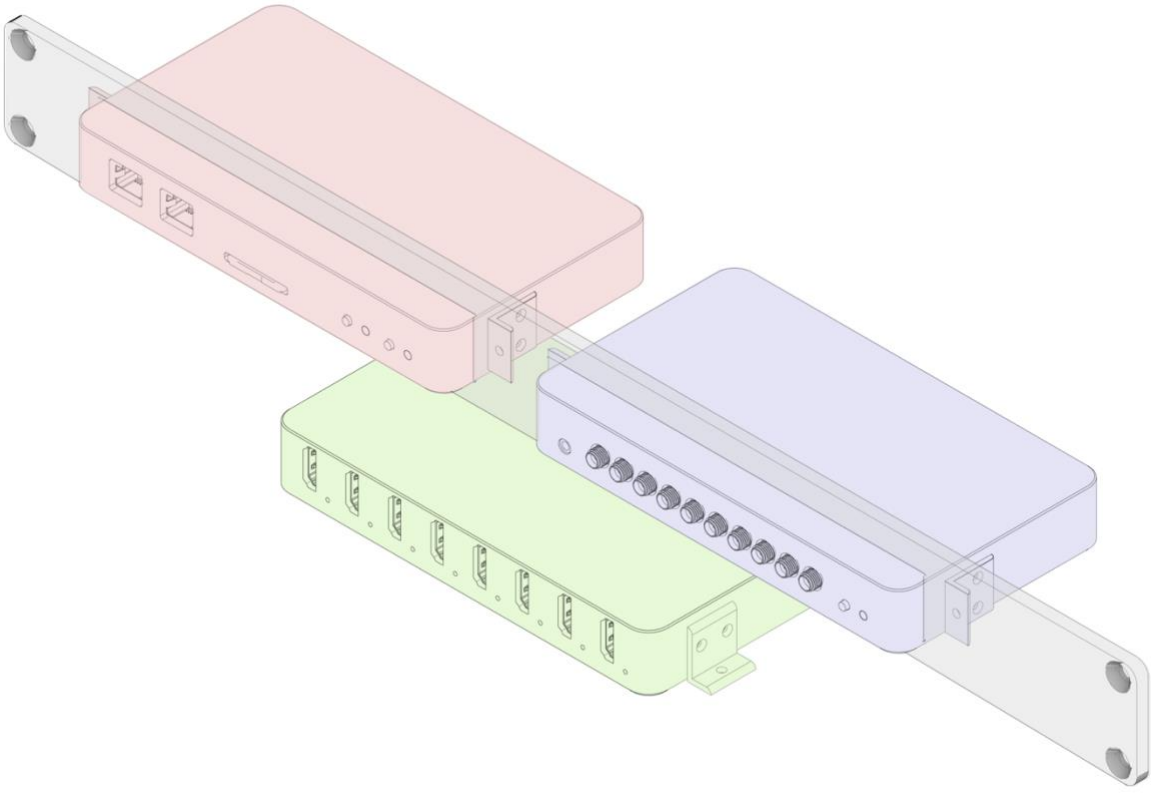
SpikeGadgets

Control Units

MCU, ECU, HCU, Logger Dock



SpikeGadgets

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Introduction

SpikeGadgets' modular back-end control units for electrophysiology and environmental control are powerful, flexible, and affordable, making them widely useful and accessible to the neuroscience community. These units are responsible for streaming neural and environmental data to the computer and relaying commands back to the headstage(s) and environmental controller. Some advantages of the hardware include:

- High channel count capability (up to 1024 channels)
- Low latency processing in conjunction with Trodes software
- Real-time control of environmental and perturbation components using easy-to-learn scripting environment (StateScript)
- Technical support from the SpikeGadgets team
- Easy integration between devices and the open-source Trodes software suite.

Figure 1- MCU and ECU in forward position on 19-inch rack mount

Hardware setup

The most basic hardware configuration uses a Main Control Unit (MCU) and one headstage input. Using this simple configuration, users can stream neural data (up to 1024 channels) to a computer and collect digital events from up to six peripheral devices. The MCU has six TTL inputs. For more advanced environmental

monitoring and control, an Environmental Control Unit (ECU) can be added, as pictured in Figure 2. For experiments involving freely-moving animals, a commutator is generally used between the headstage and the MCU to allow rotation without cable twisting. An HDMI cable is used between the headstage and the commutator, as well as between the commutator and the MCU. For setups involving non-mobile animals, users have the option to combine streams from multiple headstages using the Headstage Combiner Unit (HCU). The output of the HCU is plugged into the MCU as if it were one headstage.

All three control units require 5V power to function. **Note:** Only use the included power adapters, as some adapters can introduce significant noise onto the recordings. The MCU has a separate ground input (2mm banana plug) which should be connected to a shared ground used by all components of the recording and behavioral environment. A central ground point should ideally be used by all devices to reduce the risk of ground loops.

