

# Actimetre System

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## Summary Overview

Actimetre is short for "Activity Metre". It is intended to measure the activity of lab animals, typically rats in cages, using commodity electronic components. For a hardware cost of less than 10€ per cage, the system can record 6 axes of activity (acceleration XYZ and gyroscope XYZ) at up to 100Hz.

At the base of the system is the MPU-6050 sensor which measures XYZ-axis acceleration and XYZ-axis rotational speed at up to 4kHz. At the next level is a ESP32-S2 which has 2 I2C ports. It can therefore control up to 4 sensors (2 addresses on 2 ports). The ESP32-S2 supports WiFi, so it connects to the Actiserver, which is an OrangePi Zero3 running Debian Linux. Actiserver also provides the WiFi AP service to the ESP32-S2, as well as being the data repository. It is connected via Ethernet to the central dashboard which helps monitor and manage the system. The whole system can theoretically contain up to 35000 sensors.

The entire system is fairly robust to disruption, except the Central component which is assumed to be highly available. Installation and configuration requires some amount of technical knowledge.

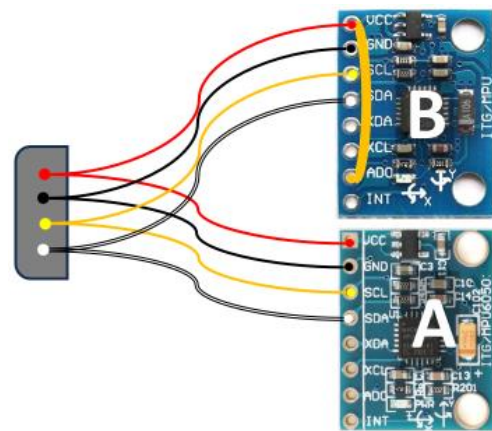
Acticentral is a single central server currently running on AWS Lightsail. It has a fixed IP address. Actiservers communicate with Acticentral via HTTP and MQTT. A single instance of the smallest 1-vCPU Lightsail type is sufficient for controlling over a dozen Actiservers, and probably much more.

### The MPU-6050 sensor

Datasheet here : [MPU-6500 | TDK InvenSense](#).  
Invensense says it's not recommended for new designs, but it's the only 6-axis sensor chip sold on a consumer-grade module at low cost.

The AD0 pin can be connected to either GND (0x20) or VCC (0x21) to control the sensor's I2C address. The 0x20 is called the "A" sensor, the 0x21 unit is "B".

We need four lines (VCC, GND, SDA, SCL) to reach the S2. One "A" sensor and one "B" sensor forms a pair, and their cables join in a single JST 2.54 4-pin connector.



The cable also has a USB type-A connector for easily attaching/detaching sensors to the Actimetre.

### The Lolin S2 mini module

Presentation here: [S2 mini — WEMOS documentation](#). There are numerous copycat modules being sold on AliExpress.com. Most copycats have now solved their quality issues, and the units are reliable. However for best results it is recommended to use Wemos' original units, sold on their official storefront.

The Espressif ESP32-S2 chip is described here: [ESP32-S2 Wi-Fi MCU | Espressif](#). Espressif provides a [board support library for Arduino IDE](#).

## The OLED display

The 0.96 inch 128\*64 OLED screen with a SSD1306 controller on I2C interface is a ubiquitous component. It can be found from many places from AliExpress.com. Be sure to use the newer, more compact version with yellow and blue lines.



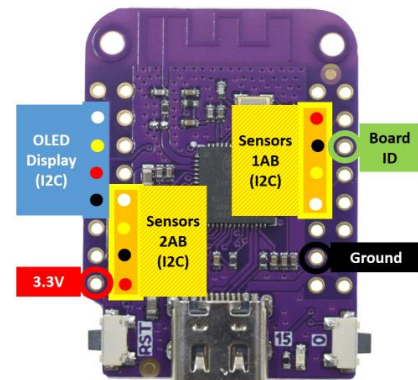
## The Actimetre module

An Actimetre is composed of:

- a Lolin S2 mini module made by Wemos ([https://www.wemos.cc/en/latest/s2/s2\\_mini.html](https://www.wemos.cc/en/latest/s2/s2_mini.html))
- a 0.94-inch diagonal 128x64 OLED I2C display
- two 4-pin JST 2.54mm ports for connecting sensors

Note that these components are directly soldered on the S2 mini module, so the Actimetre doesn't require additional PCB. Each Actimetre draws less than 250mA at most, so 4 of them can be powered by a low-cost USB 2.0 hub and a 1A power supply.

