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**Running head** “Smartphone Attachment For Stethoscope Recording”

**Smartphone Attachment For Stethoscope Recording**

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**Abstract**

With the ubiquity of smartphones and the rising technology of 3D printing, novel devices can be developed that leverage the “computer in your pocket” and rapid prototyping technologies toward scientific, medical, engineering, and creative purposes. This paper describes such a device: a simple 3D-printed extension for Apple’s iPhone that allows the sound from an off-the-shelf acoustic stethoscope to be recorded using the phone’s built-in microphone. The attachment’s digital 3D files can be easily shared, modified for similar phones and devices capable of recording audio, and in combination with 3D printing technology allow for fabrication of a durable device without need for an entire factory of expensive and specialized machining tools. It is hoped that by releasing this device as an open source set of printable files that can be downloaded and reproduced cheaply, others can make use of these developments where access to cost-prohibitive, specialized medical instruments are not available. Coupled with specialized smartphone software (“apps”), more sophisticated and automated diagnostics may also be possible on-site.

**Keywords**

iPhone, stethoscope, audio recording, 3D printing, STL, Shapeways, smartphone, app, sound, selective laser sintering, fused deposition modeling

**1. Introduction**

The following is more of a “how to” than a laboratory procedure; this is worth noting for two reasons. First, 3D printing handles much of the heavy lifting, creating the component that acts as interface between the iPhone and the stethoscope. Once printed, the component and related pieces require minimal preparation for use. Second, I am trained and work as a visual artist, and this device is born out of my creative research. The stethoscope attachment was originally conceived as a device for making interesting, experimental audio recordings. The additional use as a medical instrument provides further evidence of something I believe strongly: that research in the arts can have practical and important applications in STEM fields.

Such a device could be used for a variety of medical purposes, including remote diagnosis of cardiovascular or respiratory issues, real-time telemedicine between a specialist and a health worker in a remote or underserved region, and, with the addition of custom-written smartphone applications, performing automated, audio-based analysis for diagnosis by non-professionals. While electronic and recording stethoscopes do exist, they are very expensive (see Reference 3). Coupled with this attachment, even an inexpensive, store-bought acoustic stethoscope can make recordings sufficient for diagnosis.

The central part of the device is a 3D printed interface between the iPhone (selected because it is the most ubiquitous smartphone today, though this design could easily be adapted for other devices) and a standard acoustic stethoscope (see Figure 1). The part is 3D printed in selective laser-sintered (SLS) nylon or ABS plastic, and is friction-fit to the bottom of the phone where the microphone is located. A barbed fitting at the base of the attachment connects the stethoscope’s PVC tubing. A hole down the barb carries sound from the tubing directly into the smartphone’s microphone, the same way sound in a traditional stethoscope is passed through the earpiece into the ear.

In order to capture the full range of adult chest sounds, higher-quality stethoscope heads have two sides: the *diaphragm* for higher frequency sounds in the range of approximately 100–1000 Hz, and the *bell* for lower frequency sounds in the range of 20–100 Hz (see Reference 1). The microphone in the iPhone 4 (released in 2010) has an attenuated frequency response, as we might guess in a consumer device not intended for high-fidelity audio. However, it is capable of recording the entire frequency range outlined above, with a very flat frequency response past 200 Hz. This suggests that, as an inexpensive, portable, and very flexible device, the iPhone is very well-suited for recording the sounds from a stethoscope.

**2. Materials**

1. Stethoscope head with fitting for standard 3/16 – 1/4” (4.75 – 6.3mm) ID tubing.
2. Standard stethoscope tubing (single lumen), 3/8” OD, 3/16 – 1/4” (4.75 – 6.3mm) ID, at least 6” long (see Note 1).
3. 3D-printed iPhone attachment, either using a commercial service printing in laser-sintered nylon (preferable), or locally using a hard material such as ABS or PLA plastic (see Figures 2 and 3). For an overview of 3D printing technologies, see Reference 4.
4. iPhone generation 4 or above.
5. Sound recording app for iPhone such as the pre-installed “Voice Recorder.”
6. Optional: audio post-production software for filtering recordings to improve the clarity of recordings, especially of low-frequency sounds such as heartbeats; the free, open-source Audacity is an excellent option for this purpose.

**3. Methods**

This section describes 3D printing, assembly, and use of the stethoscope attachment. The first of these instructions describe printing the attachment using the commercial service Shapeways; if a 3D printer is available locally, the attachment can be printed using a variety of alternative methods outlined in section 3.1.b (see Notes for possible issues and further suggestions).

