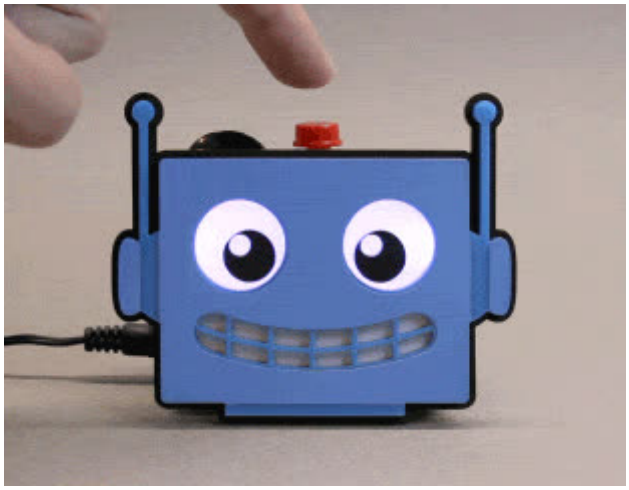
Wave Shield Talking Clock

Created by Phillip Burgess



https://learn.adafruit.com/wave-shield-talking-clock

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Overview

UPDATE: We now have a much simpler version of this project using CircuitPython and the Adafruit Prop Maker RP2040 Feather. (https://adafru.it/19BR)

Here's a different take on DIY clock projects. Whereas most dwell on visual displays, ours features Adabot's friendly face speaking the time.

Best of all, you can make this your own...give it your face and voice...or if you can do impressions, how about an Arnold Schwarzenegger or Dave Jones clock? Anything goes!

Parts List

This is a "choose your own adventure" project...you might substitute or add additional parts to the mix. Read through the whole guide (and look through your current parts stash) before planning a shopping list. Here's some of the essentials:

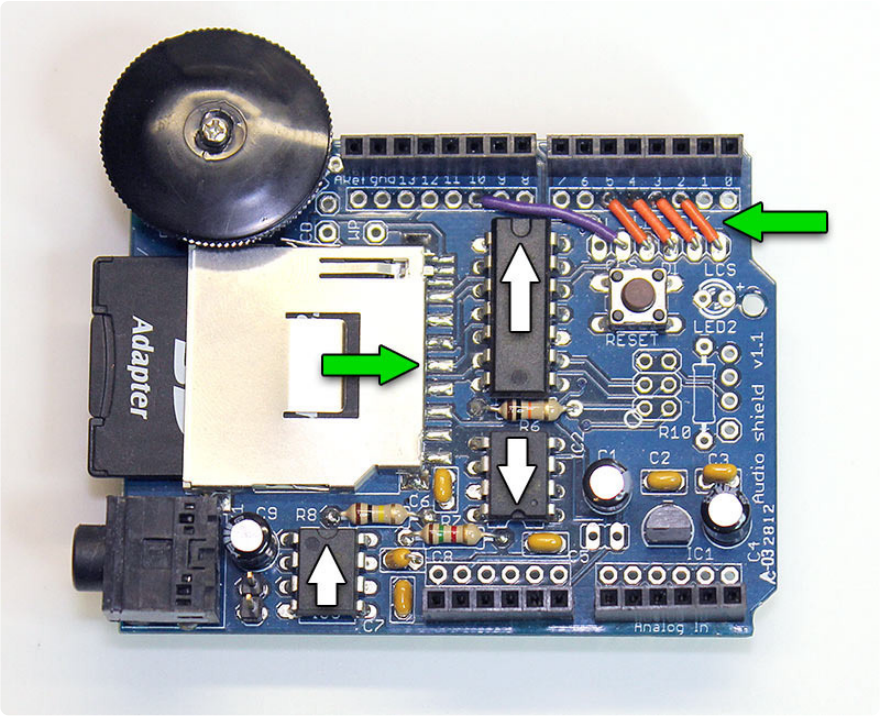
- Arduino Uno **(http://adafru.it/50).** This project will not work with the Arduino Leonardo, Mega, Due, Netduino, etc. It must be an Uno.
- Wave Shield **(http://adafru.it/94)** (assembly required).
- **SD card** (or microSD w/adapter). This is a great way to re-use older "fun size" cards...it doesn't require a lot of space!
- Either a DS1307 Real Time Clock **(http://adafru.it/264)** or a Data Logging Shield **(http://adafru.it/1141)**.
- Stacking headers **(http://adafru.it/85).** If using the Data Logging Shield, get two sets!
- **Speaker.** Either the small 8 Ohm 1W speaker (http://adafru.it/1313) in the shop, or you can add an external amplified speaker for more "oomph."
- **LEDs** and **resistors** (one resistor per LED, 180-220 Ohm for red/yellow/green, 100-150 Ohm for most others).
    - Adafruit doesn't sell individual resistors. You can find small packs at Radio Shack, Fry's, etc. If you can't find these exact values, slightly higher is totally fine.
    - Instead of regular LEDs, our clock face uses LED backlight modules (http://adafru.it/1622), but you can use whatever suits your design.
- Any sort of **momentary button**. Tactile switches, arcade buttons (https://adafru.it/dSh), etc.

- A **power source.** This could be a USB cable connected to a port on your computer, a USB phone charger (http://adafru.it/501), a 9V “wall wart” power supply (http://adafru.it/63), or a battery pack (http://adafru.it/248).
- **Soldering paraphernalia:** iron, solder, bits of wire, perhaps a breadboard (http://adafru.it/64) for prototyping.

Dry Run

Start with our Wave Shield tutorial **(https://adafru.it/Cdv).** This will guide you through assembling the shield, downloading and installing libraries and testing the board and SD card.

