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Hardware Article

# Actifield, an automated open source actimeter for rodents

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ABSTRACT

Locomotor activity in rodents is routinely assessed in the evaluation of drugs and other behavioural studies. Several proprietary lab equipment are available to measure locomotion, however their prohibitive cost may pose a challenge to newly-established and poorly funded labs. To overcome this challenge we present Actifield, an open source hardware setup to measure locomotor activity in rodents. The design consists of 3D printed and laser-cut parts as well as "off-the-shelf" electronic components. Here we demonstrate that rodent locomotor activity can be recorded using the IR motion detection system employed in Actifield. Moreover, we show in validation experiments that this hardware system is comparable to commercial and open source video tracking systems. Actifield would be particularly useful to labs in need of a reliable and inexpensive equipment that can be easily built.


Specifications table

| Hardware name | Actifield |
|---|---|
| Subject area | • Neuroscience<br>• Educational Tools and Open Source Alternatives to Existing Infrastructure |
| Hardware type | • Animal behaviour<br>• Locomotor activity recording |
| Open Source License | *GNU General Public License v2.0* |
| Cost of Hardware | *$122.91* |
| Source File Repository | https://osf.io/2wqp8/ |

## 1. Hardware in context

Locomotor activity in rodents is routinely used in preliminary tests to evaluate the effects of drugs and other experimental manipulations [1]. Further applications of locomotor activity include the study of circadian rhythms [2], measuring disease progression [3] and ruling out locomotor impairment as a possible confounding effect in other tests [4]. Hence, it is a common procedure for many labs that study animal behaviour.

Accordingly, several commercial actimeters are available for automatic recording of locomotor activity such as Panlab Infrared Actimeter, BIOSEB Infrared Actimeter and Opto-Varimex-5 Auto Track System. However, their cost poses a signifi-

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cant limitation to many research groups particularly in resource-constrained settings [5]. Therefore, as an alternative to automated tracking, some researchers resort to manual tracking methods like counting line crossings [6] or recording videos for subsequent analysis with video tracking software [7]. These methods are slow, subject to bias and difficult to automate.

Currently, several commercial and open source video tracking software have been developed to automate rodent locomotor activity recording. For instance, ANY-maze® is a versatile video tracking software which allows automation of different behavioural tests based on user preferences [8]. On the other hand, Icy is an open source bioimage analysis software with several plugins that allow users to perform a wide range of image and video analyses [9]. Although these software offer the advantage of monitoring several behaviours, the results may be affected by the level of contrast and quality of illumination [10,11]. In addition, commercial software are expensive and most open source alternatives cannot provide live results during experiments.

Again, radio frequency identification (RFID) systems have been applied to monitor the activity of individual mice in their home cages where each mouse has a unique tag [12]. However for task-related experiments such RFID systems are too complex. Furthermore, although RFID tags may be cheap, the additional cost of the equipment required to read the tags and to attach them to mice make this approach expensive on the whole [13].

Therefore in this paper, we present yet another alternative using open source technologies which offer several benefits such as lower cost, local manufacture and the possibility to customize equipment to suit local demands and materials [14]. We developed Actifield, as an open science hardware solution to record rodent locomotor activity.

## 2. Hardware description.

Actifield consists of a cuboidal test chamber (22 × 22 × 30 cm) complete with an infrared (IR) motion detection grid along with an Arduino-driven circuit and LCD screen (Fig. 1). The motion detection grid comprises sixteen IR LEDs and phototransistors arranged in square formation to create a planar grid of IR beams (2 × 2 cm) in the test chamber. As a rodent moves in the test chamber, it breaks the IR beams. This activity is detected and transmitted by IR phototransistors to the Arduino which processes and displays the activity counts on an LCD screen while simultaneously storing the results on an SD card. Because of its modular and open source design, the IR motion detection grid can easily be built in different shapes and sizes for application in other behavioural mazes e.g. elevated plus maze, T-maze, etc.

In summary:

- Actifield is about 50 times cheaper than commercial actimeters.
- Actifield performs comparably to commercial and open source video tracking systems.
- Actifield incorporates a simple design and widely-available materials, hence can be easily replicated.

## 3. Design files

### 3.1. 3D-printed parts

Two pairs of plastic parts (IR panel supports A and B) were designed to house the panels for the IR LEDs and phototransistors in position in the test chamber (Fig. 2). Each panel consists of top and bottom halves which encase the IR panels when closed. The parts were designed to fit into the test chamber when assembled.