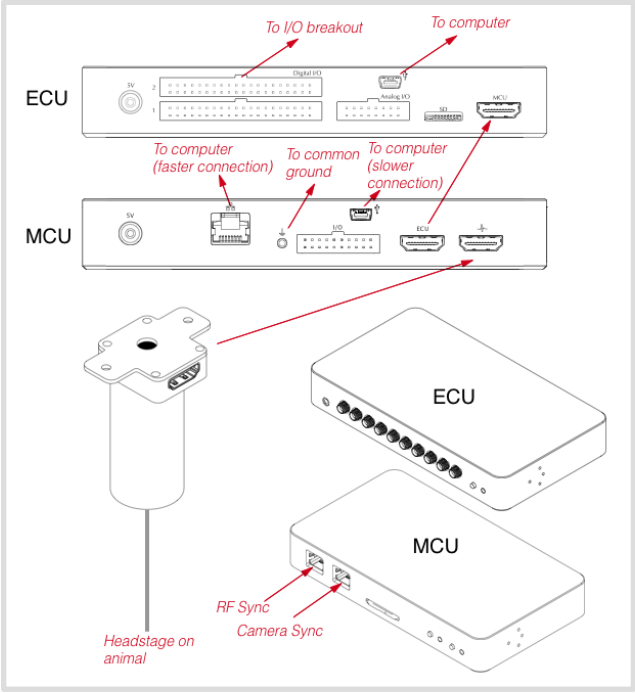


Figure 2- Connection diagram for the MCU, ECU, commutator, and headstage. For setups using a combiner unit (HCU) the out/put from the HCU plugs directly into the MCU.

The MCU can connect to the computer using either USB 2.0 or gigabit ethernet. For Windows users that 1) Are recording from 128 channels or fewer, and 2) do not have sub-millisecond control latency requirements, the USB connection is recommended for easy setup. For ethernet connection, see detailed setup instructions below.

Computer Setup

The Trodes acquisition software will run on Linux (Ubuntu), Windows, and MacOS. Either USB or Ethernet source can be used and require different setup steps depending on the operating system used.

Note: The Trodes install wizards automates Ubuntu Linux Ethernet setup and Windows USB setup so the install scripts below are not needed.

See the SpikeGadgets Wiki for more detailed information, hardware installation wizards, and troubleshooting:

https://bitbucket.org/mkarlsso/trodes

Install Scripts

Ethernet (optional)

If the Ethernet (UDP) is being used to connect to the MCU, a dedicated ethernet port on the computer for the MCU connection is needed. Configure this port for IPv4 connection with the following address and subnet:

Address: 192.168.0.2

Subnet: 255.255.255.0

The maximum transmission unit (MTU) should be set to 9000 or more. Make sure there is no firewall active for ports 8100 or 8200 (it may try to prevent a connection to the MCU). In the beginning, it may be best to disable all firewalls just to establish a connection with the MCU. Also, other network devices may block access to the hardware. For example, it is known that some USB WiFi interfaces will block network access to the MCU on Ubuntu Linux. Try disabling/unplugging all other

network interfaces to determine if this may be the case. Furthermore, try changing the network address (192.168.0.2) to 192.168.0.3 or 192.168.0.4. Anything up to 255 in the last number is allowed, but some may be blocked on your machine. To determine if your connection is good, you will need to connect to the MCU in Trodes (Connection->Source->SpikeGadgets->Ethernet). This initial connection depends on port 8200. If the connection fails, a pop-up error window will appear. If it succeeds, the white STATUS indicator on the upper right window will change to “Connected to source”. Finally, streaming data depends on port 8200. To check for successful streaming, select Connection->Stream from source. A blocked port will result in no incoming data, and the STATUS indicator will blink red.

Once a successful connection is made, we need to make sure that the incoming buffers can handle to data load by adjusting the size of the write/receive buffers used by sockets. For Ubuntu Linux (alternatively, automated in Trodes installation wizard), edit /etc/sysctl.conf (as root) and add the following lines:

net.core.rmem_max=8388607

net.core.rmem_default=8388607

net.core.wmem_max=8388607

net.core.wmem_default=8388607

For Windows (alternatively, automated in Trodes installation wizard), adjusting the size of receive buffers is done using a different procedure. To set the default size, edit (or create) the following DWORD registry keys (using ‘regedit’ program from the start menu run box) and restart Windows:

[HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Services\Afd\Parameters]

DefaultReceiveWindow (REG_DWORD) = 8384512 (decimal)

DefaultSendWindow (REG_DWORD) = 8384512 (decimal)

USB

To use USB connection, the FTD2XX driver must be installed. Follow directions in the ‘comments’ section for your OS here:

http://www.ftdichip.com/Drivers/D2XX.htm

On Ubuntu Linux, to connect the MCU and ECU via USB, the OS must be directed on how to handle SpikeGadgets hardware when it is plugged in. This only needs to be done once. Run the following command (all on one line) to copy the udev rules file to the machine:

sudo wget https://bitbucket.org/mkarlsso/trodes/downloads/spikegadgets.rules -O /etc/udev/rules.d/spikegadgets.rules

Rules will be applied the next time the hardware is connected. If already connected, unplug and replug the USB cable. The .rules file is also distributed with the precompiled binary, in Resources/SetupHelp, and in the source repository, at Resources/Linux, it can also be copied from there instead of using ‘wget’.

On Windows USB connectivity should work without any extra setup. For MacOS, make sure you run the D2xxHelper program to prevent OS X 10.11 (El Capitan) claiming the device as a serial port.