You’ll probably want to assemble it using stacking headers rather than the regular pin headers included with the shield. It’s up to you...read through the rest of this guide first and come up with a plan for your clock design, and how you might have things wired up.



Troubleshooting

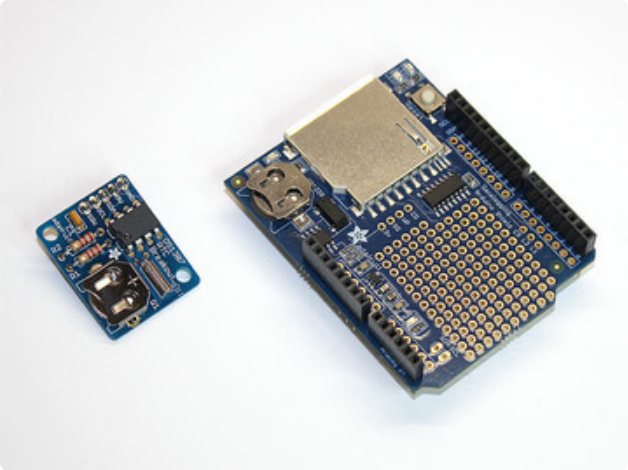
For reference, the photo above shows a properly-assembled Wave Shield. The following are the **most common errors** encountered with the product:

- The WaveHC library is not properly installed. This tutorial can offer some guidance (https://adafru.it/dit).

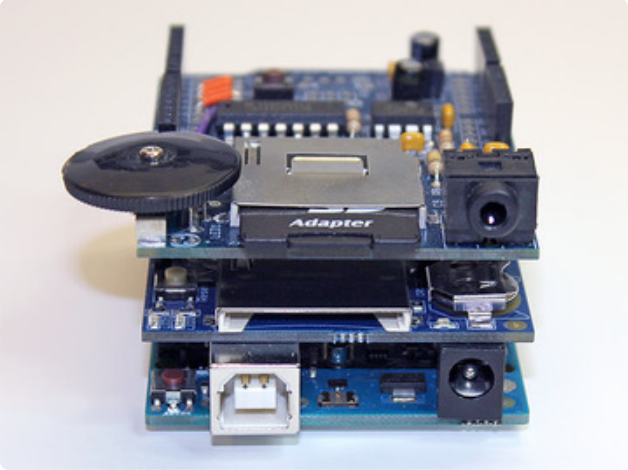
- The SD card is not properly formatted; even if your computer can read/write the card, it's not necessarily "true" to the SD specification. Try formatting the card in a digital camera if you have one.
- Jumper wires are missing (the five wires near the top edge of the board...pins 2-5 and 10).
- One or more chips are turned the wrong way (notice the arrows pointing to the "bite"), or the DAC and amp chips are swapped.
- Cold solder joints, or solder bridges...especially on the SD card slot connections. Solder should flow smoothly between pin and pad, like tiny Hersheys Kisses®. Reflow any badly-formed joints.

If your Wave Shield still refuses to work, make a new post in the Adafruit Forums (https://adafru.it/cer). Please provide clear photos of both sides of the board, and completely describe the symptoms (including any error messages in the Serial Console).

Don't continue until you have the "PiSpeakHC" demo working!

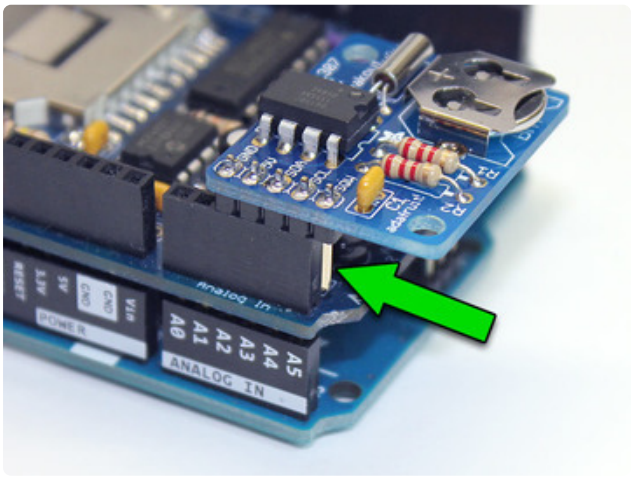


For timekeeping, you have Freedom of Choice: either the DS1307 breakout board (http://adafru.it/264) or the Data Logging Shield (http://adafru.it/1141) (with optional stacking headers (http://adafru.it/85)) can be used.



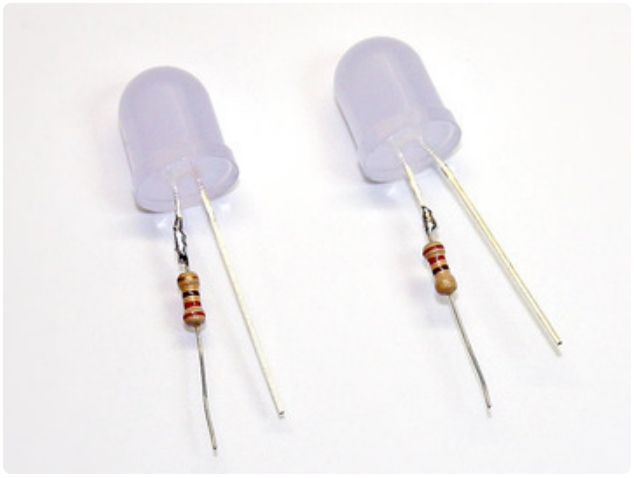
The Data Logging Shield costs a little more, but with the stacking headers installed it makes a tidy sandwich.