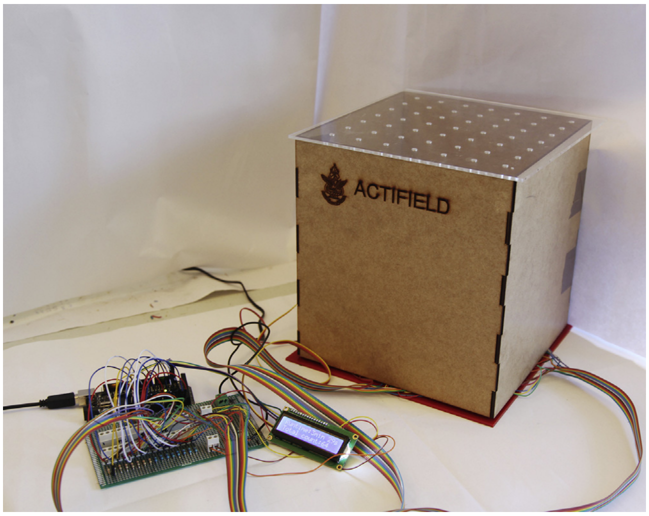


**Fig. 1.** Actifield.

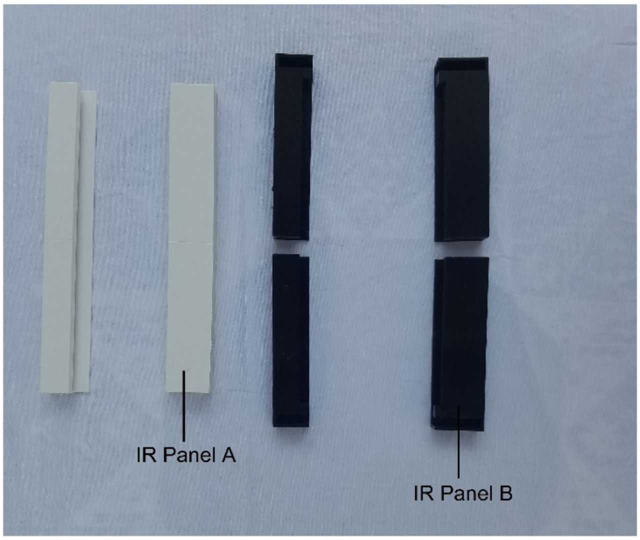


**Fig. 2.** 3D printed supports for IR emitter and sensor panels (D01).

### *3.2. Laser cut parts*

The parts of the test chamber (L01) were cut using a laser cutter with jigsaw ends that fit into each other to allow easy and secure fitting (Fig. 3). The sides of the test chamber were cut from medium-density fibreboard (MDF) (3 mm thick) whereas the floor and cover were cut from an acrylic board (3 mm thick).


**Fig. 3.** Laser cut parts of test chamber (L01).

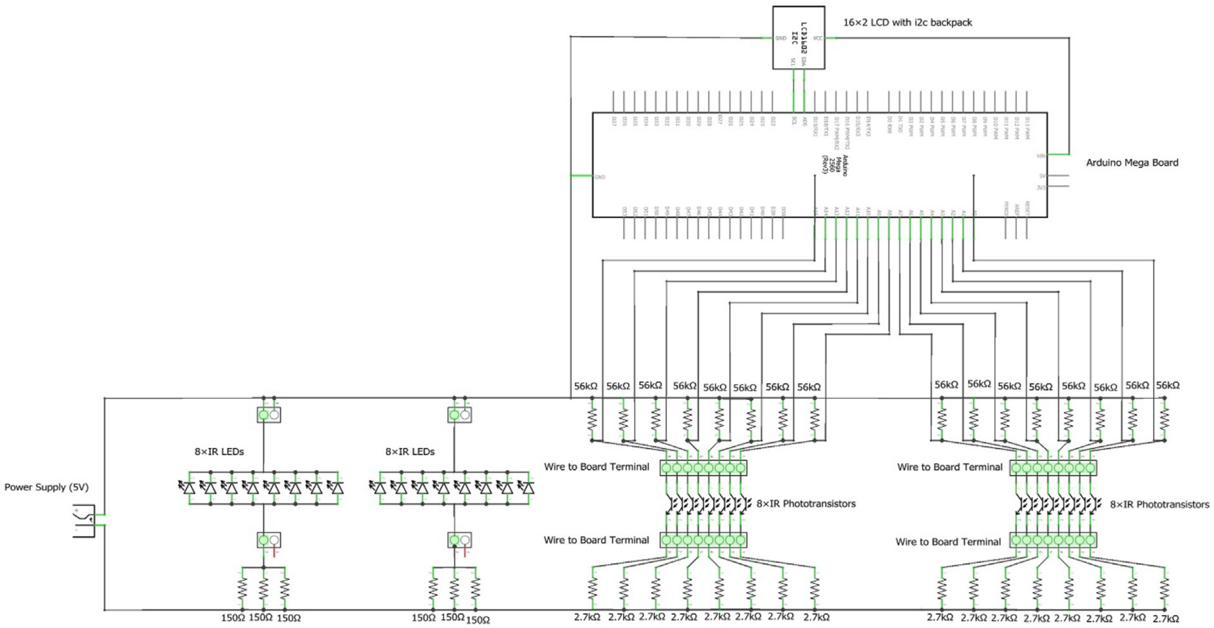


**Fig. 4.** Schematics for the electronic circuit.

### *3.3. Electronics*

The schematic diagram for the electronic circuitry of Actifield is shown in Fig. 4. The components include an Arduino Mega, SD card shield, LCD screen, circuit board, IR LEDs and phototransistors. The circuit was powered by a 5 V DC power supply.

### *3.4. Software*

The Arduino code for Actifield is available on the Open Science Framework (https://osf.io/z8df5/). The Arduino IDE and the LiquidCrystal i2C library (https://github.com/marcoschwartz/LiquidCrystal_I2C) are required to execute the code. The algorithm of the loop function of the code is shown in Fig. 5.