Trodes Software Installation

The latest version of Trodes, install script, hardware installation wizards, and troubleshooting can be found here:

https://bitbucket.org/mkarlsso/trodes

Main Control Unit (MCU)

Introduction

The Main Control Unit (MCU) is the central controller of all SpikeGadgets hardware. It is designed to make electrophysiology experiments easy to execute but is also powerful enough to handle the most complex and cutting-edge applications. In its most basic operation, the MCU accepts digital data from our various types of electrophysiology headstages and streams the data to a computer via USB2.0 (up to 128 channels) or ethernet (up to 1024 channels). It also communicates with other SpikeGadgets devices, such as the Environmental Control Unit, tethered headstages, and combines all data streams from the Headstage Combiner Unit (HCU) into a single stream. During autonomous mode, the system records data directly to an SD card, which can dramatically simplify the workflow for multi-system recording setups where multiple experiments are occurring simultaneously for high-throughput data collection.

The unit is compact, allowing it to be utilized in small spaces, and can be mounted to hardware with the included L-brackets. The brackets can be positioned in one

of three orientations: forward, up, or down. When placed in the forward direction, the MCU can be mounted to the SpikeGadgets 19” rackmount plate.

MCU Specifications

Maximum channel count	1024
Connection to computer	Ethernet or USB
Logging options	Computer or SD card
DIO	6 TTL inputs plus optional ECU data
Neural inputs	Single headstage or output of HCU
Sampling clock rate	20 and 30 kHz supported
Closed- loop hardware-computer-hardware delay	Less than 1ms (median)

Controls and Indicators

On the front face of the unit, there are two control buttons and two indicator lights. The button to the right is used to turn the system on and off. To turn on, push down once and release. To turn off, push and hold for two seconds. When turned on, if a headstage is plugged into the system and no errors occurred during initialization, the light to the right of the power button will turn green. If no headstage was detected or if an error occurred, the light will blink orange.

The second button is used to start and stop recordings to the SD card (autonomous mode). If no card has been inserted in the SD card slot, then this button is inactive. Once a card is inserted, the indicator light to the right of the record button will turn green if the card's configuration was read without errors. Otherwise, the light will blink orange to indicate an error. After the card has been inserted, push the record button and release to start recording. Push and hold for two seconds to stop recording.

Figure 3- Front and back controls on Main Control Unit (MCU)

Inputs/Outputs

On the front face of the unit, there are two customizable jacks, labeled Aux 1 and Aux 2. These jacks allow custom modifications to the system, allowing peripheral devices to interact with the system. By default, Aux 1 is used to communicate with radio synchronization transceiver for untethered headstages, and Aux 2 receives pulses used for syncing frames on an Allied Vision GigE camera. If you require custom interfacing with the unit, contact us for more information.

The front face also has a slot for an SD card. To insert an SD card, slide a card into the slot until it clicks into place. To remove the card, push in first and allow the internal spring mechanism to push the card out before pulling it out.

The back side of the unit contains the majority of the I/O. The power jack is located on the left side of the unit (looking from the back). **Note:** Only use the included 5V power supply with this unit. Other supplies can either damage the unit or produce unwanted electrical noise during recordings.

Moving to the right, the next connector is an RJ45 ethernet connector. This is used to stream data out via gigabit ethernet. Make sure the ethernet cable is labeled “CAT5e” in order to stream at gigabit rates. The cable can either be plugged directly into a computer’s ethernet input, or to an ethernet network switch rated for gigabit speeds.

The third connector is for system ground. While not always necessary, grounding the system to the same ground used for all other hardware or to any shielding equipment often helps reduce electrical noise.

The fourth connector is a 20-pin header used to sample digital events from other hardware (Figure 4). By default, only Din pins 1-6 are turned on for digital event logging. If requested, this connector can also be configured for additional digital lines, including up to eight outputs with custom behavior (hardware synchronization, etc).

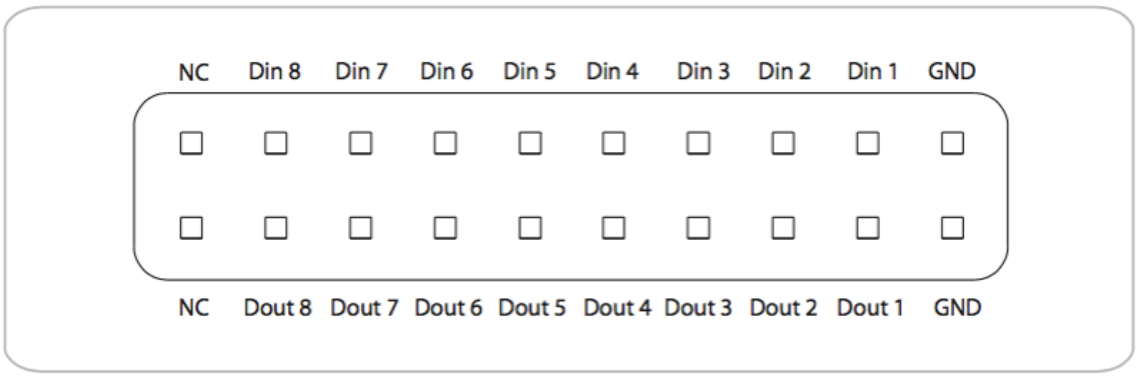


Figure 4- 20-pin header for digital event sampling

Pin mappings for MCU digital I/O port. Douts 1-8 are turned off by default but can be enabled for custom applications.

The fifth connector is an HDMI type A connector used for communication with the ECU. A standard off-the-shelf cable is used to connect the two units.

