfaces and code although more and more products now support Python. The site includes a tremendous

[1] The numitron was a seven-segment display using incandescent filaments for the segments. Because they were daylight readable, they were used in gas pumps before first LEDs then LCDs became the standard pump display technology. See https://LAoE.link/RCA_Numitron.html

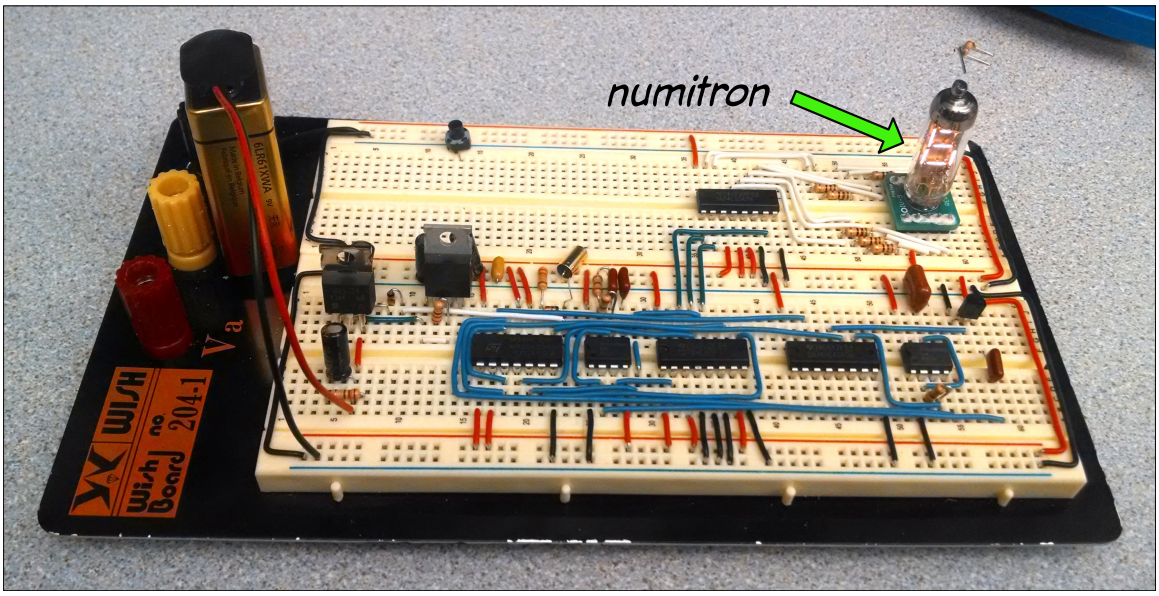

Figure 28O.1: ES52 Numitron die built by Grace Kossia & Valentina Lyau.

number of blogs and tutorials for learning electronics and using Adafruit's products. (https://LAoE.link/Adafruit.com)

SparkFun Similar to Adafruit, though perhaps more commercial. SparkFun, too, often provides helpful breakout boards, blogs and tutorials. Both our microcontroller and LCD display are SparkFun products. (https://LAoE.link/SparkFun.com)

Parallax Good for robotics parts such as chassis, and a good collection of sensors. (https://LAoE.link/Parallax.com).

Pololu Offers a selection of both electronics and mechanical parts geared (pun intended) towards robotics. (https://LAoE.link/Pololu.com).

Electronic Goldmine This is a surplus shop, so the selection is unpredictable and odd. Some interesting sections including the Clearance Bin, Unique Items, Antique & Vintage Components, and Rare and Esoteric along with a large selection of electronics kits. (https://LAoE.link/Electronic_Goldmine.com)

DigiKey A traditional electronics distributor with an enormous inventory, DigiKey has fair shipping charges and accepts small quantity orders. We recently ordered a few SPI DAC's and shipping was quick and reasonable. The site also has a nice set of learning resources for students and engineers. (https://LAoE.link/DigiKey.com)

Amazon Love 'em or hate 'em, Amazon has become the world's marketplace. When you feel the need to play with a $10 tiny RP2040 microcontroller *now*, Amazon Prime's free two-day shipping may save the day compared to a traditional distributor's $50 minimum order and absurd shipping charges (but see Digi-Key above). (https://LAoE.link/Amazon.com)

