Open Acoustic Devices

New Support for GPS Synchronisation in the Standard AudioMoth Firmware

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Previous versions of the AudioMoth standard firmware supported using connected GPS modules to set the internal clock time and to geolocate recordings. From version 1.11.0 of the AudiomMoth standard firmware, and version 1.12.0 of the AudioMoth Configuration App, new configuration features allow greater control of when GPS fixes are acquired, and a new tool automates the processing of recordings and GPS fix data to generate WAV files that are synchronised to GPS time to within a few milliseconds.

1 Introduction

Previous versions of the standard AudioMoth firmware supported using external GPS modules (see Figure 1), powered up briefly five minutes before each recording period, to set the internal clock and to geolocate recordings. On each GPS time setting event, the actual sample rate of the recordings that followed was also measured allowing the synchronisation of recordings to GPS time. The results of the GPS fixes were written to a `GPS.TXT` file. However, the firmware allowed at most four GPS fixes per day (one before each recording period) and generating synchronised recordings required additional software that was not provided.

From version 1.11.0 of the AudiomMoth standard firmware, and version 1.12.0 of the AudioMoth Configuration App, new tools have been added to better support the use of external GPS modules in generating GPS synchronised recordings. By default, the AudioMoth will now acquire GPS fixes two minutes before each recording period, and also immediately after each recording period. It is possible to change the GPS fix time from 1 minute up to 15 minutes and also to acquire GPS fixes before and after each individual recording within each recording period (see Figure 2). This allows the number of GPS fixes acquired each day to be flexibly controlled by these settings, the scheduled recording periods and the record/sleep cycle settings configured.[1]

[1] Note that the acquisition of GPS fixes is opportunistic and will never interrupt the requested recording schedule. The AudioMoth will attempt to acquire a GPS fix as long as there are at least 30 seconds available before the scheduled start time of the next recording.

Figure 1: *Two AudioMoth devices with GPS hats.*

In addition, the AudioMoth Configuration App has a new processing option that reads the GPS.TXT file recorded by the AudioMoth and generates GPS-synchronised WAV files (see Figure 3). These WAV files are aligned to start at the requested recording start time, and resampled to have the exact sampling rate requested.[2] Events within these WAV files are shown to be typically aligned with GPS time to within a few milliseconds.

2 Clock Accuracy and Drift

The AudioMoth uses two clocks to control the timings of recordings. Recordings are started according to

[2] Like the GPS-synchronised WAV files generated using the AudioMoth-GPS-Sync firmware and associated AudioMoth GPS Sync App, these GPS-synchronised WAV files have a `_SYNC` postfix added to their file name.

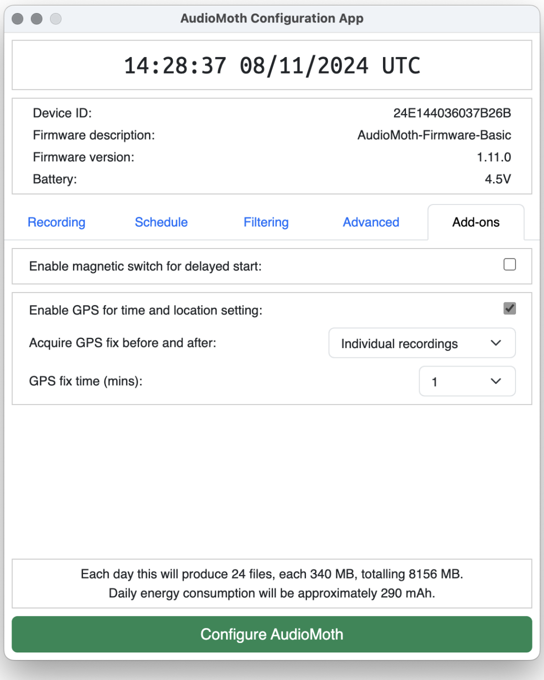

Figure 2: *AudioMoth Configuration App showing new GPS fix options.*

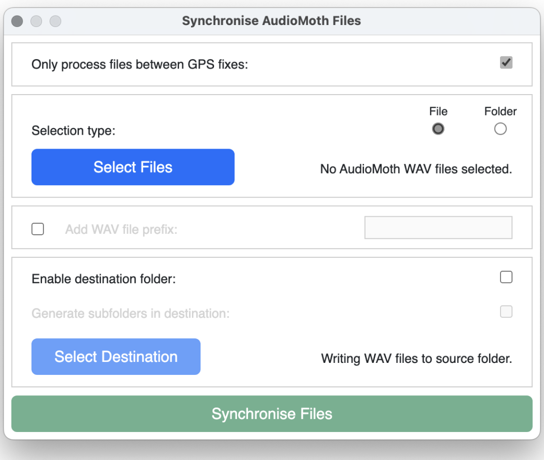

Figure 3: *AudioMoth Configuration App showing new processing option to generate GPS-synchronised WAV files.*