We won't be using the SD card slot on the Data Logging Shield for this project. Don't even put a card in there or there will be... trouble.



The less expensive DS1307 breakout board provides just the clock function.

This can be connected using a solderless breadboard (http://adafru.it/64) and jumper wires (http://adafru.it/1956). Or — with the 5-pin header installed — you can use the trick shown here and plug it into pins A2-A5 (the remaining pin isn't used here and hangs off the end). **This requires a special setup in the code**, which we'll get to shortly.

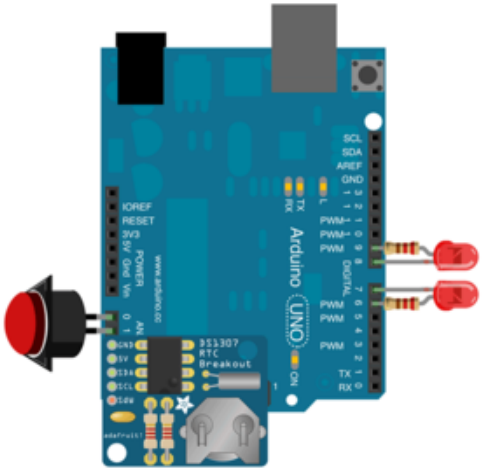


Resistors are soldered to each of the LEDs that'll provide the face animation (one for eyes, one for the mouth). For red, yellow or green LEDs, use a 180-220 Ohm resistor. For all other colors, use 100-150 Ohm.

The resistor can go on the anode (+) or cathode (–) side of the LED; they're not picky. Here I chose +.

I'm using 10mm red LEDs for the dry run; later I'll substitute LED backlight modules instead.

Any sort of **momentary pushbutton** can be used to activate the clock. Tiny tactile buttons (http://adafru.it/1489) work great on a breadboard. Big arcade buttons (http://adafru.it/471) are irresistable. Advanced users could modify the code and wiring to use a capacitive touch sensor (http://adafru.it/1374) or PIR (motion) sensor (http://adafru.it/189).



Here's how things are wired up. The Wave Shield (and Data Logging Shield, if used) aren't shown in the stack here, but would actually be installed atop the Arduino first.

The DS1307 (if used instead of the Data Logging Shield) connects to pins **A2–A5** (the SQW pin on the board isn't used and hangs off the edge).
Pushbutton connects between **A0** and **A1**.
"Mouth" LED connects to pins **D6** (+) and **D7** (–).
"Eyes" LED connects to pins **D8** (–) and **D9** (+).
Note the orientation on the two LEDs!

You'll need a library for the realtime clock:

Click to Download RTClib

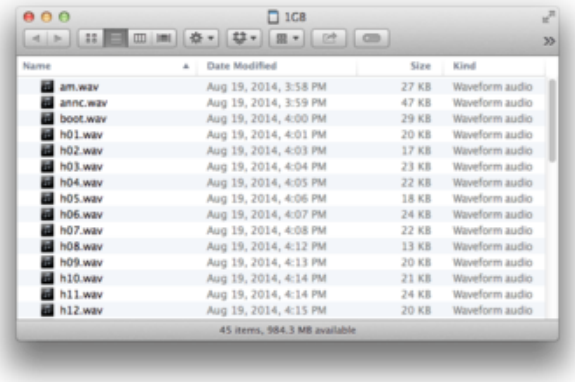
https://adafru.it/cxm

Install RTClib as any other Arduino library; unpack, move folder to Arduino sketchbook/Libraries folder, will be active on next restart.

Next, download the Arduino code and the example WAV files (Adabot's voice) for the project:

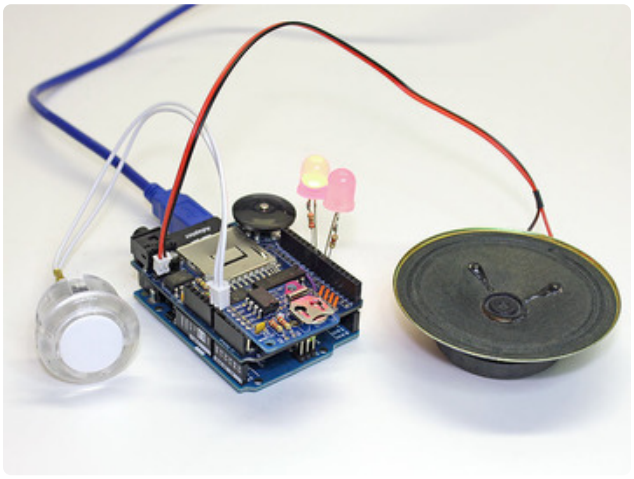
Click to Download Code and WAVs

https://adafru.it/dSn



After unpacking, copy the WAV files (not the WAVs folder, but the files inside) to the root folder of the SD card. Eject and return the card to the Wave Shield.

Move the TalkingClock folder to your Arduino sketchbook folder. Restart the Arduino IDE and you should be able to load the sketch and upload it to the board.



If all goes well, you should hear Adabot say “Hi there!” Tap the button to hear the current time. One LED (the “eyes”) should periodically blink, the other flashes when Adabot talks.

The workings of the code are explained on the last page of this guide. Some folks just want to make the clock, that’s cool.

If the RTC hasn't been used before, the TalkingClock sketch will automatically initialize the clock to the date & time the program was compiled.