**Design files summary**

| Design file name | File type | Open source license | Location of the file |
|---|---|---|---|
| IR Panel A bottom | STL | GNU General Public License v2.0 | https://osf.io/s5tru/ |
| IR Panel A top | STL | GNU General Public License v2.0 | https://osf.io/s5tru/ |
| IR Panel B bottom | STL | GNU General Public License v2.0 | https://osf.io/s5tru/ |
| IR Panel B top | STL | GNU General Public License v2.0 | https://osf.io/s5tru/ |
| Test Chamber floor | SVG | GNU General Public License v2.0 | https://osf.io/rfqsm/ |
| Test Chamber cover | SVG | GNU General Public License v2.0 | https://osf.io/rfqsm/ |
| Test Chamber side A | SVG | GNU General Public License v2.0 | https://osf.io/rfqsm/ |
| Test Chamber side B | SVG | GNU General Public License v2.0 | https://osf.io/rfqsm/ |
| Schematics | FZZ | GNU General Public License v2.0 | https://osf.io/6hvsq/ |
| Actifield Code | INO | GNU General Public License v2.0 | https://osf.io/z8df5/ |
| Diagnostic Code | INO | GNU General Public License v2.0 | https://osf.io/8yw5t/ |

## 4. Bill of materials

**Bill of Materials**

| Designator | Component | Number | Cost per unit - $ | Total cost – $ | Source of materials | Material type |
|---|---|---|---|---|---|---|
| C01 | Joy-Compatible Board Arduino ™ MEGA 2560R3 | 1 | $25.73 | $25.73 | https://www.conrad.de/de/joy-it-kompatibles-board-arduino-mega-2560r3-1409778.html | Metal, semi-conductor |
| C02 | Breadboard | 8 | $1.16 | $9.27 | https://www.reichelt.de/Streifenraster/H25SR075/3/index.html?ACTION=3&GROUPID=7786&ARTICLE=8276&START=0&OFFSET=16&SID=95WrYMcqwQATMAADa3ulcfd1e686f54ee6322b38b3f291ee5df64&LANGUAGE=EN | Polymer, Composite |
| C03 | PCB Protoboard for Arduino | 1 | $0.34 | $0.34 | https://www.aliexpress.com/item/20pcs-5x7-4x6-3x7-2x8-cm-double-Side-Copper-prototype-pcb-Universal-Board-for-Arduino-Free/765383366.html?spm=2114.search0104.3.1.43bb852acMizDa&ws_ab_test=searchweb0_0,searchweb201602_1_10152_10151_10065_10344_10068_10342_ | Polymer, Metal |
| C04 | 2-pin terminal block | 16 | $0.28 | $4.49 | https://www.reichelt.de/AKL-059-02/3/index.html?ACTION=3&GROUPID=7546&ARTICLE=36598&START=0&OFFSET=16& | Polymer, Metal |
| C05 | Solder Wire | 1 | $1.09 | $1.09 | http://uk.farnell.com/multicore-solder/d9922-2m/solder-wire-99-3-0-7-227deg-0/dp/9887105 | Metal |
| C06 | Jumper wires | 1 | $4.10 | $4.10 | https://www.pollin.de/p/steckbruecken-sortiment-65-teilig-511007 | Metal, polymer |
| C07 | Resistors | 1 | $2.28 | $2.28 | https://www.pollin.de/p/sortiment-messwiderstaende-100-stueck-800297 | Semi-conductor |
| C08 | Ribbon cable | 1 | $3.01 | $3.01 | https://www.conrad.de/de/flachbandkabel-rastermass-127-mm-16-x-008-mm-bunt-3m-7000058337-meterware-604069.html | Metal, polymer |
| C09 | IR LED | 16 | $0.95 | $15.16 | https://www.conrad.de/de/ir-emitter-940-nm-40-5-mm-rund-radial-bedrahtet-lite-on-lte-5208a-1127316.html | Semi-conductor |
| C10 | IR | | | | Phototransistor | 16 |
| $0.89 | $14.23 | https:// | | | www.conrad.de/de/ir-detektor-rund-radial-bedrahtet-5-mm-940-nm-20-lite-on-ltr-3208e-1127310.html | Semi-conductor |
| C11 | 16 × 2 LCD screen with i2c backpack | 1 | $11.47 | $11.47 | https://www.reichelt.de/Entwicklerboard-Zubehoer/DEBO-LCD-16X2-BL/3/index.html?ACTION=3&LA=446&ARTICLE=192143&GROUPID=8244&artnr=DEBO+LCD+16X2+BL&SEARCH=lcd%2Barduino&trstct=pos_11 | Semi-conductor, metal |
| C12 | Heat Shrink tubes | 1 | $2.05 | $2.05 | https://www.pollin.de/p/schrumpfschlauch-sortiment-nachfuellset-farbig-800411 | Polymer |
| C13 | Power supply (5 V, 2A) | 1 | $5.79 | $5.79 | https://www.pollin.de/p/steckernetzteil-quatpower-psn5-2000m-5-v-2-a-micro-usb-351537 | Semi-conductor, metal |
| C14 | SD Card Shield | 1 | $13.90 | $13.90 | https://www.seeedstudio.com/SD-Card-Shield-V4-p-1381.html | Semi-conductor, metal |
| D01 | 3D-printed IR panel supports | 4 | $1.00 | $4.00** | | Polymer |
| L01 | Laser-cut Arena parts | 6 | $1.00 | $6.00** | | Polymer, MDF |