Surplus Stores There are still some independent electronic surplus stores, some with physical locations, worth looking at. Try https://LAoE.link/Apex_Surplus.com or https://LAoE.link/Anchor_Electronics.com.

eBay And don't forget to try eBay, which sometimes offers great bargains and is a place to look for hard to find and obsolete parts. We have found 1970s era Numitrons and even older Nixie tubes on eBay. (https://LAoE.link/eBay.com)

28O.2 A source of small parts for mechanical linkages

Specialized parts like bearings, gearing, belt drives, and universal joints are available at SparkFun (above) and also at both a specialized site and at Amazon's general "Industrial & Scientific Store."

Amazon Industrial & Scientific Store Lacks the coziness of the Small Parts, Inc. that Amazon bought, but accesses a great variety of parts. (https://LAoE.link/Amazon_Industrial.html)

Stock Drive Products A smaller site, less overwhelming. (https://LAoE.link/Stock_Drive_Products.com)

28O.2.1 Mechanical: motors, etc.

Stepper motors: The stepper's appeal is that it does not require use of *feedback* for precise control of positioning.

1. Two types: unipolar versus bipolar.

   - **Unipolar.** Unipolar is the easier configuration to drive, requiring only a transistor switch on each "phase" winding (typically, this is a switch to ground, as in Fig. 28N.27). The motor will provide six leads – the usual four leads for the opposite ends of the two windings, plus two more for the center tap of each winding. Sometimes the two center taps will be combined, reducing the number of leads to five.
   - **Bipolar.** These 4-lead motors omit the center tap, and thus require a pair of drivers that can both *source* and *sink* current. Such drivers are available in integrated form and are called "H-bridge." Though harder to interface, the bipolar is more efficient than the unipolar, whose windings keep half their length always idle.

2. Resolution and power. Typical stepper motors provide 200-steps-per-revolution and need substantial current 0.3–1A, at perhaps 10V.[2]

[2]For example, the Adafruit bipolar NEMA-17 size – 200 steps/rev, 12V 350mA

3. Small stepper motors. Smaller motors usually show coarser resolution – for example, SparkFun offers a small motor with 48 steps per revolution – but Adafruit has one with a gear reduction to give finer resolution.[3] The smallest that we have encountered is less than 1cm in diameter.

4. Stepper drivers. As noted in §28N.6, one can sidestep the work of writing code to drive a stepper motor by taking advantage of a driver IC. For example, the Adafruit 2448.

28O.3 "Servo" motors

These pulse-width controlled motors lend themselves to computer control because pulse duration is not hard to regulate with a microcontroller. They come in two forms:

1. Radio-control model type: position control.

   These are sold as actuators for use in RC models. (You may have read a description of these in §26N.3.2.) They rotate through about 180°, holding a rotation position that is determined by the width (duration) of a logic pulse sent to the motor repeatedly. They are available in many standard sizes from "nano" to "large", use little power and provide substantial torque (the motor is small, but geared way down).

   Applications: useful to steer a car, e.g.; but strong enough for, say, positioning a small robotic arm.

2. Continuous-turn type: rotation rate control.

   These differ from the usual in using pulse width to determine not shaft *position* but rather rate and direction of rotation. A pulse of standard width (1.5ms) produces *no* rotation; a pulse of shorter or longer duration produces rotation in one direction or the other, at a rate roughly proportional to the difference from the standard pulse width. A 1ms pulse produces full speed in one direction, 2ms evokes full speed in the opposite direction. These are used in the car chassis described in §28N.3.9, one servo driving each of two wheels.

28O.4 Nitinol muscle wires

1. Muscle wires: tiny pullers.
   One company at least really does call these "muscle wires."[4] Their more serious name is shape memory or nitinol wire. They shorten (by 3–7%) with considerable force when heated if they've been stretched while in their cool, soft state.

[3] The SparkFun ROB-10551 and Adafruit 918 respectively.
[4] http://LAoE.link/Muscle_Wires.com

This slight shrinkage percentage implies that a long wire is needed to provide any substantial actuating "stroke." A small company called Miga Motors makes an ingenious stroke enhancer that essentially folds a longish wire. This scheme achieves a stroke of 0.3″ from a credit-card size circuit board. One such device is the MigaOne-15, shown in Fig. 28O.2.[5] It includes a contact that permits an intelligent driver circuit to sense full travel in order to shut off power, preventing damage from excessive heat.

