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The Gem Infrasound Logger: A Lightweight, Low-Power, Low-Cost, Open-Source Infrasound Logger

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Abstract

Low-frequency acoustic waves (called infrasound) are used for monitoring atmospheric disturbances including nuclear tests, volcanoes, and other powerful phenomena. Brief but focused infrasound campaigns enable the study of a wide range of sites and phenomena at low cost and with few workers. However, the cost, weight, and general inconvenience of commercial data loggers has limited past infrasound campaigns. To solve this problem, I developed an Arduino-based infrasound logger (the Gem) with a fraction of the cost, weight, and installation time. The Gem has since been adopted by several institutions for infrasound recording at volcanoes, stratospheric balloons, and river rapids.

The Gem Infrasound Logger: a Lightweight, Low-Power, Low-Cost, Open-Source Infrasound Logger

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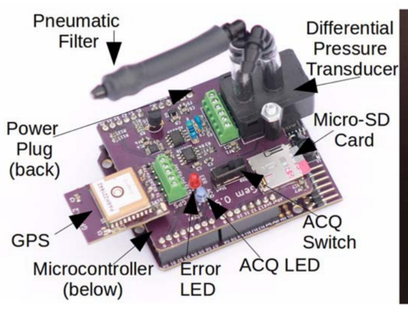
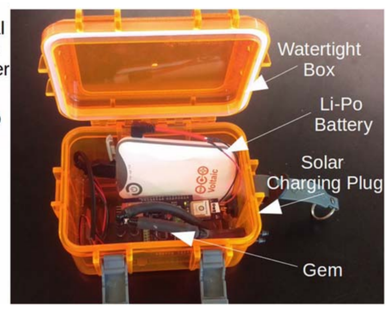
Limitations of Existing Infrasound Logging Systems

- Expensive data loggers with limited selection
- Recording in risky sites and platforms discouraged by high cost
- Expensive, awkward cabling needed for sensor connections
- Long installation time due to cable management, concealing
- Heavy and bulky: difficult to transport, aerial use limited to very large platforms
- Complex, error-prone installation procedure

Solution: the Gem Infrasound Logger

- Inexpensive, can be built in lab with student labor and basic tools
- Light weight and small size
- Fast, simple, cable-free setup procedure
- Lower power consumption, longer battery life than other options
- Easy to customize for specialized applications: user can modify code, enclosure, sensor, and signal conditioning parameters
- Gem described in detail in [1]; code and designs available at [2]





Gem vs. Best Commercial Logger (DATACUBE-3)

	DATACUBE-3 logger with 3 infraBSU sensors	3 Gem Infrasound Loggers
		
Weight	Normal 2875 g; Minimum 1100 g for 1 sensor	Normal 1100 g; Minimum 78 g for 1 sensor
Cost	~$3000	~$1000
Time to install and take down	9 minutes (much longer if cables need to be concealed)	3 minutes, no cables to conceal
Installation steps	13 without confirmation, 1 with confirmation	6 with confirmation
Open-source?	No	Yes: hardware designs, firmware, and software are all open-source
Array size	Up to 15 m from center, multiples of 3 sensors	Unlimited

Designing an Infrasound Logger

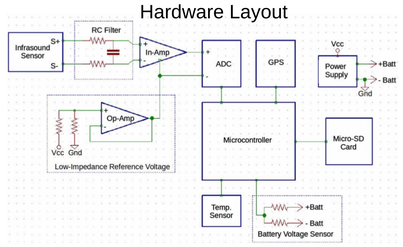
Several essential components must be integrated to record any sensor to disk:

- Analog-digital converter
- Microcontroller
- Storage medium (e.g., SD card)
- Power supply
- Weatherproof enclosure

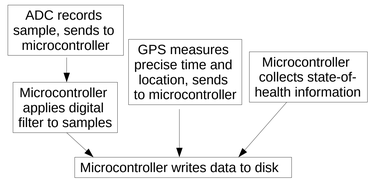
Infrasound logging in particular requires precise sample timing (≤2.5 ms), moderately high resolution (≥16 bits) and sample rate (≥100 Hz), anti-aliasing filtering, and moderate amplification (gain ≥ 20). The following additional components are required for infrasound:

- Analog signal conditioning (low-pass filter, instrumentation amplifier)
- GPS (for precise timekeeping)
- Infrasound sensor [3]

Hardware Layout



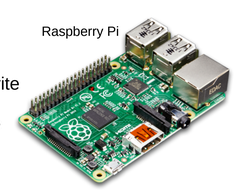
Logging Firmware Summary



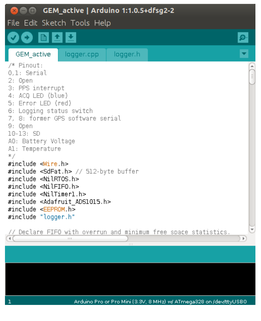
The components cost <$200 total and do not require specialized engineering techniques to integrate. With the help of do-it-yourself electronics techniques, this kind of problem is feasible for a determined non-specialist.