The connector farthest to the right is an HDMI type A jack, used to receive input from a single headstage or from the Headstage Combiner Unit. Signals from headstages without HDMI output must first be connected to the Headstage Combiner Unit or an active commutator (see table below for headstage classifications). Headstages with the HDMI converter included, either directly on the headstage or in the cable, can plug directly into this jack. Headstage inputs are detected when the system is powered on. Make sure that the unit is reset after plugging in a headstage or the output from the Headstage Combiner Unit, otherwise the signals will not be properly detected.

Headstage with HDMI output	**Headstages with SPI output**
HH128	UH32
Modular (stacking) headstage	HH128np (128-channel headstage without processor)
	MiniLogger32

The mini USB jack is used to stream signals to and from a computer if the ethernet connection is not used. The maximum number of channels that can be streamed

via USB is 128. An FTDI USB driver will need to be installed on the computer (see installation instructions for Trodes above for more information).

Advanced Settings

Set Custom RF Channel

For high-throughput experiments involving more than one data logging headstage, the RF channel can be customized to start/stop recording on a select headstage or set of headstages. You can download the command prompt to set the RF channel here:

http://www.spikegadgets.com/resources/resources_downloads.html

Command prompt notes:

The program will detect a connected MCU and headstage. If there is no headstage detected, only the MCU RF channel will be changed.

When called with no arguments, the program will return the current channel of the detected MCU and headstage.

When called with an argument between 2-70, the program will attempt to change the RF channel for the detected devices.

The program will readout channel 0 if the RF channel has not been set by the user. In this case, the system is using the default RF channel of 2.

The headstage and MCU used the 2.4GHz band. Each channel is 1MHz wide.

Environment Control Unit

Introduction

The Environment Control Unit (ECU) is a powerful tool for controlling and recording the state of peripheral devices, such as lights, levers, beam breaks, lasers, audio cues, solenoids pumps, and synchronization signals from 3rd party hardware. These environmental I/O's can be integrated with StateScript, a simple, yet powerful scripting language to control the timing of input and output events with high temporal resolution in hardware.

The unit is equipped with 32 digital inputs, 32 digital outputs, 8 analog inputs, and 4 analog outputs. All digital and analog input channels are streamed to the Main Control Unit at a sampling rate of 30 kHz, and the information is combined with the neural data before being sent to the computer.

ECU specifications:

Digital I/O	32 inputs (0 to 5V) and 32 outputs (0 to 3.3V)
Analog Inputs	8 inputs (-10 to 10V range, 13-bit digitization)
Analog Outputs	4 outputs (0 to 5V range, 16-bit DAC)
Breakout connectors	10 channels routed to front SMA connectors (1 Ain, 1 Aout, 4 Din, 4 Dout)
Connection to computer	USB
Run modes	Standalone or stream to MCU
Sampling clock rate	30kHz
Hardware scripting	StateScript

Controls and indicators

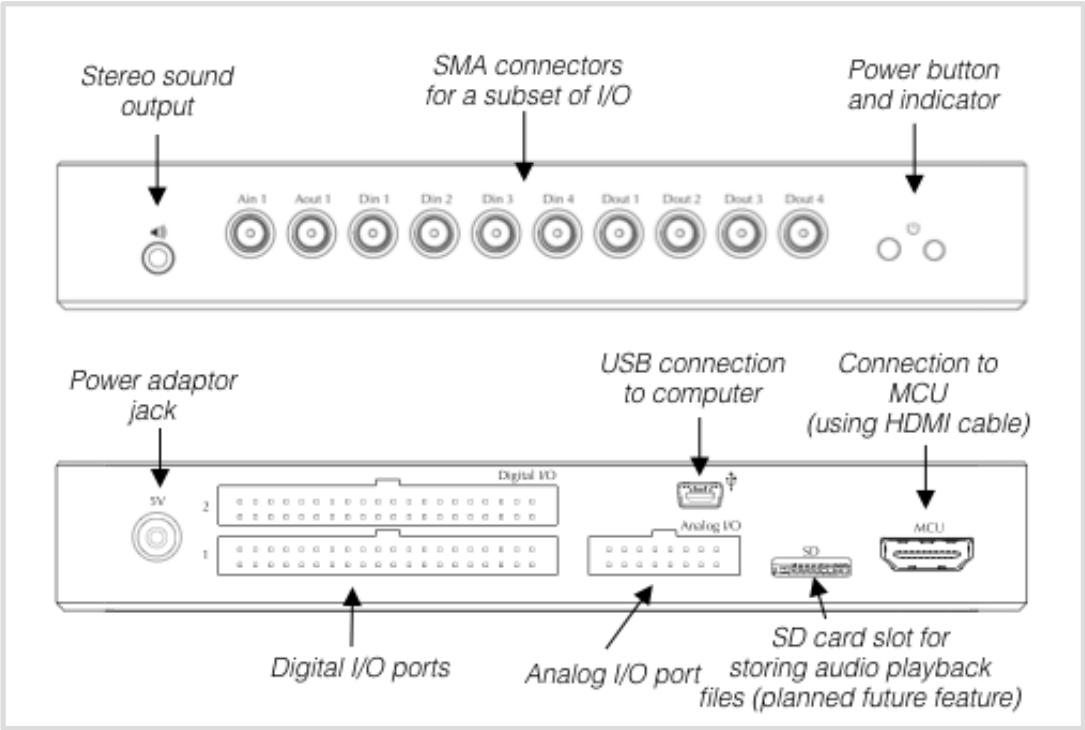


Figure 5- Front and back views of the ECU

On the front face of the unit (Figure 5) there is one control button and one indicator light. The button is used to turn the system on and off. To turn on, push down once and release. To turn off, push and hold for two seconds. Once the system is turned on, the indicator light will turn green. At that point, the StateScript control system and data streaming to the MCU is enabled.