time kept by the onboard real-time clock. This uses a low-frequency crystal oscillator (LFXO) with a nominal frequency of 32768 Hz. Once recordings have started, their sample rate is determined by the high-frequency crystal oscillator (HFXO) which provides the processor's clock and has a nominal frequency of 48 MHz.

Both of these crystals exhibit an offset from their nominal value due to manufacturing tolerances and also an additional dependence on temperature. Figures 4 and 5 show the measured clock frequencies of an individual AudioMoth as it cycles through six days

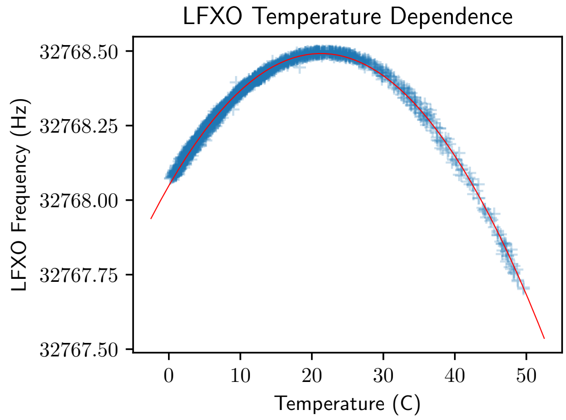

Figure 4: *Temperature dependence of the LFXO crystal oscillator.*

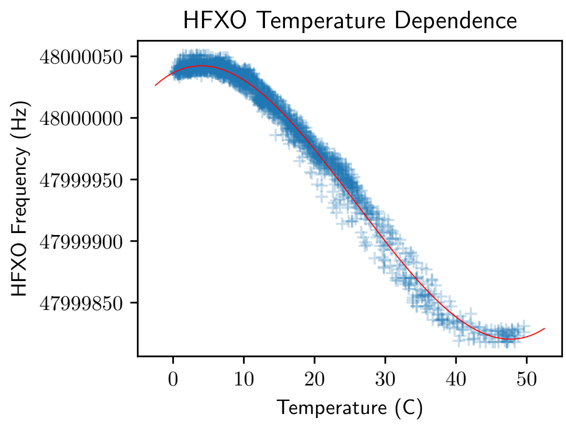

Figure 5: *Temperature dependence of the HFXO crystal oscillator.*

of diurnal temperature variations. The measured frequencies are shown with quadratic (LFXO) and cubic (HFXO) best-fit curves. Note that percentage-wise the LFXO exhibits approximately 10 times greater temperature dependence than the HFXO. This has implications for how recordings should be scheduled to achieve maximum accuracy.

To correct recordings for the offset and temperature dependence of the LFXO we make use of the fact that each time the GPS is powered up to update the AudioMoth clock time, the drift since the last update is also measured. This data is recorded in the `GPS.TXT` file that the AudioMoth generates alongside the requested WAV files (see Figure 6). This allows the actual start time of any recording between two GPS fixes to be estimated; correcting for clock drift. In addition, we can estimate the actual sample rate of the AudioMoth throughout the recording by interpolating between the measurements of the actual sample rate made at the GPS fixes before and after the recording.[3]

[3]Note that in the first estimate, a constant LFXO frequency is assumed, and in the second estimate a linear change in HFXO fre-