**The approximate cost of materials and machining in a maker space in Cape Town, South Africa.

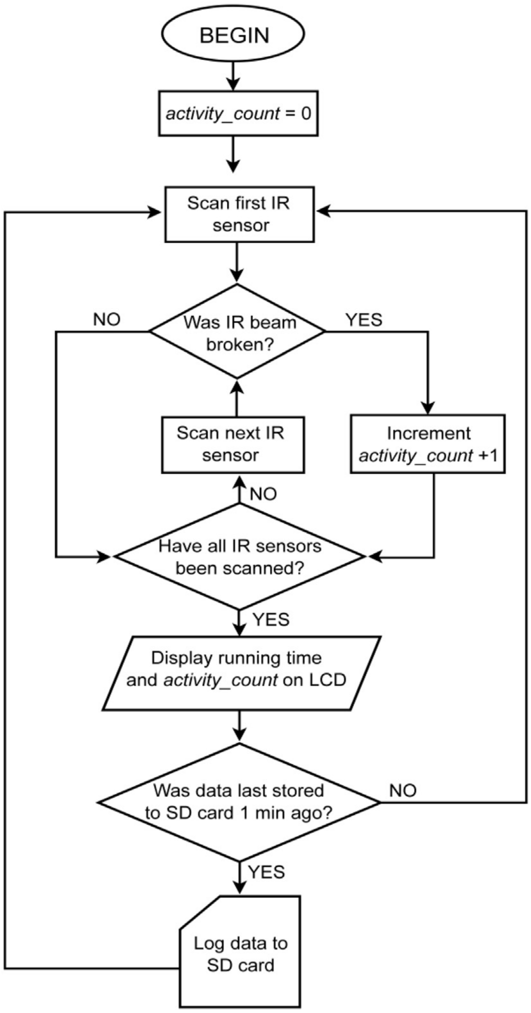


**Fig. 5.** Flowchart of the loop function of the Arduino code. The loop function is continuously called while the Arduino is powered on, therefore, it is the main part of the code.

## 5. Build instructions

Follow the instructions below to build the complete system. See V01 in the supplementary files for a video guide of the assembly process.

### *5.1. Assemble test chamber*

Build the test chamber by assembling the six-laser cut parts (L01): the floor (red-coloured acrylic), cover (transparent acrylic with ventilation holes) and four sides (MDF) (Fig. 3). Assemble the four sides of the test chamber using the jigsaw joints and secure with epoxy resin (Fig. 6). The floor and cover remain detachable for easy cleaning and access to test animals.

### *5.2. Assemble the IR detection system*

#### *5.2.1. Prepare the IR panels*

Begin by joining eight breadboards (C02) in pairs by using epoxy resin to make the four panels which will hold the IR LEDs and phototransistors (Fig. 7a, b). Fix eight IR phototransistors (C10) each to two panels to form the receiver panels (Fig. 7a). Fix eight IR LEDs (C09) each to two panels to form the emitter panels (Fig. 7b). The IR LEDs should be fixed to the panels as follows: Attach the first LED 20 mm (8 holes) from the left edge and 30 mm (12 holes) from the bottom edge of the panel. The remaining seven LEDs should be fixed 25 mm (10 holes) apart in line with the first LED. Fix the phototransistors in the same manner to ensure the IR LEDs and phototransistors line up properly when set in the test chamber.