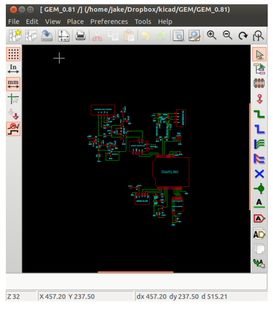
Do-It-Yourself Electronics

User-friendly platforms like Arduino and Raspberry Pi (right) enable beginners in electronics to quickly learn to connect peripheral devices to a processor and write programs that integrate them. These education-oriented systems can often be developed into specialized and powerful research tools.



Arduino Uno





Free, open-source software lowers barriers to entry for new electronics designers. The Arduino IDE (left) simplifies the process of writing and uploading firmware. The design program KiCAD (right) enables designers to create custom circuit boards, which can be manufactured at low cost even in small quantities.

A thriving ecosystem of hobbyist-oriented vendors provides easy-to-use but powerful electronic components, and online forums help provide technical support for beginning users. As beginners gain experience, they can “graduate” to more general suppliers selling parts that are less user-friendly but with better prices and selections.

Acknowledgments:

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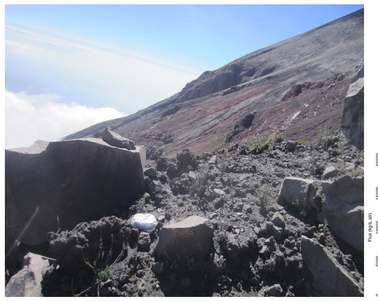
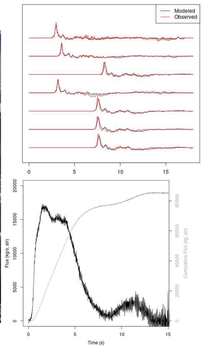
Application Examples

The strengths of the Gem infrasound logger have resulted in its use in several conventional and unconventional infrasound campaigns (three examples shown here). The Gem has so far been adopted for research at six other institutions worldwide.



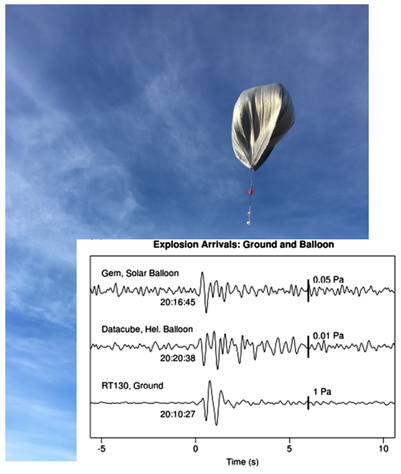


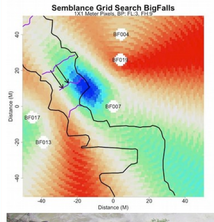
Fuego Volcano, Guatemala

- The Gem’s high portability enabled one worker to carry ten units with camping gear (left)
- Theft-prone site required low-cost, easily concealed instruments
- Despite noisy setting, dense sensor network led to accurate eruptive gas estimates (right)

Stratospheric Solar Balloons

- High-altitude balloons at float can detect infrasound from distant explosions (right) [4]
- Floating helium balloons are extremely costly; solar hot air balloons reduce total cost by >1000x but only carry light payloads
- The Gem is the only known infrasound logger light enough to fly on solar balloons
- Method is being developed for nuclear test monitoring, and for seismology on planets with extreme environments like Venus





South Fork of the Payette, Big Falls rapid

- River rapid physics are difficult and dangerous to measure directly
- 2016 project used infrasound network to reveal hydrodynamics of river rapids [5]
- East bank of river was accessible only by class IV kayak, so highly portable instruments were needed
- Low-cost, easily concealed instruments are essential in this high-traffic, theft-prone site

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[3] Marcillo et al., 2012. Implementation, characterization, and evaluation of an inexpensive low-power low-noise infrasound sensor based on a micromachined differential pressure transducer and a mechanical filter, J. Atmos. Ocean. Technol. 29, 1275–1284.
[4] Bowman and Albert, 2018. Acoustic event location and background noise characterization on a free flying infrasound sensor network in the stratosphere. Geophys. J. Int., 213(3), 1524-1535.
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