If you ever need to change the time, here’s a minimal sketch that does the same thing, setting the clock to the compile time:

```
#include &lt;Wire.h&gt;
#include &lt;RTClib.h&gt;

void setup() {
  pinMode(A2, OUTPUT); digitalWrite(A2, LOW);       // Power RTC breakout
  pinMode(A3, OUTPUT); digitalWrite(A3, HIGH);      // On pins A2, A3
  Wire.begin();                                     // Init I2C
  RTC_DS1307::begin();                              // Init real-time clock
  RTC_DS1307::adjust(DateTime(__DATE__, __TIME__)); // Set to compile time
}

void loop() { }
```

After running this code on the board, upload the TalkingClock sketch again and it should be speaking the correct time!

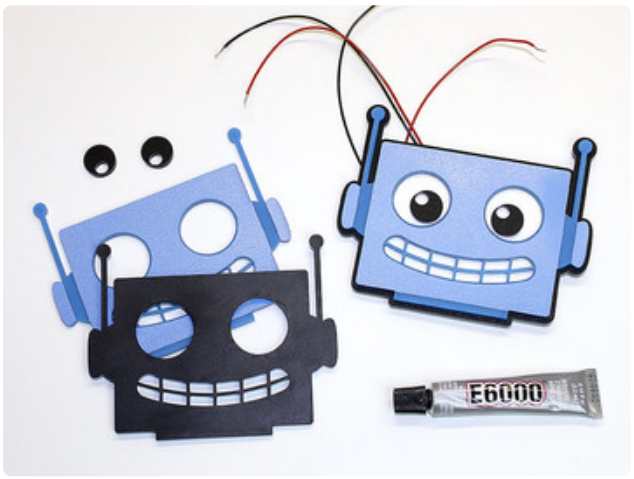
Arts & Crafts

What will your clock look like? Chuck Norris? HAL 9000 (https://adafru.it/Cdx)? We like Adabot (https://adafru.it/aVg)!

If you’re adept at **3D printing**, this adorable Adabot model (https://adafru.it/Cdy) could perhaps be adapted to the task.

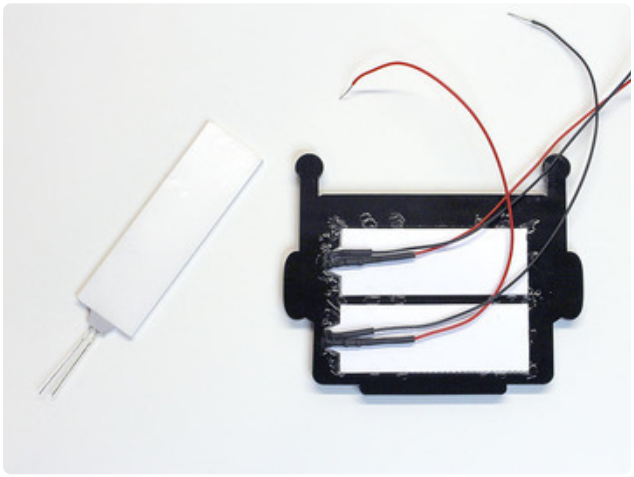
If you’re more craft-inclined, or had a different character in mind, you can come up with your own design that leverages your existing skill set (or provides an opportunity for new ones you always wanted to learn).

I've got a bad habit of making everything a laser cutter job...but really, you could use anything...from papercraft to a teddy bear to a Godzilla toy!



I used a paint-and-etch technique. Medium blue acrylic was painted black on the back side (acting as a stencil to block light from the LED backlights) and light blue on the front. Laser engraving etched away the light blue paint over certain areas to reveal the darker blue plastic underneath, then the lit areas and the outline were laser cut. A separate piece of black acrylic provided the pupils and the backing plate/border.

Because the acrylic is painted, the layers are glued together using E6000 instead of acrylic cement.



The back piece has cutouts for two medium LED backlight modules, aligned with the eyes and mouth cutouts on the front. The backlights were cut down slightly using a scroll saw so the proportions of the face wouldn’t need changing.

The clear protective layer on the backlights’ front face should be peeled off before final assembly. The white layers should not be peeled.

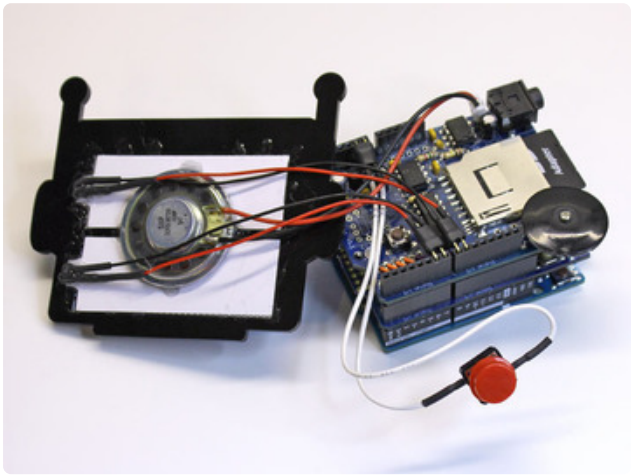
I dug through my parts stash to find smaller components that would fit behind the face...

The shiny red button is important because there's no force in the universe more powerful than the compulsion to press shiny red buttons.

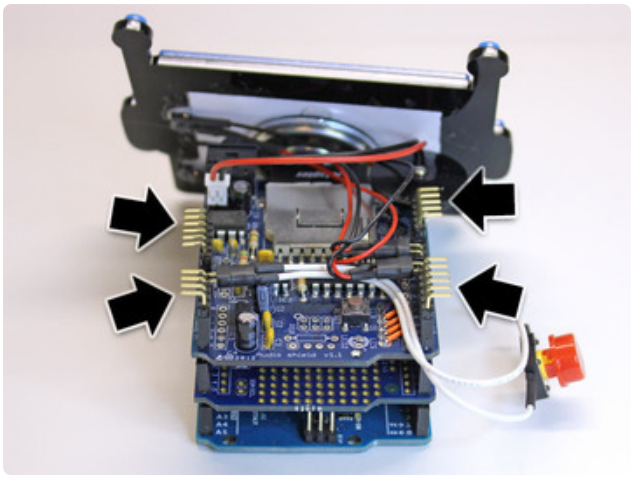
The speaker was scavenged from an electronic farting birthday card (my family is so classy!). No, really. I'm using it here because it was surprising loud for its size... I'm sure the makers of the farting birthday card were thinking the same thing.