Figure 6- ECU front and back

Inputs/Outputs

On the front face of the unit, there are ten SMA connectors. These connectors duplicate a selected subset of the total I/O channels for convenience. Ain1 and Aout1 are analog input and output, respectively. Din(1-4) are four digital inputs, and Dout (1-4) are four digital outputs.

On the back face of the unit, all of the I/O channels are accessible via 0.1” pitch headers. The digital I/O pins are divided into two banks, where each bank contains 16 digital inputs and 16 digital outputs (Figure 7). The inputs will safely receive up to 5V inputs, but anything above 5.5V is not recommended. They use TTL gate

logic, where inputs between 0-0.8V is a “low” logic state and inputs between 2-5V is a “high” logic state (in-between voltages may trigger either state). If inputs are left floating (nothing connected) they are pulled down to a low state using a 47 kOhm pull-down resistor. The outputs use a 3.3V signal during the high state. These outputs are intended for logic output only and are not intended to drive large currents. We recommend pairing the ECU with a SpikeGadgets breakout panels that uses driver circuits capable of delivering larger currents.

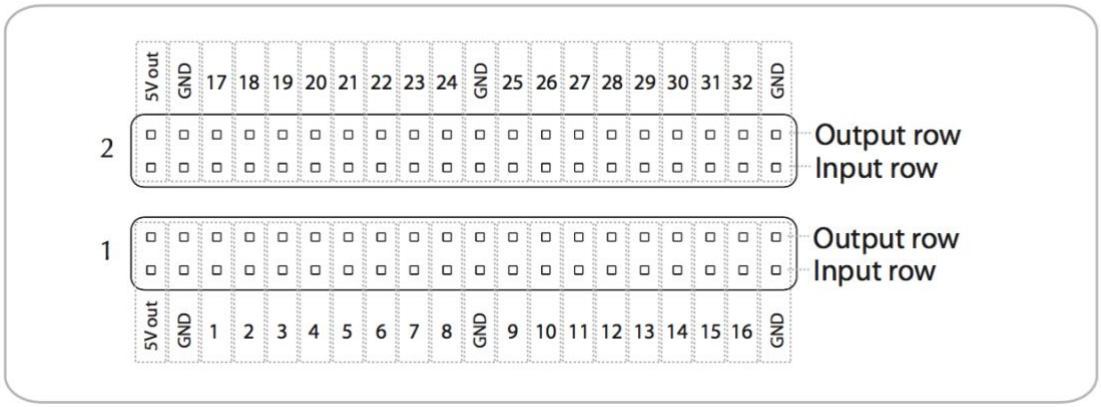


Figure 7- Digital I/O ports for the ECU. There are two ports, each with 16 inputs and 16 outputs, plus 5V out to power peripheral devices. The pin number mappings are shown above and below the ports.

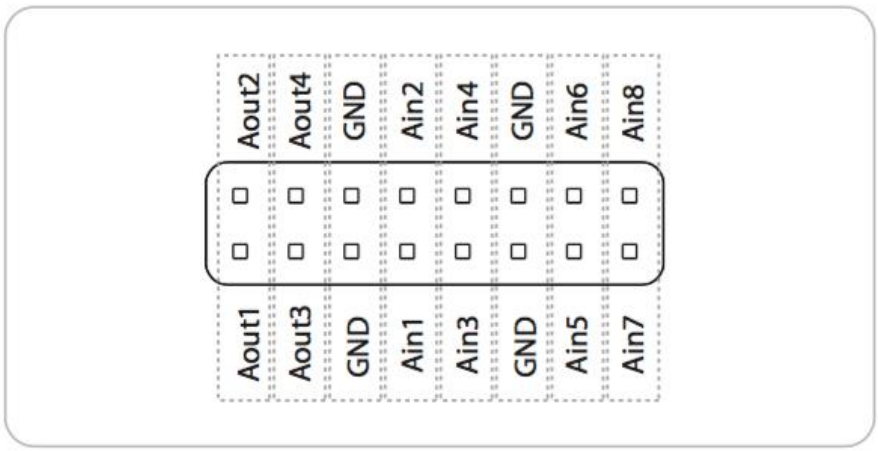


Figure 8- Analog I/O port for the ECU. There are eight analog input pins (labeled AinX) and four analog output pins (labeled AoutX).

The analog I/O channels are accessible from a 3rd smaller bank of pins (Figure 8). The input pins will digitize voltages between -10 V and 10V using a 12-bit ADC. The output pins can deliver voltages between 0-5V.

The unit must be connected to the Main Controller Unit (MCU) via the port labeled “MCU” in order to stream data alongside neural data.

Access to the StateScript environment can be achieved via direct communication to the ECU using the mini USB port. With direct communication, the ECU can act in standalone mode where a connection to an MCU is not required.

For more information on StateScript please see:
http://spikegadgets.com/software/statescript.html

Headstage Combiner Unit

Introduction

The Headstage Combiner Unit (HCU) allows the data streams from multiple independent headstages to be combined into a single data stream. This ‘combined’ data stream is sent to the Main Control Unit (MCU) for further processing. The HCU allows up to 8 headstage streams to be combined, where the channel count for each headstage can be 32, 64, or 128 channels (1024 channel capacity). Furthermore, multiple HCU’s can be ‘daisy chained’ to allow even more headage streams to be combined.