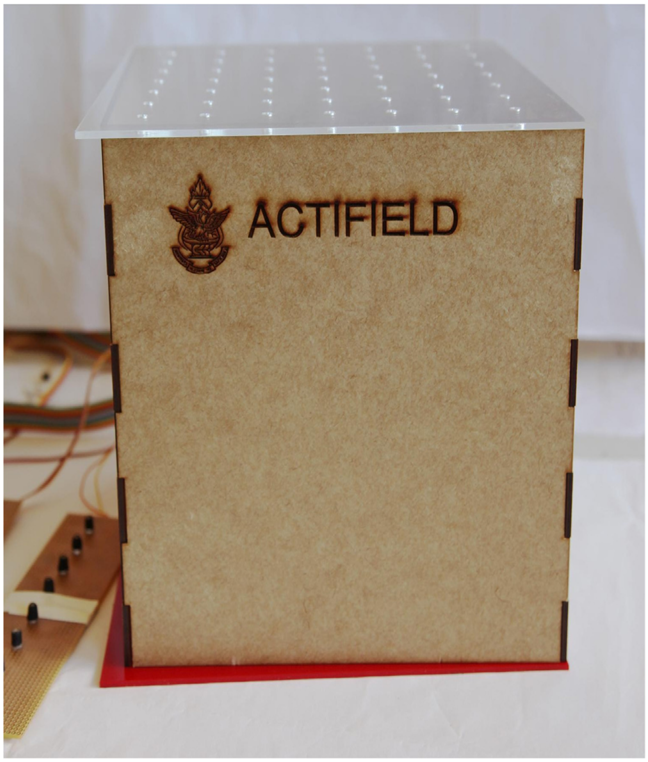


**Fig. 6.** Assembled test chamber.

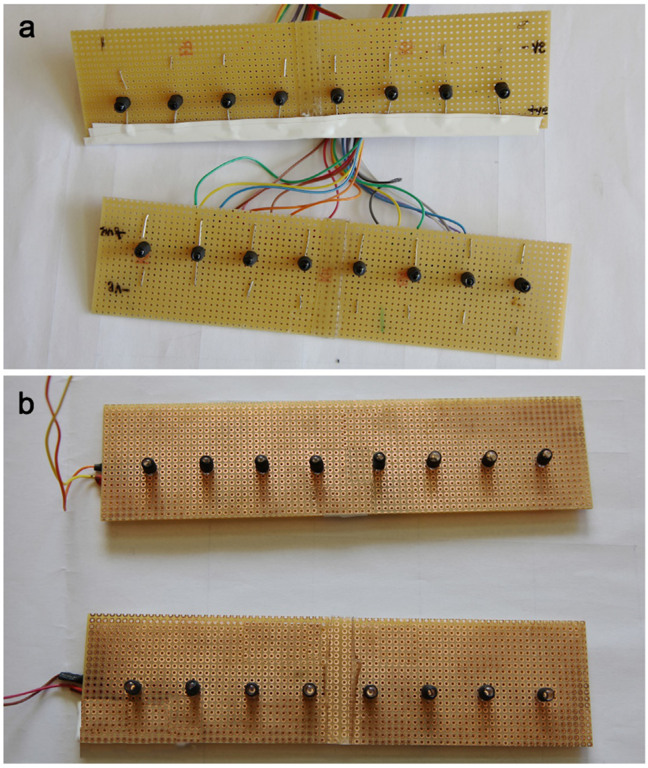


**Fig. 7.** IR receiver panel (a) and emitter panel (b).

Next, connect the IR LEDs and phototransistors in parallel as shown in Fig. 4. Wire the receiver panels with ribbon cables (C08) by soldering sixteen wires to the terminals of the IR phototransistors (in parallel) on each receiver panel. For the emitter panel, connect two wires to the first IR LED, then connect the other LEDs to this connection using wires so they are connected in parallel. When powered, all the IR LEDs on an emitter panel should emit light which can be visualized using any camera without an IR filter (Fig. 8). Cut sixteen pieces (3 mm length) of the heat shrink tube (C12) and attach to the IR LEDs and phototransistors (Fig. 9). Secure the heat shrink tubes by applying light heat with a soldering iron. This is done to narrow the IR beams emitted and detection angle of the phototransistors. As shown in Fig. 10, the glow was more prominently seen on IR LEDs without the heat shrink tubes.

*5.2.2. Assemble the IR panels into detection grid*

The 3D printed IR panel supports are each composed of top and bottom halves. Due to the size of the workspace of our 3D printer (20 $\times$ 20 cm), we printed the parts of IR panel support B in halves which were subsequently joined together with epoxy (see the black parts in Fig. 2). Carefully insert the emitter panels into the bottom halves of the IR panel supports (D01). One emitter panel should be placed into each of the IR panel supports (i.e. IR Panel A and B). In the same manner, insert the receiver panels into the remaining two IR panel supports. Arrange the four IR panel supports in a square ensuring that the emitter and receiver panels are aligned and face each other (Fig. 11). Complete the assembly of the grid by fixing the upper halves of the IR panel supports (Fig. 11). The two emitter and receiver panels are now assembled to provide the grid of IR beams for the test chamber. The 3D printed supports are designed to form an encasing for the IR panels with windows that open into the test chamber. This is to ensure that the IR LEDs and phototransistors are exposed to be able to emit and detect IR radiation respectively while shielding them from the test animals.