Normally I'd aim for a nice enclosure with all the parts and fasteners hidden as best as possible...but wanted to use a different tack for this one. Putting the electronics in plain view invites questions. "What's this thing? You made this? Can I make this too? What's Arduino?"

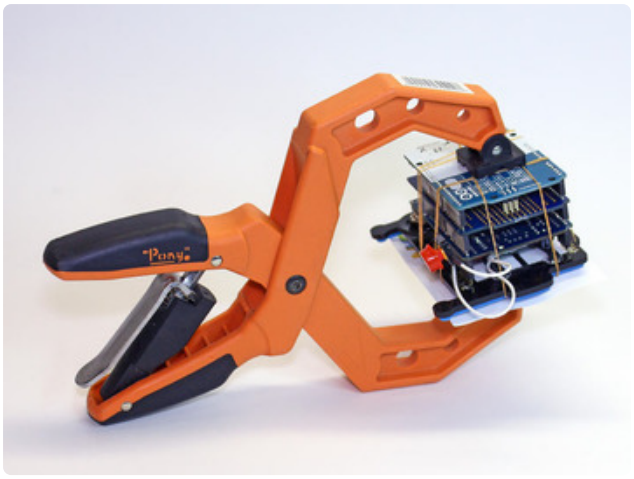
We can make a tidy board stack using the Data Logging shield. Or the RTC breakout works with just a little more soldering & wires.



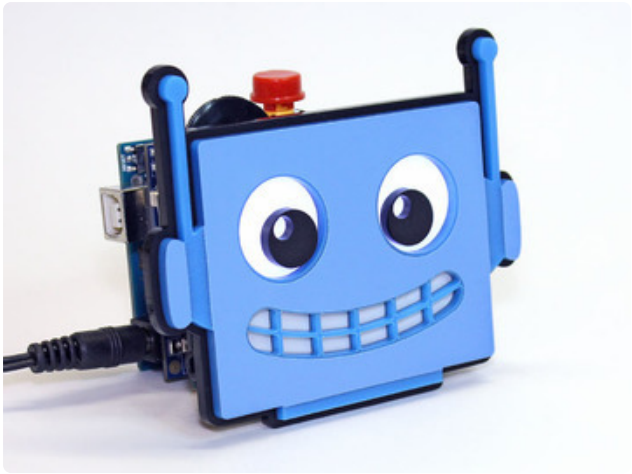
Speaker glued in place. Great, this will all fit behind the face...but how to attach it to the Arduino?



Right-angle pin strips were inserted into all the free spaces in the headers...

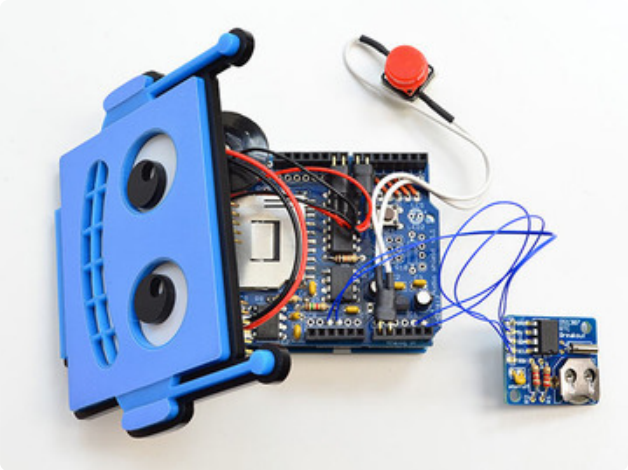


The “flat” side of the pins were then glued to the back of the face using epoxy. Essentially, we’ve made the face into an Arduino shield, albeit one with no electrical function. Ha!



The finished clock, plugged into a 9V power supply, eyes lit and awaiting a button-press.

I like that the Arduino silkscreen is visible and rightside-up, so people can see what makes it tick.



Here's an "alternate plan B" assembly, using the RTC breakout rather than the Data Logging shield. Four wires are run from the breakout board to SDA, SCL, +5V and GND. Then space was found underneath the Wave Shield where the board could be taped (there happens to be a blank spot with no conductive bits to worry about).

Recording New Voices

To record new voices for the clock, you'll need a computer with sound input capability (or a USB microphone) and audio software that can edit and save WAV files (such as the free, cross-platform Audacity (https://adafru.it/c9T)).

My telephone answering machine speaks timestamps in awkward, stilted English. Maybe you have some talking gadget like this.

Though using high quality voice samples, they were recorded and are played back with no regard to the intonation we as humans apply to the same words when used in different parts of sentences. Probably a cost consideration, to use the smallest ROM possible. But we have a whole SD card at our disposal and can cut loose!

For example, when you or I say "It's 12:12 pm," the first and second "twelve" have a slightly different inflection...and you'd say "20" differently than the 20 at the start of "21." To make our spoken time slightly less awkward-sounding, a few repetitious bits of speech are recorded, and the sketch reassembles these with some simple rules.