The unit is compact, allowing it to be utilized in small spaces, and can be mounted to hardware with the included L-brackets. The brackets can be positioned in one of three orientations: forward, up, or down. When placed in the forward direction, the HCU can be mounted to the SpikeGadgets 19” rackmount plate.

HCU specifications:

Max channel count	1024 or 256 (using 128 or 32 channel headstages)
Connection to MCU (or to daisy-chained HCU)	HDMI
Supported headstages	UH32 and HH128 (version without processor)

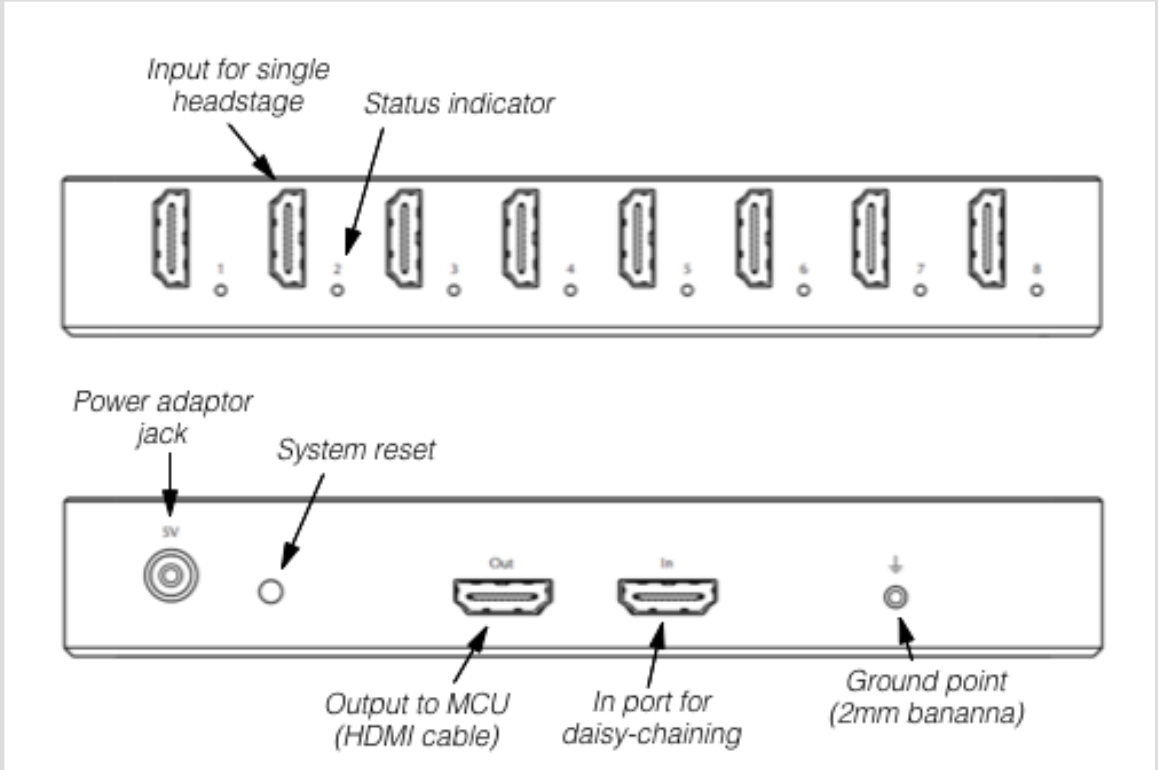


Figure 9- Front and back views of the HCU.

Controls, Inputs/Ouputs, and indicators

On the front face of the unit, there are eight HDMI ports. Each port is used to connect to one headstage. Headstage channel counts can be either 32, 64, or 128. When a headstage is detected, an LED indicator to the right of the port will light up, coder coded according to the headstage type. Green, yellow, and red corresponds to 32, 64, and 128 channels, respectively.

On the back side of the unit, there are two additional HDMI ports. These are not for headstage inputs. One is labeled “Out”. Use the included HDMI cable to connect the HCU to the MCU using this port. The “Out” port can also be used to daisy-chain multiple HCU’s. In this case, connect the “Out” port on one HCU to the “In” port of a second HCU. The last HCU in the chain should use its “Out” port to connect to the MCU.

Figure 10- Back of the HCU

If any headstages are added or removed when the unit is powered on, the re-detect button may need to be pushed to recognize the new configuration. To prevent this button from being pushed accidentally, it is recessed inside the enclosure. The LED indicators on the front of the unit should be used to determine the current configuration. When the unit is first powered on, the configuration is automatically detected.

The unit is powered with the included 5V AC adapter. **Note:** Do not use other adapters to power the system, as the wrong voltage may damage the electronics. Also, some power supplies cause unwanted noise to invade the neural recordings.

Finally, there is a grounding point on the unit, which is connected to the grounding point of the MCU. Generally, only one grounding point or uninterruptible power source should be used at once to prevent ground loops.

Logger Dock

Introduction

When running cable-free recordings, the Logger Dock is a powerful asset for streamlining your experiments. In addition to being compact and affordable, the ability to start/stop recording on multiple headstages synchronously makes it the perfect tool for high-throughput assays.