**3.1.a. Printing The Attachment Using Shapeways’ 3D Printing Service**

*Shapeways, a 3D printing service based in the United States and the Netherlands, provides very high-quality printing in a variety of materials.*

1. Visit the following link to order a 3D-printed version of the stethoscope attachment: <http://shpws.me/oQUX>.
2. Choose a material color from the “Material Options” dropdown menu – default is white (see Note 2).
3. Click the “Buy Now” button to order the printed model in the material specified (see Note 3); at time of writing, commercial printing of the attachment was approximately $30 USD.

**3.1.b. Alternatively, Print Using a Local 3D Printer**

*Inexpensive 3D printers designed for consumer/hobbyist use such as the Makerbot or open-source RepRap may be substituted without loss of audio fidelity, though they may take more work to produce usable prints.*

1. Visit the project’s GitHub repository: <https://github.com/jeffthompson/iPhoneStethoscopeAttachment>.
2. Download the necessary files by clicking the “Download ZIP” button in the right sidebar. This includes the printable stereolithography (STL) files, as well as supporting documents and sample recordings.
3. Print using a hard material such as ABS or PLA plastic at 100% infill; other settings will depend on model of 3D printer (see Note 4).
4. Clean and sand/file printed model as necessary for a smooth finish.

**3.2. Prepare Stethoscope Tubing**

*A single length of flexible PVC tubing is needed to connect the chestpiece to the 3D printed attachment. This can be repurposed from an existing stethoscope or bought in bulk and cut to size (see Note 1).*

1. Cut one section of stethoscope tubing using a sharp knife or scissors. If using the tubing from an existing stethoscope, cu below the fork to form a single tube. Length is variable but less than 15” (38cm) can make it difficult to maneuver; very long tubing will likely cause a reduction in the fidelity of the audio.

**3.3. Assemble the Attachment**

*For an image of the completed assembly, see Figure 2.*

1. Slide one end of the stethoscope tubing over the barb in the stethoscope head until secure.
2. Insert the other end of the stethoscope tubing over the barb at the bottom of the 3D printed attachment; the tubing should fit tightly but can be carefully removed (see Note 5). While the 3D printed parts are sturdy, care should be taken not to break the barb when attaching the tubing.
3. Slide the 3D printed attachment over the bottom of the phone; the half-circle cutout in the attachment should align with the “home” button. Slide the attachment in until the bottom of the phone hits the bottom of the 3D printed attachment (see Note 6).

**3.4. Test and Record**

1. Turn on the phone and launch an audio recording app like Voice Recorder (see Note 7).
2. Set your app’s settings to highest quality possible, if available. Higher sample rate and bit depth will result in higher-fidelity recordings. Avoid recording in compressed formats like MP3 if non-compressed formats such as WAV or AIFF are available.
3. Press record and test the stethoscope. Depending on your app’s sensitivity settings, loud sounds such as tapping the stethoscope head should be very clearly picked up as sharp spikes by the microphone (see Note 8).

**3.5. Audio Processing and Analysis**

*While the recordings from the stethoscope may be used without any processing, some filtering will make the isolation of certain sounds easier, especially for automated analysis.*

1. A variety of adult chest sounds can be heard with a stethoscope and can be identified by their frequency ranges. These include “low heart sounds (including first, second, and third heart sounds) from 20 to 115 Hz; medium/high heart sounds (including systolic and diastolic murmurs) from 200 to 660 Hz; vesicular (normal) breathing from 150 to 1,000 Hz; bronchial breathing from 240 to 1,000 Hz; and crepitations (crackles) greater than or equal to 750 Hz” (see Reference 1).
2. For lower frequency sounds like heartbeats, a low-pass filter may be useful for removing noise and more clearly identifying the beats; this can be applied after the recording is made, or with a custom app in real-time (see Figures 4-6).