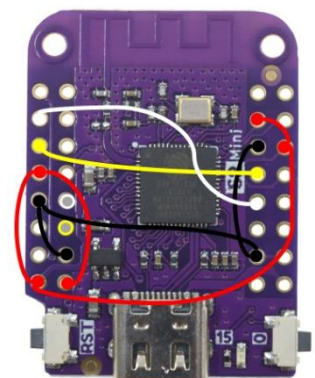
The display is on the "up" side, which is the side of the module with the USB connector. The connectors to the sensors (I2C, 4-pin JST 2.54) will be on the opposite side. This connector carries VCC, GND, SCL, SDA signals. The display shares the I2C port with Sensor pair "1" (I2C port #0).



There are 9 lines to connect, preferably by wrapping. The JST connectors must be soldered because the legs don't have enough length for wrapping. The screen will be soldered last and will cover all the wires.

Cabling information for S2x board.

```
o EN 1 x x 40 39 x
:sda: (i)3 2 x :vcc:{d}38 37 x
OLED:scl: (j)5 4 x Sens:gnd:{w}36 35(bd)
Disp:vcc:(ac)7 6 x #0:scl:{j}34< 33 x
:gnd:(vz)9 8 o :sda: :sda:{i}21< 18 x
x 11 10 o :scl:Sens x 17 16 x
x 12 13{v}:gnd:#1 (wz)GN1 GN2 x
(ab)3V3 14{c}:vcc: X 15 VBUS X
```

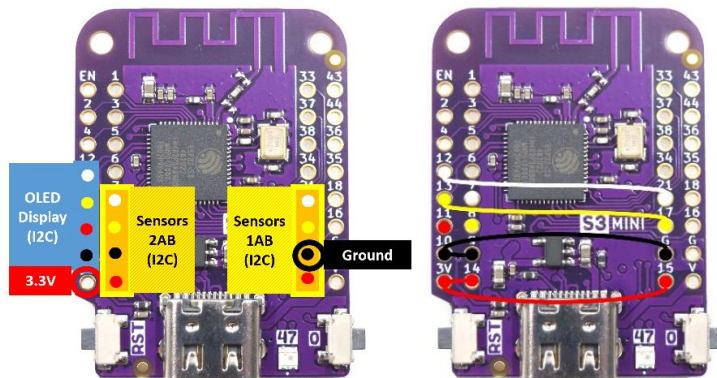


Cabling information for S3i board. The I2C#0 connector's position and orientation are different.

```

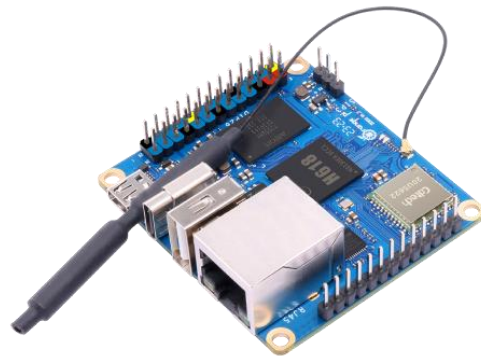
X EN 1 x x 33 43 x
x 2 3 x x 37 44 x
x 3 5 x x 38 36 x
:sda: (i)12 6 x x 34 35 x
I2C:scl: (j)13 7 o :sda: Port:sda:{i}21< 18 x
Disp:vcc:(ac)11 8 o :scl: #0:scl:{j}17< 16 x
:gnd:(yz)10 9{y}:gnd:Port :gnd:{z}GN1 GN2 x
(ab)3V3 14{c}:vcc:#1 :vcc:{b}15 VBUS X

```



## Actiserver

The Actiserver can be any Linux-based SBC (single-board computer) with both Ethernet and WiFi. It must support WiFi AP (which some USB dongles don't). 1GB of RAM is recommended. The software has been tested on Raspberry Pi3 (1GB), Pi4 (2GB), CM4102000; NanoPi NEO3 (2GB) with a RTL8812 USB WiFi dongle; Orange Pi Zero2 (1GB) and Zero3 (1GB). The [Orange Pi Zero3](#) (1GB) has the best cost/performance ratio and supports an external antenna for better reception.



Actiserver software was written in [Kotlin](#) using [IntelliJ IDEA](#). It relies on OpenJDK 17's JVM and therefore is portable across a wide range of systems.

## Communication protocols

Communication between Actimetre and Actiserver is a simple socket connection. The Actiserver acts as WiFi AP, but doesn't provide a bridge to its Ethernet connection. Since an Actimetre will know the Actiserver's local IP address (192.168.4.1 by default), it can address it directly. Actiserver software listens on port 2883 at that address, and accepts socket connections. If a socket connection is broken for any reason, the Actimetre reboots by itself, and Actiserver knows the Actimetre is down.

Once a socket is established, Actimetre starts the communication by sending an initial 12-byte packet containing its board type, its MAC address, what sensors are present, and the SW version. Actiserver responds with the unique Actim ID that is assigned to this Actimetre, as well as the current UTC time in 32-bit epoch seconds since 1970. This allows Actimetre to timestamp all its data.