The logger dock has three primary functions:

- **Acquisition**: Wirelessly start and stop your assays with the logger dock through *Trodes* while recording environmental events using up to 3 digital and 1 analog inputs.
- **Data offload**: Using the microSD card slot (for the HH128) or the mL32 port, quickly offload recorded neural data and seamlessly merge with environmental data for export and analysis.
- **Charging**: While offloading data, the dock will also charge your batteries (configuration available for external batteries used with HH128) to make sure you can get back to recording in the blink of an eye.

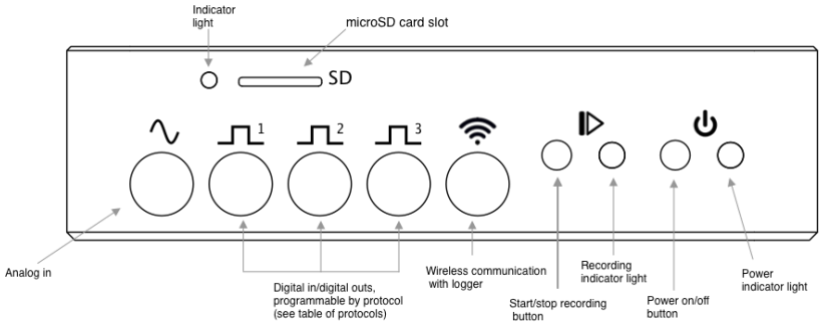
The Logger Dock also supports the SpikeGadgets ECU for environmental configurations that require up to 32 digital and 8 analog inputs, and 32 digital and 4 analog outputs.

Logger Dock specifications

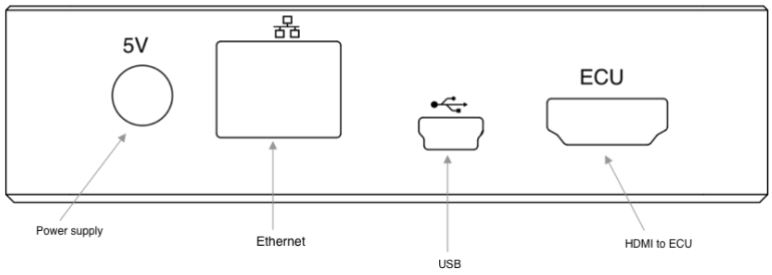
Dimensions	97 x 80 x 25 mm
Connecting Cable	USB
Compatible with	miniLogger 32, HH128, custom loggers
Synchronization range	15 feet
Charging time?	~1 hour, varies based on configuration
Upload speed	25 MBps
Power	5v linear connector
Environmental	1 analog i/o, 3 digital i/o

Controls and Indicators

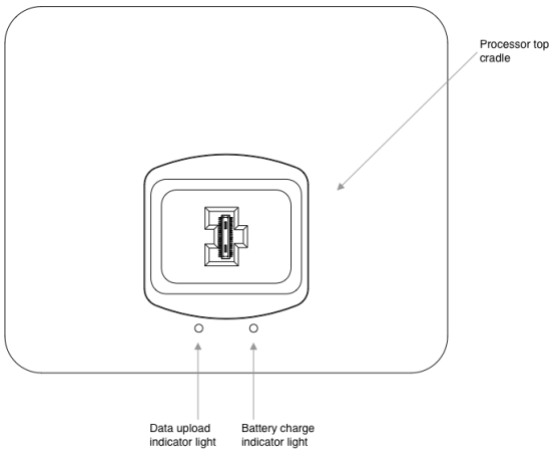
Front



Back



Top



LED Indicators

Indicator	Location	Color/Pulse	Meaning
Battery	Top	Red	Battery is charging
	Top	Green	Battery is fully charged
Data upload	Top	Green- blink	Data is uploading
	Top	Solid blue	Upload complete
	Top		
Recording	Front	Red	Start command from computer received, recording
Recording	Front	Off	Recording is stopped
SD card	Front	Fast red blink	Error mounting or reading microSD card
SD card	Front	Slow green blink	Reading/writing microSD card
SD card	Front	Solid blue	MiicroSD card detected and mounted but no activity
SD card	Front	Off	No microSD card inserted

Setup

Checklist:

- Logger Dock
- 5V power supply
- Antenna
- USB cable
- Datalogger GUI installed on your computer: https://bitbucket.org/mkarlsso/trodes/downloads/
- miniLogger 32 or HH128 headstage

Power

To turn the Logger Dock on, make sure the 5V power supply is plugged in and briefly press the Power button. To turn off, press the power button down for 2-3 seconds until the system shuts off.

Initial Configuration

Ensure that the data-logging headstage and the Logger Dock are set to the same sampling rate, either 20kHz or 30kHz. Typically both are shipped out at a default 20kHz sampling rate. To check or change the sampling rates connect the Logger Dock with the datalogger headstage plugged in to a computer and run the Datalogger GUI. At the top of the window select, Edit logger config to change the sampling rate on the headstage and Edit dock settings to change the sampling rate of the Logger Dock.

Charging Processor Battery

miniLogger 32

To charge the miniLogger 32, place the processor top on the top of the Logger Dock itself. For simultaneous charging and data upload, the Logger Dock should also be connected to a computer via a USB cable.