GPS.TXT

```
08/11/2024 17:59:01.572 UTC: GPS switched on for fix between recordings.
08/11/2024 17:59:02.190 UTC: Received first GPS message.
08/11/2024 17:59:33.277 UTC: Received GPS fix - 50.820840°N 1.593358°W at 08/11/2024 17:59:33.000 UTC.
08/11/2024 17:59:34.026 UTC: Received pulse per second signal.
08/11/2024 17:59:34.265 UTC: Received GPS fix - 50.820839°N 1.593361°W at 08/11/2024 17:59:34.000 UTC.
08/11/2024 17:59:35.269 UTC: Received GPS fix - 50.820844°N 1.593358°W at 08/11/2024 17:59:35.000 UTC.
08/11/2024 17:59:36.277 UTC: Received GPS fix - 50.820899°N 1.593343°W at 08/11/2024 17:59:36.000 UTC.
08/11/2024 17:59:37.026 UTC: Received pulse per second signal.
08/11/2024 17:59:37.447 UTC: Received GPS fix - 50.820867°N 1.593336°W at 08/11/2024 17:59:37.000 UTC.
08/11/2024 17:59:38.026 UTC: Received pulse per second signal.
08/11/2024 17:59:38.278 UTC: Received GPS fix - 50.820842°N 1.593336°W at 08/11/2024 17:59:38.000 UTC.
08/11/2024 17:59:39.026 UTC: Received pulse per second signal.
08/11/2024 17:59:39.271 UTC: Received GPS fix - 50.820847°N 1.593336°W at 08/11/2024 17:59:39.000 UTC.
08/11/2024 17:59:40.026 UTC: Received pulse per second signal.
08/11/2024 17:59:40.275 UTC: Received GPS fix - 50.820879°N 1.593335°W at 08/11/2024 17:59:40.000 UTC.
08/11/2024 17:59:41.026 UTC: Received pulse per second signal.
08/11/2024 17:59:41.276 UTC: Received GPS fix - 50.820865°N 1.593328°W at 08/11/2024 17:59:41.000 UTC.
08/11/2024 17:59:42.000 UTC: Time was updated. The internal clock was 26ms fast.
08/11/2024 17:59:42.000 UTC: Actual sample rate will be 48000.211 Hz.
08/11/2024 17:59:42.000 UTC: GPS switched off.

08/11/2024 18:59:01.565 UTC: GPS switched on for fix between recordings.
08/11/2024 18:59:02.184 UTC: Received first GPS message.
08/11/2024 18:59:49.307 UTC: Received GPS fix - 50.820814°N 1.593341°W at 08/11/2024 18:59:48.956 UTC.
08/11/2024 18:59:50.021 UTC: Received pulse per second signal.
08/11/2024 18:59:50.385 UTC: Received GPS fix - 50.820779°N 1.593353°W at 08/11/2024 18:59:49.956 UTC.
08/11/2024 18:59:51.021 UTC: Received pulse per second signal.
08/11/2024 18:59:51.327 UTC: Received GPS fix - 50.820807°N 1.593330°W at 08/11/2024 18:59:51.000 UTC.
08/11/2024 18:59:52.021 UTC: Received pulse per second signal.
08/11/2024 18:59:52.504 UTC: Received GPS fix - 50.820809°N 1.593331°W at 08/11/2024 18:59:52.000 UTC.
08/11/2024 18:59:53.021 UTC: Received pulse per second signal.
08/11/2024 18:59:53.328 UTC: Received GPS fix - 50.820809°N 1.593336°W at 08/11/2024 18:59:53.000 UTC.
08/11/2024 18:59:54.021 UTC: Received pulse per second signal.
08/11/2024 18:59:54.328 UTC: Received GPS fix - 50.820787°N 1.593343°W at 08/11/2024 18:59:54.000 UTC.
08/11/2024 18:59:55.021 UTC: Received pulse per second signal.
08/11/2024 18:59:55.332 UTC: Received GPS fix - 50.820829°N 1.593318°W at 08/11/2024 18:59:55.000 UTC.
08/11/2024 18:59:56.000 UTC: Time was updated. The internal clock was 21ms fast.
08/11/2024 18:59:56.000 UTC: Actual sample rate will be 48000.212 Hz.
08/11/2024 18:59:56.001 UTC: GPS switched off.
```

Figure 6: *Contents of GPS.TXT file showing measurements of clock drift and the actual sample rate before and after a recording.*

3 Synchronisation Accuracy

To measure the accuracy of the GPS synchronisation we use one GPS-connected AudioMoth to generate a signal at precisely 30 seconds past each minute. The generated signal is synchronised to the pulse-per-second (PPS) output of the GPS module and is accurate to better than 1 microsecond.[4]

The signal from this AudioMoth is fed to four other AudioMoth, all running the standard AudioMoth firmware (see Figure 7). Each of these four AudioMoth is configured with a single 24-hour recording period. The recording duration is set to 59 minutes and the sleep duration is set to 1 minute. This results in a GPS fix between each 59-minute recording (see Figure 6).