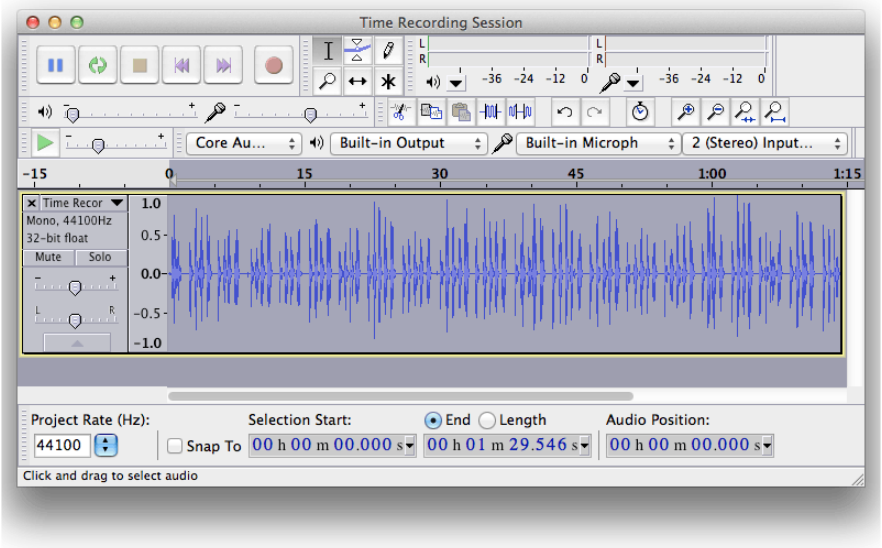
About half the audio you record will be discarded, but reading this complete script helps capture a more believable inflection for each word — don't edit down, read each sentence in full, with a pause in-between. Don't run words together...you'll need to "Shatnerize" a bit, with a full stop between each word, but otherwise try to keep the same pitch as you would when speaking normally. And avoid the tendency to be "sing-song" with pairs of lines (where pitch alternates up and down on contrasting words); state each sentence as a standalone thing.

For consistency in tone and volume, read the full script in one pass, then edit later. Don't record, edit and save as you go. The words in **bold** are kept. The rightmost column lists the corresponding filenames (don't speak these) that should be assigned to each bold word. For example, read the Shatnerized sentence "It's one o'clock am." "It's" is just there to help with the hour inflection; discarded later. The next three words are later copied into new files: h01.wav, m00.wav and am.wav. Trim any silence from the start and end of each word; there's a small gap during playback anyway, as each file is accessed.

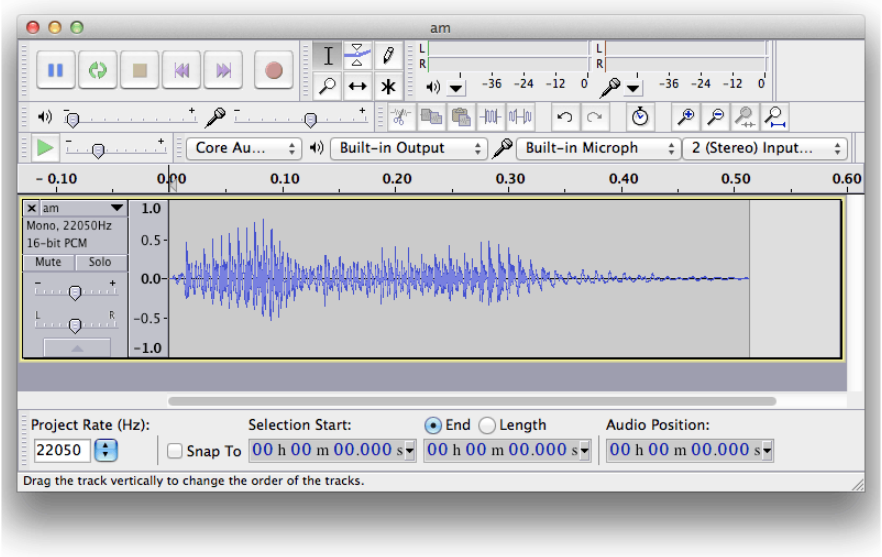
Phrase					**Filename(s)**
"**Hello**" (or other startup sound)					boot
"**The time is...**" (or other announcement message)					annc
It's	**one**	**o'clock**		**am**	h01, m00, am
It's	**two**	**ten**		am	h02, m10
It's	**three**	**twenty**		am	h03, m20
It's	**four**	**thirty**		am	h04, m30

It’s	**five**	**forty**		am	h05, m40
It’s	**six**	**fifty**		am	h06, m50
It’s	**seven**	**oh**	**one**	am	h07, m0x, m1
It’s	**eight**	**twenty**	**two**	am	h08, m2x, m2
It’s	**nine**	**thirty**	**three**	am	h09, m3x, m3
It’s	**ten**	**forty**	**four**	am	h10, m4x, m4
It’s	**eleven**	**fifty**	**five**	am	h11, m5x, m5
It’s	**twelve**	oh	**six**	am	h12, m6
It’s	one	twenty	**seven**	am	m7
It’s	two	thirty	**eight**	am	m8
It’s	three	forty	**nine**	am	m9
It’s	four	**eleven**		**pm**	m11, pm
It’s	five	**twelve**		pm	m12

It’s	six	**thirteen**		pm	m13
It’s	seven	**fourteen**		pm	m14
It’s	eight	**fifteen**		pm	m15
It’s	nine	**sixteen**		pm	m16
It’s	ten	**seventeen**		pm	m17
It’s	eleven	**eighteen**		pm	m18
It’s	twelve	**nineteen**		pm	m19



I recorded the full session at a high bitrate (44.1 KHz 32-bit float) and cleaned up the sound a little (normalize, etc.) before downsampling to a more manageable 22 KHz 16-bit PCM...this is more than sufficient for voice. Then the essential words were clipped out into their own files...