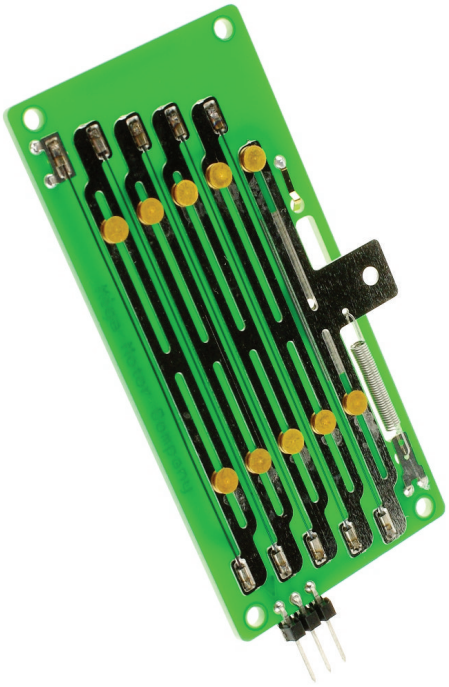

Figure 28O.2: MigaOne amplifies stroke length for nitinol wire actuator.

Nitinol actuators call for very large currents, since the current's job is to heat the wire with I^2R power; but the power needn't be applied for long if a brief contraction is required. So a small battery can do the job, if duty cycle is very low, keeping the whole setup small.

2. Applications: tiny robots.
   A couple of students made a six-legged bug using muscle-wire – and concluded that they would never touch muscle wire again: it gobbles current, doesn't pull very hard, and is pesky to build with (requiring tensioning adjustments). Still, you can't find an actuator lighter than the nitinol wire.

   The wires can be used to mimic the behavior of tendons, making a crude hand with wiggleable fingers.[6]

[5] This is neat but expensive at about $50 and appears to be a discontinued product. For alternatives, see https://LAoE.link/Memory_Metal_Driver.html and https://LAoE.link/Miga_Robotics.com

[6] Kits for such hands are offered by MuscleWires.

28O.5 Transducers

Sound:

1. Ultrasonic send, receive "speaker"/microphone.
   These are small diaphragms tied to a piece of piezo-electric stuff, and are resonant at about 40kHz. Transmitter and receiver are either identical or very similar to one another.

   Applications: ranging (send a burst; listen for echo); communication (send data as sequence of bursts).

2. Integrated ultrasonic transducer and amp.
   This was the method Polaroid developed as rangefinder for its cameras. The method is mimicked in MaxBotix rangers.[7] The EZ1, for example, offers a sensing range from 6 to 254 inches, in 1″ increments. It provides an output in three forms: analog, pulse-width, and RS232 serial. These rangers are available in various sensitivities. Note an alternative ranging method that uses *infrared* light. This is mentioned in §28N.3.10. That IR device shows better resolution, but shorter range.

Infrared:

1. IR remote-to-logic signal translator.
   This was described in §27W.2. The translator converts each 36kHz to 40kHz burst put out by a typical IR remote into a single logic level. (In the example shown in Fig. 26N.8, a burst produces a logic Low; silence produces High.)

   Applications: a circuit with brains (your computer) can translate the serial stream of logic levels that an IR remote provides. A properly synchronized 8-bit shift-register, done with computer or with hardware, could, in principle, give you 256 options. See Chapter 27W for an example using an IR remote to control the Lullaby Jukebox.

2. Passive differential IR motion detector.
   An "alarm" signal is asserted when the IR image of a room changes. 3.3V to 12V, logic-level output.[8]

Color discriminator: An IC array of detectors, each with a color filter. Two ingenious people paired this device with optical fibers in an effort to read resistor color codes. The resistor colors were badly defined and defeated them – but the machine was able to read the colors of a ribbon cable, much of the time. Pretty good. You may enjoy the challenge

[7] These are available at `https://LAoE.link/MaxSonar.html`.
[8] For example, see SparkFun SEN-13285.

of improving on their machine to automate resistor sorting.[9] For specifications, see the Parallax site.[10]

Acceleration; rotation rate: Many accelerometers are offered by Adafruit, Parallax, and SparkFun. You should check their sites for new models even niftier than the ones we have noticed. These companies typically offer a 'breakout board.