The AudioMoth were deployed over 24 hours and the resulting recordings were analysed. The time offset of each impulse (see Figures 8), for each minute of the 24 hours was measured within the WAV files recorded and is shown in Figure 9. The results show a small time offset at the start of each fifty-nine-minute recording, as the recording starts just 10 to 20 seconds after the time is updated at the last GPS fix. The exceptions are the recordings from 19:00 to 19:59 and from 03:00 to 03:59 with AudioMoth 4. In these cases, the GPS acquisition timed out and the time was not updated. The plot shows a drift of approximately 50 ms over the preceding hour (due to the offset and temperature dependence of the LFXO).

The results also show a steadily increasing time offset throughout each fifty-nine-minute recording. This is because the sample rate of the device does not match exactly that which was requested and assumed during the analysis of the WAV file (due to the offset and temperature dependence of the HFXO). The average actual sample rate of each AudioMoth, recorded in the `GPS.TXT` file was 48000.204, 47999.993, 48000.022 and 48000.144 Hz respectively. This corresponds to AudioMoth 1 and AudioMoth 4 showing the greatest drift with time offsets of 15 and 10 ms respectively at

quency is assumed. We expect additional errors to arise when there are large temperature changes between GPS fixes such that the LFXO and HFXO frequency changes no longer comply so closely with these assumptions.

[4] The signal is generated by placing a 2K7 resistor across the external microphone input and then enabling and disabling the microphone bias power supply to generate an impulse.

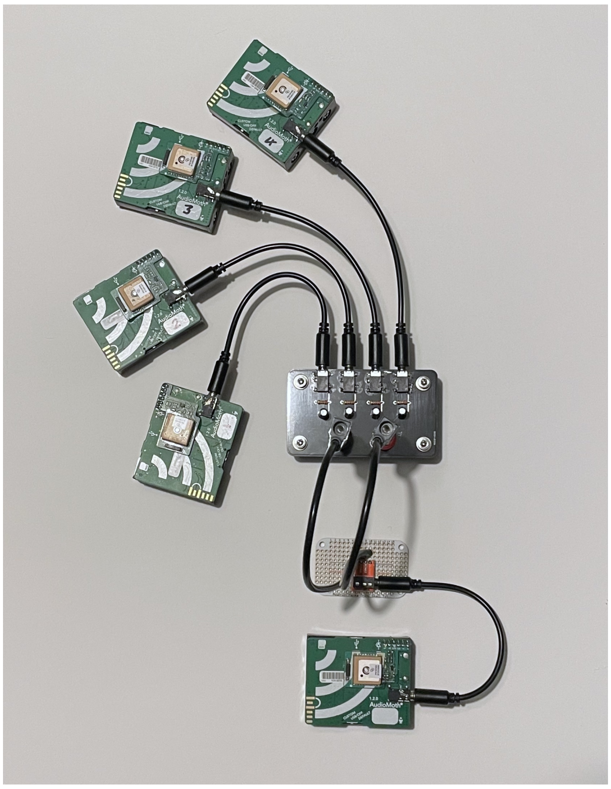

Figure 7: *Experimental setup where one AudioMoth generates a GPS synchronised signal that is distributed to four AudioMoth running the standard firmware.*