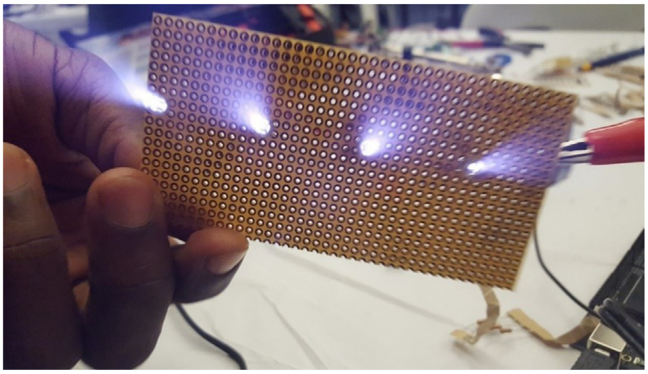

**Fig. 8.** Testing the IR emitter panel using a smartphone camera.

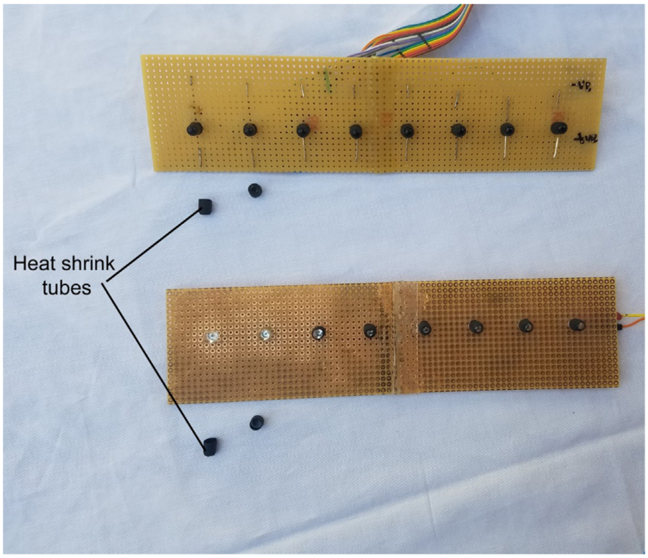


**Fig. 9.** IR LEDs and phototransistors with heat shrink tube covers.

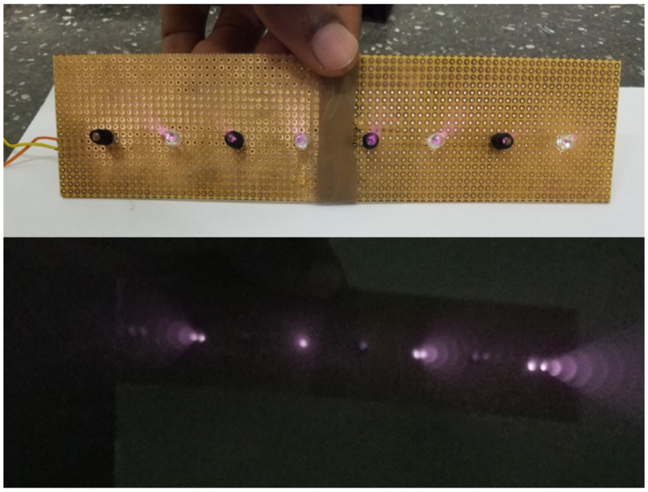

**Fig. 10.** Narrowing of IR beams using heat shrink tubes. LEDs with and without the heat shrink tubes are alternated.

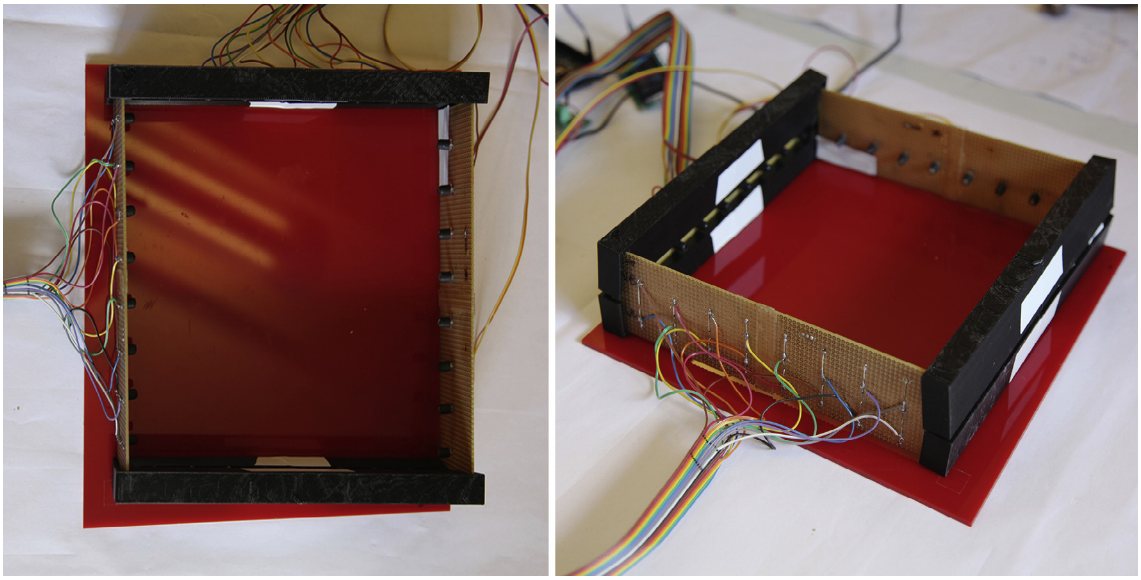

**Fig. 11.** Assembled IR motion detection grid.

*5.3. Construct the electronic circuitry*

Prepare the circuit board by wiring the electronic components onto the PCB protoboard (C03) using the circuit diagram (Fig. 4) as a guide.

*5.3.1. Connect the receiver panel*

First, attach sixteen 2-pin terminal blocks (C04) onto the PCB protoboard (C03) in two rows of eight each (designated as positive and negative rows) (Fig. 12a). Connect the wires (sixteen positive and sixteen negative) from the two receiver panels in reverse-bias onto the PCB protoboard by screwing the positive wires onto the negative row and the negative wires onto the positive row. Connect sixteen 2.7 kΩ resistors and sixteen 56 kΩ resistors (C07) to the 2-pin terminal blocks on the positive and negative rows respectively. Attach sixteen jumper wires (C06) to the sixteen terminals of the negative row. These jumper wires will serve as data cables to connect the IR phototransistors to the Arduino.

*5.3.2. Connect the emitter panel*

Next, attach two more 2-pin terminal blocks onto the PCB protoboard, one each in line with the positive and negative rows. Screw the wires (two positive and two negative) from the emitter panels into the respective 2-pin terminal