Sound files should be copied to the root folder of the SD card. To minimize delays between words, start with a freshly-formatted card, copy the WAV files and eject (card access gets progressively slower as the filesystem becomes fragmented).

How the Code Works

If you want to make any changes to the design, you'll need to understand a bit of how the code works. Certain things are dictated by the hardware, others are just programming shenanigans.

If you haven't coded for the Wave Shield before, you'll find easier-to-understand examples with the WaveHC library...the PiSpeakHC demo is pretty straightforward. The core parts of the talking clock code are very similar, no need to rehash that (or button debouncing) here.

The explanation needs to move around a bit, this isn't entirely top-to-bottom.

Near the top of the clock code, before setup(), some pin numbers are #defined:

```
// Mouth LED needs PWM, limits pin options: must be a PWM-capable pin not
// in use by the Wave Shield nor interacting with Timer/Counter 1 (used by
// WaveHC).  Digital pin 6 is thus the only choice.
#define LEDMOUTH 6
// The trigger button and eye-blink LED can go on any remaining free pins.
#define LEDEYES  9
#define TRIGGER  A0
```

The mouth LED is "animated" using the Arduino's analogWrite() function to vary the brightness. As explained on that function's reference page (https://adafru.it/aUh), this is only available on certain pins (3, 5, 6, 9–11 on the Arduino Uno).

Meanwhile, the Wave Shield is using most of those pins for communicating with the DAC card and SD card (2–5, 10–13). It's possible to rewire the shield and rewrite the code to use different pins, but that's a bit of a nuisance and would break compatibility with all of the WaveHC example code! So there's really no choice, the mouth LED needs to be on **digital pin 6**.

The analogWrite() reference mentions a problem with pin 6 though: it can't display a 0% (off) duty cycle. As a workaround, later in the code, we simply set that pin to an INPUT when the mouth is not talking, and the LED will turn off:

```
      pinMode(LEDMOUTH, INPUT); // Disable mouth
```

(The pin is never explicitly set to OUTPUT in the code…analogWrite() already does that when it's necessary.)

Save RAM with PROGMEM

The WAV filenames are stored in a global set of tables before the setup() function. The PROGMEM directive is used so these strings are **stored in flash memory instead of RAM** (which is in very limited supply, especially in any Arduino code dealing with SD cards).

A quirk of PROGMEM makes it necessary first to declare all the strings, then follow with arrays containing references to these strings:

```
const char PROGMEM
  boot[] = "boot", annc[] = "annc", am[] = "am", pm[] = "pm",
  h01[] = "h01", h02[] = "h02", h03[] = "h03", h04[] = "h04",
...
  *hours[]  = { h12, h01, h02, h03, h04, h05, h06, h07, h08, h09, h10, h11 },
...
  *mins[]   = { m1, m2, m3, m4, m5, m6, m7, m8, m9 },
  *ampm[]   = { am, pm };
```

It's explained a bit more on the Arduino PROGMEM reference page (https://adafru.it/aMw)…and in more depth in this Adafruit guide (https://adafru.it/q0e)… required reading for anyone dealing with RAM-hungry sketches!

PROGMEM strings can't be accessed directly, one must use pgm_read_word() to access the pointer:

```
      playfile((char *)pgm_read_word(&amp;hours[h])); // Say hour
```

No Weasels!

The very first thing in the setup() function is a trick we recently learned for avoiding the speaker “pop” at startup:

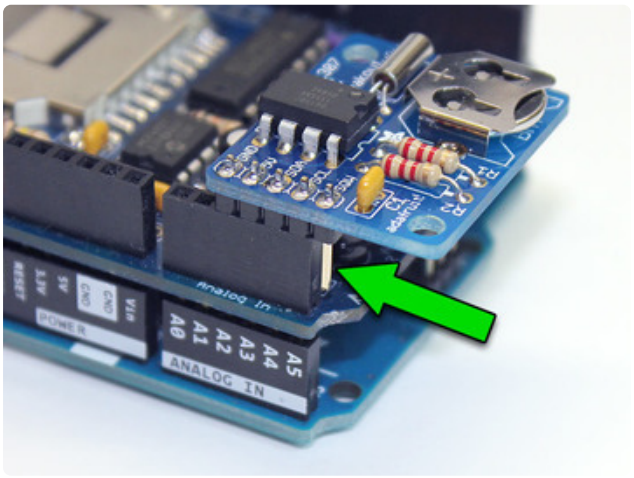
```
mcpDacInit();               // Audio DAC is
for(int i=0; i&lt;2048; i++) { // ramped up to midpoint
  mcpDacSend(i);            // to avoid startup 'pop'
  delayMicroseconds(10);
}
```

This shifts the digital-to-analog converter output from its default startup value (0) to the neutral speaker position where most WAVs start (2047) at a controlled rate.

Power Games

There are three GND pins and only one 5V pin on the Arduino. Sometimes it would be nice if there were just a couple extras...usually we use a small breadboard to provide more.

But, as long as the required power is very small (40 mA absolute max...ideally 20 mA or less) it’s totally legit to set an output pin as HIGH or LOW to provide an extra 5V or GND connection.



The DS1307 clock chip needs just a flea fart’s worth of power, so it’s no problem running the breakout board this way. The order of the pins on that board, coupled with the fact that Arduino pins A4 and A5 provide the I2C communication functions, means we can hang the board right off those pins and provide power through A2 and A3. The SQW pin isn’t used for this project, so it’s fine hanging off the edge.