**4. Notes**

1. The design of the attachment’s barb allows for some variation in the dimensions of the tubing: any tube approximately 3/16 – 1/4" (4.75 – 6.3mm) inside diameter will fit.  
   In the interest of accessibility and cost-savings, “UV-Resistant Black PVC Tubing” can be purchased in bulk from: <http://www.mcmaster.com/#5231k83/=oainxw>.
2. Shapeways’ “Strong and Flexible” material is laser-sintered nylon plastic, resulting in prints that are very strong with some flexibility. Printed parts can be easily cleaned, are dishwasher safe, and are heatproof to 80C/176F. See the following link for more information: <https://www.shapeways.com/materials/strong-flexible>.
3. Shapeways offers a variety of other materials for printing. If you would like to experiment with materials other than the default laser-sintered nylon, you will need to download the source files from GitHub and upload them to Shapeways.
4. Depending on your printer’s method and output material, specific settings may be required for a high-quality and durable print. For Fused Deposition Modeling (FDM) printing like the MakerBot, shrinkage may also require re-engineering the model based on trial and error (such considerations are not needed for laser-sintered nylon). It is suggested that FDM printers are set to 100% infill with at least 2-3 shells for a durable print.
5. This design, with the barb extending from the bottom of the 3D printed attachment, allows for the strongest connection with the tubing. An alternative design, available on the GitHub repository, simply has a hole in the bottom of the attachment for inserting the tubing. This is less sturdy but very easy to disassemble and put back together for cleaning, storage, or customization.
6. While every effort has been taken to avoid damage to the iPhone, it should be noted that the 3D printed attachment is pressure-fit to the phone’s body. Attachments printed using Shapeways’ laser-sintered nylon and MakerBot-printed ABS plastic both left no scratches on the phone’s surface, even at a tight fit and many installations/removals. However, use at your own risk.
7. Apple’s built-in Voice Recorder app is quite adequate for basic recording, but offers little manual control. Voice Record Pro (free, <https://itunes.apple.com/us/app/voice-record-pro/id546983235?mt=8>) offers manual quality adjustment (the “high quality” setting is 44.1kHz/16-bit at a bitrate of 128,000) but is limited to the AAC/MP4/M4A compressed audio formats. Audio Memos ($9.99 USD with in-app upgrades, <https://itunes.apple.com/us/app/audio-memos-pro/id290160980?mt=8>) has a large level meter and allows recording in the uncompressed WAV format. Both apps can be set to auto-upload to Dropbox and similar cloud services.
8. Better-quality audio recording apps may have adjustable gain for microphone input. If audio level problems persist, check that the stethoscope tubing and barb of the 3D printed attachment to the iPhone microphone are not blocked.

**5. References**

1. J. B. Dawson, *The Practitioner*, 1964, 193, 315-322.
2. Faber Acoustical has conducted a variety of high-quality audio testing on the iPhone 4 and related devices, though finding data on the more recent iPhone models did not turn up any reliable testing. For details on the process and graphs of the results, see: <http://blog.faberacoustical.com/2010/ios/iphone/iphone-4-audio-and-frequency-response-limitations>.
3. Various stethoscope recording devices exist but are very expensive and do not include the advanced signal processing functionality that a smartphone app could. For example, the 3M Littmann electronic stethoscope costs over $300 USD:  
   <http://www.littmann.com/wps/portal/3M/en_US/3M-Littmann/stethoscope/stethoscope-catalog/catalog/~/All-3M-Products/Brands/3M-Littmann-Stethoscopes/All-Stethoscopes?N=5002683+5927679+5932256&rt=c3>.
4. For an introduction to the technologies of 3D printing, see these useful guides:  
   “What Is 3D Printing? An Overview,” 3D Printer  
   <http://www.3dprinter.net/reference/what-is-3d-printing>

“3D Printing Technologies Explained,” Shapeways Blog  
<https://www.shapeways.com/blog/archives/1215-3d-printing-technologies-explained.html?%2Farchives%2F1215-3d-printing-technologies-explained>

**FIGURE CAPTIONS**

*Note: figures can be placed anywhere in the text, though a large version of figure #2 at the start of the chapter would be ideal. Thank you!*

Fig. 1. A schematic drawing of a standard acoustic stethoscope.

Fig. 2. A CAD rendering of the 3D printed attachment, which slides tightly onto the bottom of the iPhone. Note how the sound from the stethoscope’s tube is funneled directly into the phone’s built-in microphone. Shapes like this are difficult to manufacture, making 3D printing is an ideal solution in such cases.

Fig. 3. The completed iPhone stethoscope attachment, 3D-printed in laser-sintered nylon.

Fig. 4. The waveform from an audio recording of a human heartbeat with no filter applied. While the heartbeat is visible, there is significant noise in the recording.

Fig. 5. The same recording of a human heartbeat as Figure 4 with a low-pass filter applied. The heartbeat is much more clearly visible, especially to the untrained eye.

Fig. 6. Frequency analysis of a recording of a human heartbeat with no filter applied. While the noise floor for the iPhone’s built-in microphone is rather high, the low-frequency heartbeat is still clearly visible.