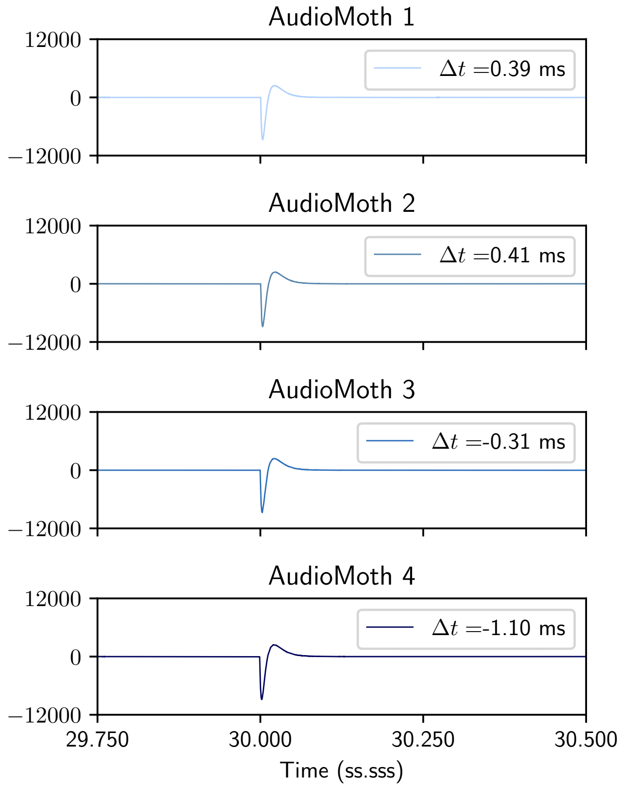

Figure 8: *Absolute time offsets within four uncorrected AudioMoth recordings.*

the end of each fifty-nine-minute recording.

Figure 10 shows the same analysis performed on the GPS-synchronised WAV files produced by the new tool in the AudioMoth Configuration App (see Figure 3). This tool reads the `GPS.TXT` file, and determines the clock drift between each GPS fix, and the actual sample rate within each recording. It offsets the start of the recording to correct for the drift of the real-time clock and resamples the recording to correct for the difference between the actual and requested sample rates. Note that the GPS-synchronised WAV files show very little drift over each fifty-nine-minute recording period, and the start times are typically within ± one millisecond of the GPS time. Furthermore, the time offsets in the two WAV files that were not preceded by a GPS fix, have reduced from 50 ms to just a few milliseconds.

4 Discussion

The results demonstrate that it is possible to generate WAV files that are synchronised to GPS time to within a few milliseconds. This uses the GPS module for approximately twelve minutes per day, resulting in a small additional energy consumption of just 6mAh.

The largest source of any remaining time offset in the GPS-synchronised recordings are offsets in the start time of the recording. This is due to the greater temperature dependence of the LFXO compared to the HFXO. The best synchronisation results are derived from making continuous recordings that start as close to a GPS fix as possible, rather than multiple shorter recordings between GPS fixes.

In areas with good GPS reception, a GPS fix time of one minute is appropriate as most of the time the GPS module will acquire a good GPS fix within thirty seconds of being powered up. However, when the GPS reception is expected to be poor (for example, when deploying below a forest canopy), increasing the GPS fix time to two minutes and using a fifty-eight-minute record and two-minute sleep cycle would be appropriate to avoid missing GPS fixes. In some settings, even longer GPS fix times may be necessary.

When greater accuracy is required the AudioMoth-GPS-Sync firmware and associated AudioMoth GPS Sync App should be used.[5] This firmware variant powers the GPS module throughout the recording and is thus able to use the GPS pulse-per-second (PPS) output to start the recording at the correct time, but also to respond to variations in the HFXO throughout the recordings. This results in recordings that are synchronised to GPS time to better than one microsecond.

[5] `https://github.com/OpenAcousticDevices/Application-Notes/blob/master/Measuring_the_Accuracy_of_AudioMoth_GPS_Synchronisation/Measuring_the_Accuracy_of_AudioMoth_GPS_Synchronisation.pdf`