Pins 7 and 8 provide grounds for the LEDs, and A1 is a ground for the pushbutton.

```
// Sometimes having an extra GND pin near an LED or button is helpful.
// Setting an output LOW is a hacky way to do this.  40 mA max.
pinMode( 7, OUTPUT); digitalWrite( 7, LOW);
pinMode( 8, OUTPUT); digitalWrite( 8, LOW);
pinMode(A1, OUTPUT); digitalWrite(A1, LOW);

// Along similar lines -- if using the DS1307 breakout board, it can
// be plugged into A2-A5 (SQW pin overhangs the header, isn't used)
// and 5V/GND can be provided through the first two pins.
```

```
  pinMode(A2, OUTPUT); digitalWrite(A2, LOW);
  pinMode(A3, OUTPUT); digitalWrite(A3, HIGH);
```

Having done this...between the Wave Shield, clock, button, LEDs and pins reserved for Serial use...we've now exhaused the Arduino's entire complement of pins.

THEREFORE: if you want to make changes to the clock and need extra control pins (e.g. two separate LEDs for the eyes), then don't this trick, or use less of it! The LEDs and trigger button can use any of the normal GND pins...the use of I/O pins for this was entirely a matter of proximity and convenience...you'll simply need to run a wire to a different part of the board is all.

Walking while Chewing Gum

The loop() function is continually polling the button and plays sounds as necessary... the latter is handled by a separate function. Trying to use conventional program flow to keep the random eye blinks going while the code also manages these other tasks would make it really bloated and complex.

A timer interrupt provides a sort of multi-tasking, periodically calling a function to handle the eye blinks.

Timers are a hairy subject. There's a very limited number of them (0, 1 and 2)...the first is already in use by the Arduino core library to provide PWM and the delay() and millis() functions...the second is used by WaveHC...leaving only Timer 2. Working with timers is not for the meek...it involves reading the ATmega328P datasheet and fiddling around with specific registers and bits:

```
  // A Timer/Counter 2 interrupt is used for eye-blink timing.
  // Timer0 already taken by delay(), millis(), etc., Timer1 by WaveHC.
  TCCR2A  = 0;                                // Mode 0, OC2A/B off
  TCCR2B  = _BV(CS22) | _BV(CS21) | _BV(CS20); // 1024:1 prescale (~61 Hz)
  TIMSK2 |= _BV(TOIE2);                       // Enable overflow interrupt
```

The eye timing doesn't require any super-specific frequency like 100.0 Hz. The way this one's set up provides a 16,000,000 ÷ 1024 ÷ 256 = 61.035 Hz period, and for the sake of timing blinks it's close enough to think of it as "60-ish Hz."

An interrupt service routine (ISR)...in this case a Timer/Counter 2 overflow condition... then handles the periodic task:

```
ISR(TIMER2_OVF_vect) {
...
```

Dirty Pool

Finally, there's the matter of modulating the mouth LED brightness in response to the audio being played. This uses a really dirty trick, nothing gentlemanly about it, and it would get you an "F" in a Computer Science class: we access one of the WaveHC library's internal variables: playpos, a pointer to the value currently being output to the speaker.

The samples are presumed 16-bit. We look at just the high byte, it provides enough resolution for the animation, and track the minimum and maximum range over a very brief interval (however long it takes for 256 iterations of this loop to execute...which may actually be much quicker than 256 values from the WAV, that's okay).

```
// Sound level is determined through a nasty, grungy hack:
// WaveHC library failed to make certain global variables static...
// we can declare them extern and access them here.
extern volatile int8_t *playpos; // Ooooh, dirty pool!
int8_t s, lo=0, hi=0, counter=-1; // Current sample, amplitude range

for(wave.play(); wave.isplaying; ) {
  s = playpos[1];             // Audio sample high byte (-128 to +127)
  if(++counter == 0) {        // Mouth updates every 256 iterations
    int b = (hi - lo) * 4;    // Scale amplitudes for more brightness
    if(b &gt; 255) b = 255;      // Cap at 255 (analogWrite limit)
    analogWrite(LEDMOUTH, b); // Update LED
    lo = hi = s;              // Reset amplitude range
  } else {
    if(s &lt; lo)      lo = s;   // Track amplitude range
    else if(s &gt; hi) hi = s;
  }
}
```

Normally it's good form for a C++ class to declare its internal variables as private, so they're not accessible to outside code. This allows the developer of the class to make drastic internal architectural changes to the library without breaking outside code that relies on it...everything passes through an Officially Sanctioned Set of Methods and/or Variables That (ideally) Will Not Change Across Versions™.

So here we're exploiting the fact that the WaveHC class variables are all public...we can get in there and peer at what the library's doing. **This is not without risk:** if there's any update to that library that either changes the code's inner workings or simply declares those members private, **our software breaks!** This is why it's bad form. If that should happen, we'd either have to require the use of an older version of the library, or make our own fork that provides a clean and proper interface for similar functionality.

Can I use NeoPixels instead of discrete LEDs?

No. The realtime requirements of the Wave Shield and NeoPixels don't play nice together. But if you have two pins available, WS2801 or LPD8806 LED pixels are a possibility!

How about LED matrices?

Yes, but...

It's a substantial addition, and we don't have a ready-made recipe for this. The Animating Multiple LED Backpacks (https://adafru.it/iwB) guide may offer some insights...it combines a Wave Shield and LED matrices for a talking face, but not reading the time. You'd need to devise a "mash up" of these two.

I'm trying to sleep but that blinking is keeping me up. Can the eyes stay lit?

Sure...just comment out the line in the interrupt routine where the eyes turn off:

```
//      digitalWrite(9, LOW);
```