You probably want a range of just a few g.[11] With two axes, you can sense *tilt*.

SparkFun offers a helpful discussion on their site of many alternative accelerometers.[12]

- Analog output, 3-axis ($\pm 3g$, 3V supply): ADXL335.
  Sometimes analog output is nice, letting you see on a scope screen a live image of the device outputs. The controller's ADC can read these values – but to read three axes with a single ADC requires use of an analog multiplexer. The SAMD21 includes such a multiplexer, allowing the single ADC to read all three axes in succession. Adafruit offers a breakout board for this accelerometer (Product ID: 163), a board that includes a 5V-to-3.3V regulator.
- Digital output: SPI or I^2C: ADXL345 (selectable range, ± 2 to $16g$, 3V supply). SPI interface is not hard to handle, especially with microcontroller hardware implementation of SPI (see Chapters 26L and 26W. The accelerometer outputs are not viewable on a scope screen, but their values can be displayed on a laptop's screen through the Segger IDE. And taking the inputs in digital form is tidier and easier than what's required if the accelerometer speaks analog. SPI obviates need for successive ADC operations that include multiplexing ADC input pins.

Gyro: A small solid-state gyro gives an analog output proportional to angular acceleration. Here one axis may be enough, and analog output is more common than digital.

- 1-axis, analog output (3V supply): LY530AL (SparkFun but now end of life).
- 3-axis, I^2C and SPI output, breakout board permits 5V supply and 5V control signals: L3GD20H from STMicro (Adafruit).

Accelerometer and gyro combined: You can get accelerometer and gyro on one IC to make things more compact. For example, the AdaFruit BN0085 (but expensive at $25.95) or the Sparkfun LSM6DS0 (only $13).

[9] Before you do this hard work, should we remind you that there is an easier way to determine the value of a resistor? Probably not.

[10] However, it is expensive at $89. The part is TAOS TCS3200-DB

[11] One g, as may you know, is the acceleration due to gravity here on the surface of earth.

[12] SparkFun's Accelerometer, Gyro and IMU Buying Guide.

Surely lots of neat improved models will be coming along, so treat our list of devices as only a snapshot of what was available back in 2023. As these devices are incorporated into cell phones and even smart watches, the prices drop significantly.

Magnetic field: Two basic sorts are available: plain and fancy.

1. Plain: Just Hall-effect sensors. Linear output proportional to current: a breakout board by SparkFun, ACS723. Simpler, inexpensive sensors give Yes/No detection. For example the US1881 (latching) or AH1815 (non-latching) from SparkFun.

2. Fancy: a digital compass. Adafruit provides a 5V-compatible breakout board using a Honeywell 3-axis HMC5883L IC. The circuit uses two orthogonal coils to sense variations in the orientation of the earth's magnetic field relative to each of the two coils. The 3-axis readings are delivered with I^2C.

Force: Small flexible sheets that change resistance when flexed. For example, the Adafruit 1/2 inch dia force sensor.

Speech generation: A two-IC board takes ASCII characters in serial form (SPI) and does its best to pronounce the text phonetically. The SparkFun DEV-18873 using the Epson S1V30120 speech synthesis IC. (Sadly, now discontinued - but if you need "clear, and accurate Chinese speech synthesis effect," here's one at Amazon.).

Speech recognition: This is a very hard task – rendered utterly easy by someone's IC and little printed-circuit board: SparkFun's MIKROE SpeakUp Click (also discontinued) which recognizes up to 200 different voice commands one you train it. If you win the lottery, the SparkFun Nicia Voice ($82) includes a Neural Network process for voice recognition along with an accelerometer, gyro and magnetometer plus bluetooth connectivity in a tiny low-power package

Just getting it to work is nowhere near a project. The challenge is to think up an interesting application. The thing is small (about $1''$-by-$2''$), so it could, in principle, be mounted on a little vehicle (controlled by a microcontroller, probably – but not necessarily), permitting control of the vehicle by voice.