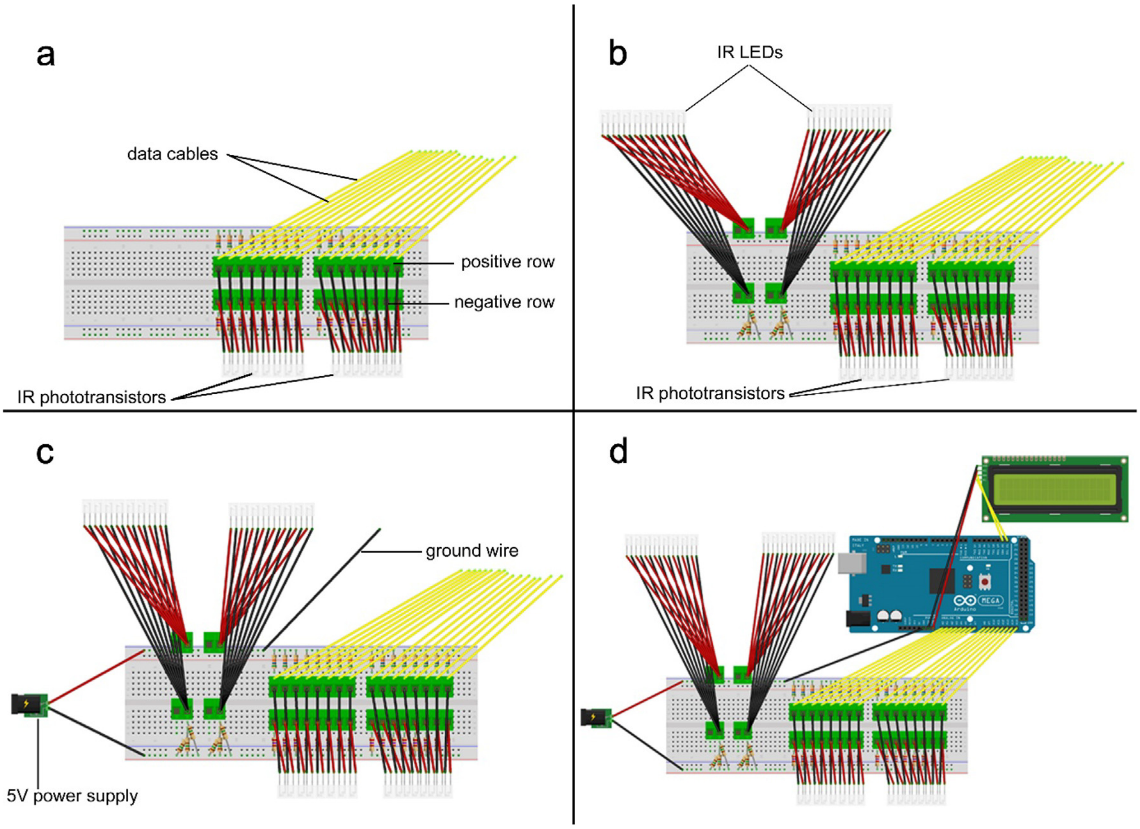


**Fig. 12.** Stages in constructing the electronic circuit.

blocks (Fig. 12b). Connect two sets of three parallel 150 Ω resistors (C07) to the positive terminals of the 2-pin terminal blocks.

### *5.3.3. Connect the power supply*

Connect the positive and negative wires from the 5 V DC power supply (C13) to the appropriate 2-pin terminal blocks (Fig. 12c). Connect the positive and negative rows of 2-pin terminal blocks to the power supply by soldering the connections. Attach, one jumper wire to the negative row. This jumper wire will be used to ground the negative row. Lastly, solder all connections between components on the PCB protoboard.

### *5.3.4. Set up the Arduino*

Firstly, fix the SD card shield (C14) onto the Arduino Mega (C01). Connect the sixteen jumper wires from the circuit board in order from top to bottom to the analog input pins (A0 to A15) of the Arduino. Next, connect the ground jumper wire (see 5.3.3) to the Arduino ground (GND) pin. This is to ensure that the Arduino and the circuit board share a common ground. Finally, connect the four pins of the LCD screen (C11) to the Arduino GND, $V_{in}$, SCL and SDA pins respectively (Fig. 12d). Fig. 13 shows a picture of the complete electronic circuitry.

## *5.4. Assemble Actifield*

Place the IR detection grid onto the acrylic floor. Carefully mount the test chamber over the IR detection grid (Fig. 14). Actifield is now ready for operation (Fig. 15).

## **6. Operation instructions**

Actifield is designed for simple day-to-day operation. Below is a step-by-step guide to the use of Actifield once assembled (See V02 in the supplementary files for a video guide).

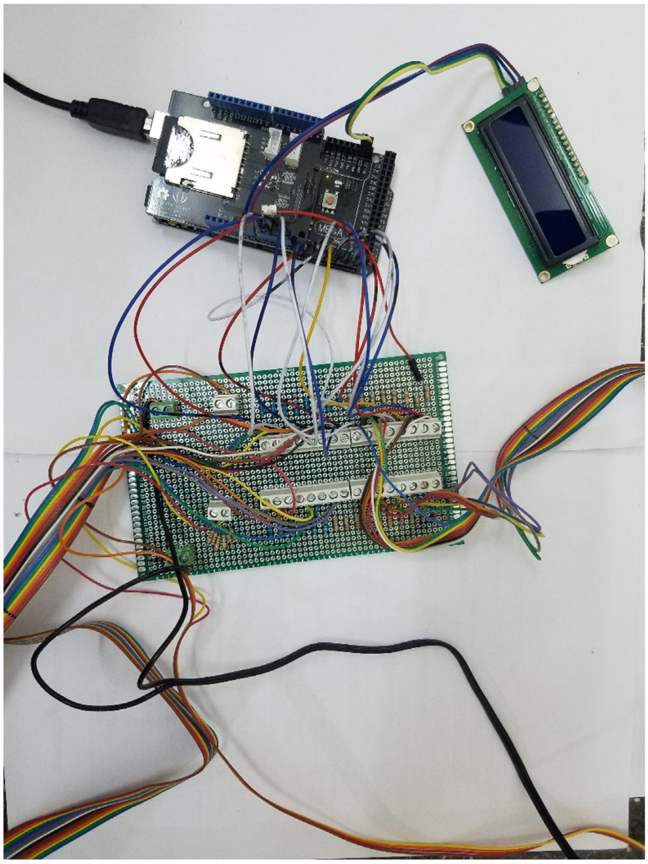

**Fig. 13.** Electronic circuitry of Actifield.

1. Power Actifield by plugging the 5 V DC power supply to the mains. This provides power for the circuitry without the Arduino. Be careful when working with mains electricity to prevent electrocution.
2. Connect the Arduino to a computer by with a USB cable. This provides power to the Arduino.
3. Wait for the system to run the initialization routines (Fig. 16). During the initialization, the system tests the phototransistors, SD card and LCD screen to ensure they are working properly before running a test. An error message is displayed if any of these is defective. Troubleshooting advice is provided in Table 1.
4. Gently place the test animal into the test chamber and cover it. Observe the count and running time on the LCD screen (Fig. 17). After the test, remove the animal from the test chamber.
5. Retrieve results from the SD card. The data is stored as a comma-separated value (CSV) file which can be viewed with any spreadsheet application e.g. Microsoft Excel.
6. The floor of the test chamber should be cleaned in between runs and after each day's experiment.