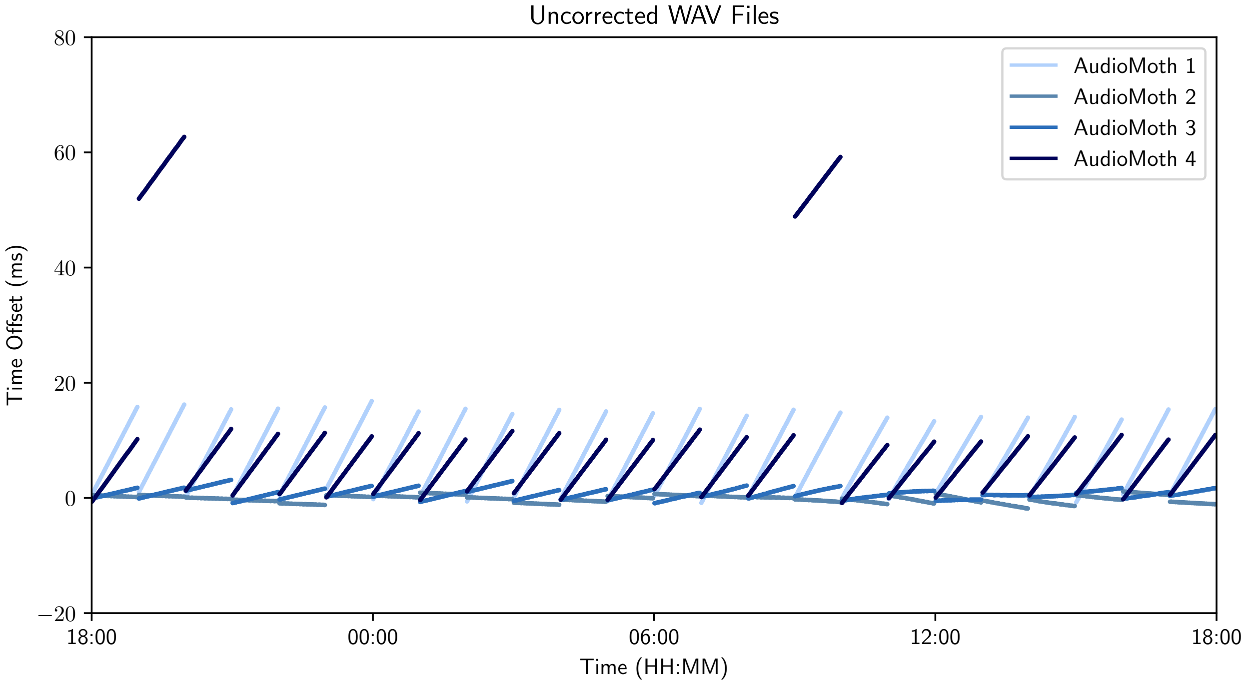

Figure 9: *Absolute time offsets over 24 hours for four sets of uncorrected AudioMoth recordings.*

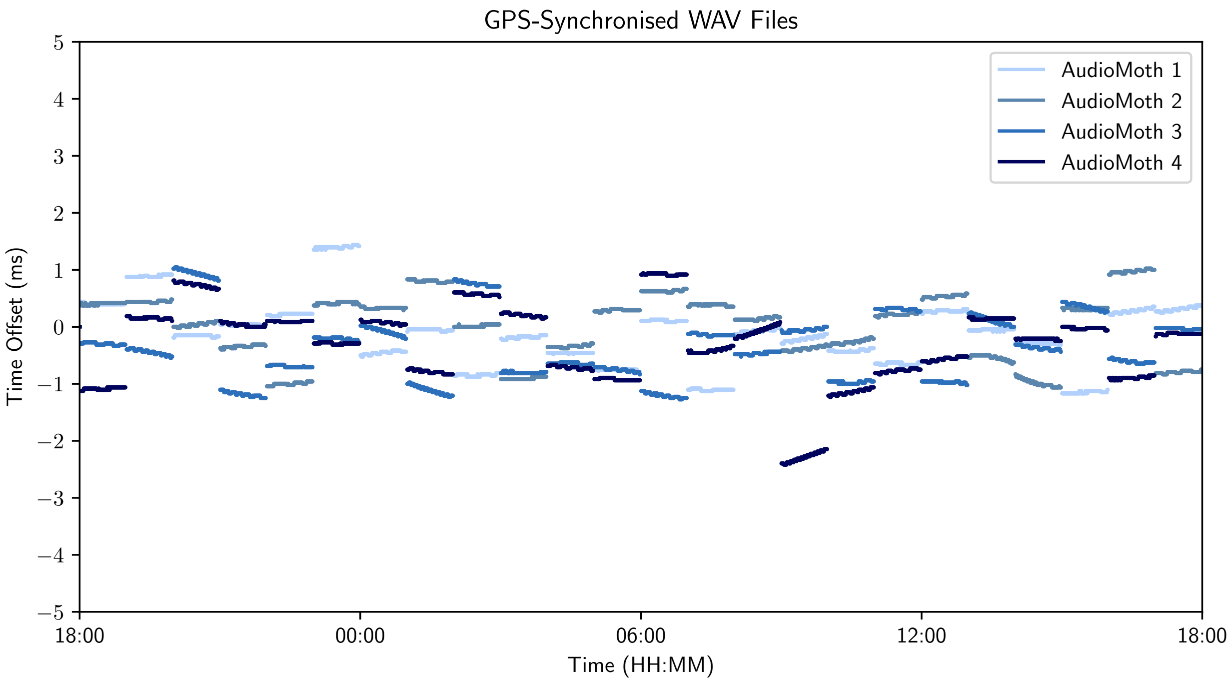

Figure 10: *Absolute time offsets over 24 hours for four sets of GPS-synchronised AudioMoth recordings.*