28O.6 Displays

1. liquid crystal (LCD).
   Nearly all use the industry-standard interface that looks like a single I/O location; the computer feeds the display successive ASCII codes (7 or 8 bits), and the display takes care of placing the characters properly. This requires six or seven I/O lines,

although an add-on board can convert this parallel interface to a serial protocol.[13] An alternative is the SparkFun SerLCD series which we used in the microcontroller labs, which supports all three serial protocols, UART, SPI and I^2C.

Applications: wordy output for many sorts of gadget. (These may not be very exciting since they only take our little computer a little way toward the very chatty LCDs that you're accustomed to on big computers.)

2. OLED bit-mapped display.
These provide beautiful high-resolution images or text displays, usually quite small. Their interface, at the time of writing, remains difficult. Adafruit provides libraries of code to help. Adafruit has a series of OLED display boards, for example, a 128-by-32 1" diagonal SPI display for $17.50.[14]

3. "Intelligent" LED display: 2-character or 4-character alphanumeric.
These are small. Each character occupies a single I/O address, and wants to be fed ASCII. For example, Siemens PD2435. Handsome, but obsolescent. Try `https://LAoE.link/Octopart.com` to find stock.

   Good for small, brief, bright verbal output.

4. Bar-graph.

   - LED: An array of LEDs. You may have seen similar displays used as VU meters on audio equipment. Simple ones call for wiring each LED. For example, Adafruit's KWL-R1025BB. Fancier ones use a serial interface (also at Adafruit).
   - Electrostatic: "E-Ink." The appeal of E-Ink displays is zero power-consumption after a level is written. The difficulty is their peculiar drive requirements: a brief pulse at ± 15V to turn a segment On or Off. But you might enjoy showing off your skill in making your own driver. The company takes the annoying line that their parts' drive demands are *confidential* (they ask a user to sign a non-disclosure agreement!). It's no secret though, and drive for a few segments is not hard to implement.

     A 14-segment bar graph is available: SCD722003 (Digikey). So is a 6-character numeric display: SCB721001 (Digikey).

28O.7 Interface devices

Output:

[13] Adafruit provides this "back pack" board: I^2C/SPI Character LCD Backpack, PRODUCT ID: 292.
[14] PRODUCT ID: 661. These are available also from the usual distributors, including Digi-Key.

- Solid-state relay. These will turn On/Off a heavy AC load (motor, lamp, appliance) safely using a logic-level as input. For example, the SparkFun's COM-13015 supports up to a 40A load. Input is optically coupled to the high-voltage parts, so your circuit remains isolated from the scary 120V supply.

In and Out:

1. Radio serial link. A simple radio link could carry digital data: the simplest scheme would be to turn a transmitter ON, then OFF, then ON… The simplest transmitting device would be a fast logic-level oscillator gated ON or OFF (you could use a MOSFET to apply power or not). The simplest receiver would be an amplifier driving an "envelope detector" – a simple 1-diode AM detector like the one you met in §3L.5.2. You might build the amplifier from scratch; or you may prefer to look for an IC amp. A comparator could then determine whether the envelope-detector showed that a burst of signal was coming in ("1") or not ("0").

   At its simplest, this burst/no-signal waveform could generate the logic-level pulse that controls the position of a *servo motor* (see above), steering a little car, say. If you were more ambitious, you could use this simple radio link to send serial data in one of the standard conventions – using conventional RS-232 (to a UART on the receiving end) or perhaps I^2C, mentioned just above.

   The easier way to proceed is to buy ready-made Send and Receive modules. See for example SparkFun's many "RF link" boards, some simple (such as transmitter WRL-10534 and receiver WRL-10532). These are "indiscriminate," so call for some intelligence on your part. Some integrate UART serial I/O.

   Still easier is to start with a board that converts between SPI and radio, though the software needed may be substantial. The Adafruit 433MHz transceiver and Adafruit 915MHz transceiver provide relatively slow (19.2kbps) communication over 200 to 500 meters (at 433MHz) or 2km (at 915Mhz) line-of-sight. We have not tried these.

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