After this, all data flow is from the Actimetre to the Actiserver. Since both parties know who they're connected to, no more handshake is necessary.

Once Actimetre enters its main loop, it sends a data packet at the sampling frequency it is set to. The default frequency is 50Hz for the S2 board and 100Hz for the S3. This frequency can be changed by pressing the button on the Actimetre. A data packet is composed of a 5-byte header containing the millisecond timestamp and the sampling frequency, followed by payloads of 12 bytes per sensor. The payload is made of 16-bit signed integers for each of the sensor's output: Accelerometer XYZ axes and Gyroscope XY axes.

That data is decoded by Actiserver who appends each reading in a text format to the appropriate file in the repository. Data repository is in `/media/actimetre` and the file name encodes the Actim ID as well as the start time of the data capture. Actiserver can be configured to start a new file when a certain size is reached (default 1GB) or when a certain time has elapsed (default 24 hours). See the installation instructions for details on how to configure Actiserver.

Actiserver, when it boots up, seeks connection to Acticentral, which is at `actimetre.fr`. Acticentral provides a HTTP CGI entry point, `https://actimetre.fr/cgi/acticentral.py`, that is used for all communication. Note that there is no open back-channel to Actiserver. All communication from Acticentral to Actiserver is handled in the response message to GET or POST requests.

Request	Request type	URL parameters	POST data	Response
Actiserver active	POST	<code>action=actiserver</code> <code>serverId=server ID</code>	Full data on status of Actimetres connected to this Actiserver	Registry data
New Actimetre	GET	<code>action=actimetre-new</code> <code>mac=MAC of Actimetre</code> <code>version=SW version of Actimetre</code> <code>serverId=server ID</code> <code>bootTime=boot time of Actimetre</code>		Unique (based on MAC) Actimetre ID assigned to this Actimetre
Actimetre offline	GET	<code>action=actimetre-off</code> <code>actimId=ID of Actimetre</code>		None

The full data Actiserver sends in the POST request contains information on itself, including: its configured server ID, its machine type, SW version number, and disk status. It also contains information on all the Actimetres currently connected to this server, including: MAC, board type, SW version, last boot time, sensor configuration, sampling frequency, disk usage, RSSI and connection quality. This information is used by Acticentral to display the Dashboard.

The Acticentral Registry contains the complete list of all Actimetres known to the system, with their corresponding MAC address and unique ID. This data is JSON-encoded and sent to Actiserver as a response string to the POST request.

Acticentral publishes monitoring information on its HTTP server at `https://actimetre.fr`. This data is refreshed every 15 seconds, based on the latest data received from the Actiservers. Note that Acticentral does not store any sensor data.

Acticentral software is mostly a large [Python 3.9](#) script that is called via HTTP CGI for handling requests from Actiserver and actions on the HTML page. The same script is also triggered by a systemd timer for periodic refreshes. HTTP is served by [Apache HTTPD 2.4](#).

## Appendix

### Recap total BOM for 80-sensor system with 20 Actimetres and 2 Actiservers

Prices are taken from the lowest found on AliExpress.com, including delivery to France. Unit: EUR(€). Acticentral cost is not taken into account. Cost would rise by ~23€ (0,30€ per sensor) if using S3 (capable of 100Hz sampling rate) instead of S2.

Component	Cost for system	Cost per sensor	Note
Sensor	83.28	1.04	Batches of 10
I2C Cable (2x1m 4P)	67.84	0.85	1m per sensor
USB type-A pair	36.48	0.46	1 pair per sensor
S2 mini module	99.22	1.24	Copycats are half this price
0.96" I2C OLED display	29.00	0.36	1 per Actimetre
JST 2.54 4P connectors	4.11	0.05	1 pair per 2 sensors
Power supply (1A)	5.83	0.07	1 per 4 Actimetres
USB 2.0 hub 4-port	8.95	0.11	1 per 4 Actimetres
USB cable (A to C)	17.48	0.22	1 per Actimetre
Zero3 (1GB)	42.83	0.54	2 units
256GB microSD (A1 spec)	32.82	0.41	Lowest €-per-GB ratio
Power supply (4A)	6.34	0.08	1 per Actiserver
USB cable (A to C)	3.14	0.04	1 per Actiserver
APX to SMA cable	2.00	0.03	1 per Actiserver
External antenna	4.14	0.05	1 per Actiserver
Total cost excl. assembly	443.46	5.54	

### Limitations and Future work

The sampling frequency can only be changed by pushing a button on the Actimetre. Also, it is reset to its default when the Actimetre reboots. The frequency should be settable from the Dashboard.

Actiserver stores data on its own SD card, and will stop working properly if the card becomes full. There is no warning that this is about to happen; an alert should be issued when disk space runs low.

The graph on the Dashboard still has some issues.

Grouping of Actimetres by project should be more controlled.

Email alert when an Actimetre of Actiserver goes off-grid, or when other anomaly is detected.