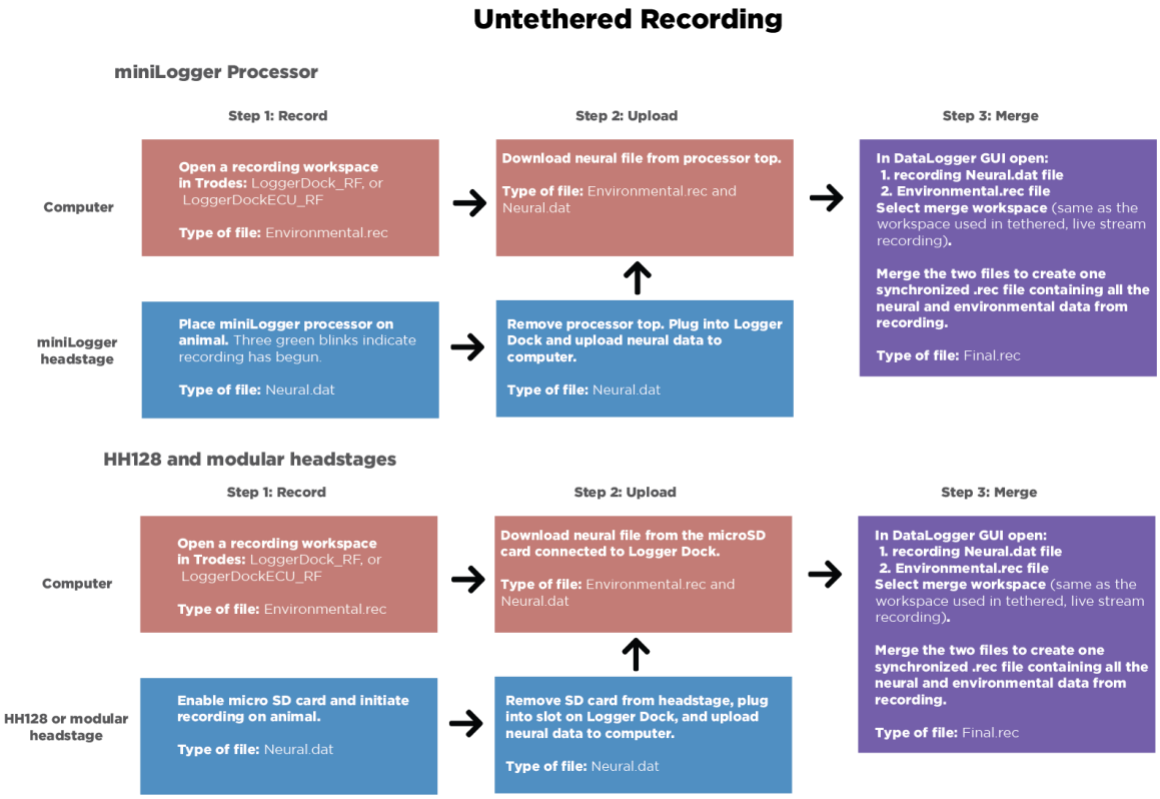
Figure 11 miniLogger 32 charging on Logger Dock

HH128 and other data loggers

For headstages where the battery is not built into the logger top, simply remove the battery from the headstage and plug the white connector into the corresponding white box on the top of the Logger Dock.

Figure 12 Battery charger for HH128 and other data loggers

Workstations



For datalogging there are two workstations needed:

1. The workspace used to collect environmental data (from the docking station) during recording.

2. The workspace that will define the final merged file containing the environmental data and the neural data from the logger (we call this the merge workspace.

The docking workspace should be used during the recording and the merge workspace is the file that should contain the spiking configuration.

Alternate option: To run the merge as a command line tool for greater flexibility follow the instructions here:
https://bitbucket.org/mkarlsso/trodes/wiki/SDFunctions

Offloading Data

miniLogger 32

After a recording session, with the Logger Dock connected to a computer via a USB cable, place the processor top in the cradle of the Logger Dock. Proceed with data extraction using the DataloggerGUI or scripts (see: https://bitbucket.org/mkarlsso/trodes/wiki/DataLoggerGUI).

HH128

After a recording session, with the Logger Dock connected to a computer via a USB cable, remove the microSD card from the HH128 and insert into the slot on the front of the logger dock. Proceed with data extraction using the Datalogger GUI or scripts.

Acquisition mode

To record, open the docking station workspace. Once the workspace is open, select *Connection>Source>SpikeGadgets>Dock(USB)*. You should see a message at the bottom of the window verifying connection to the MCU.

Next, select Connection>Stream from source to start streaming data from the docking station. This will also initiate a radio command from the docking station to the headstage to start logging data to the SD card.

To record environmental events, create a new recording file from the Trodes menu (*File> New recording*) and then start recording (*File> Record*). Then stop the environmental recording (*File> Pause*) and close the recording file (*File> Close file*). To stop recording on the headstage, navigate to (*Connection> Disconnect)*.

Note: The Logger Dock enables local recordings to your wireless headstage's microSD card only. For live streaming to check channels, connect to the MCU.

Uploading Data

Then, plug the processor top into the docking station and use the Data Logger GUI (see instructions here: https://bitbucket.org/mkarlsso/trodes/wiki/DataLoggerGUI) to transfer the neural data to your computer and merge the data with the environmental record.

Update Firmware

Please contact the SpikeGadgets team on your lab's private channel for support updating headstage firmware with the Logger Dock.

About SpikeGadgets

SpikeGadgets is trying something new. Our hybrid approach is to design and sell powerful hardware that interfaces with an open-source software platform supported by a large community of scientists and developers. Our goal is to support the efforts of the open-source community in a commercially-sustainable way.

Technical Support

If you would like technical support, please email us at support@spikegadgets.com.