## 7. Validation and characterization

We validated Actifield by measuring the spontaneous locomotor activity of mice in our lab. This specific use case demonstrates the basic functionality of Actifield for locomotor activity recording.

### 7.1. Animals

Eight ICR mice of both sexes (body weight, 25–30 g) were obtained from the animal house of the Department of Pharmacology, Kwame Nkrumah University of Science and Technology. These mice had been raised under standard conditions (temperature 24–28 °C, relative humidity 60–70% and 12 h light–dark cycle) in the animal house in groups of 10–12 in stainless steel cages (34 cm × 47 cm × 18 cm) with soft wood shavings as bedding. The mice had access to commercial feed and water *ad libitum*. The experiment was performed in the light phase (between 12:00 and 14:00 GMT). All procedures and techniques used in the experiment were in accordance with principles regarding the protection of animals used for experimental

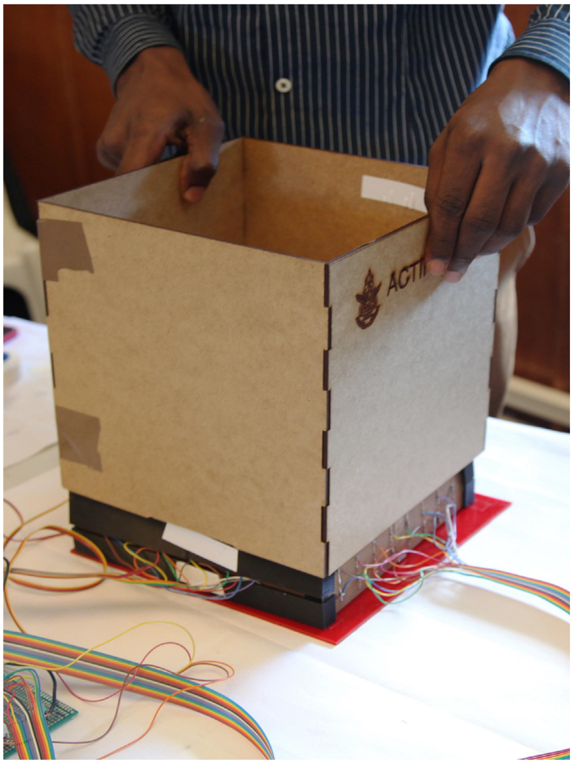

**Fig. 14.** Mounting test chamber over IR detection grid.

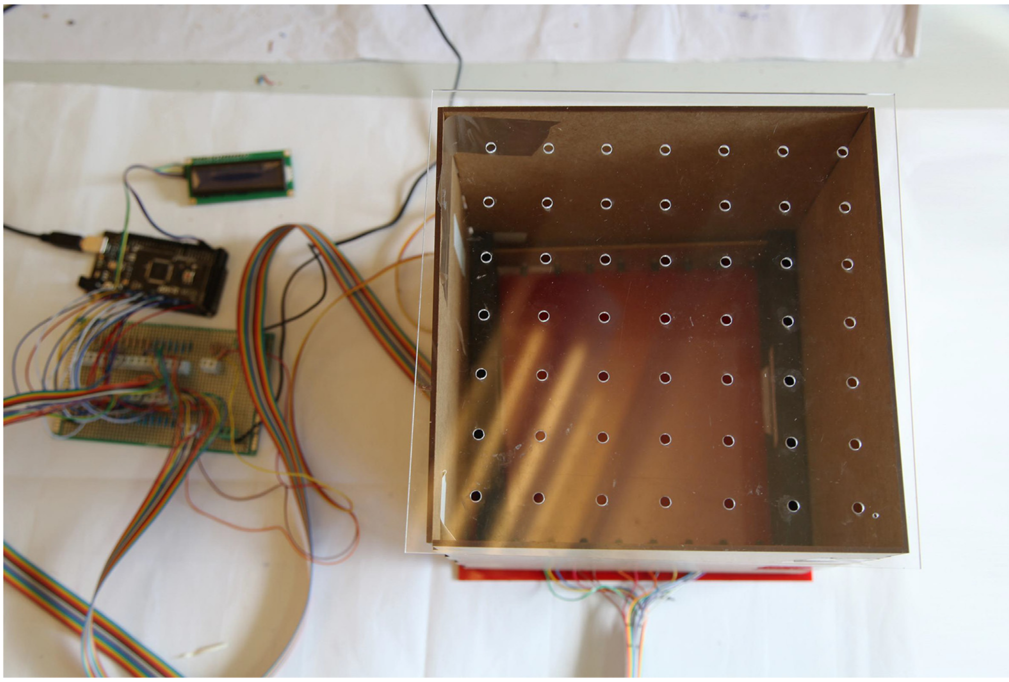

**Fig. 15.** Bird's-eye view of Actifield.

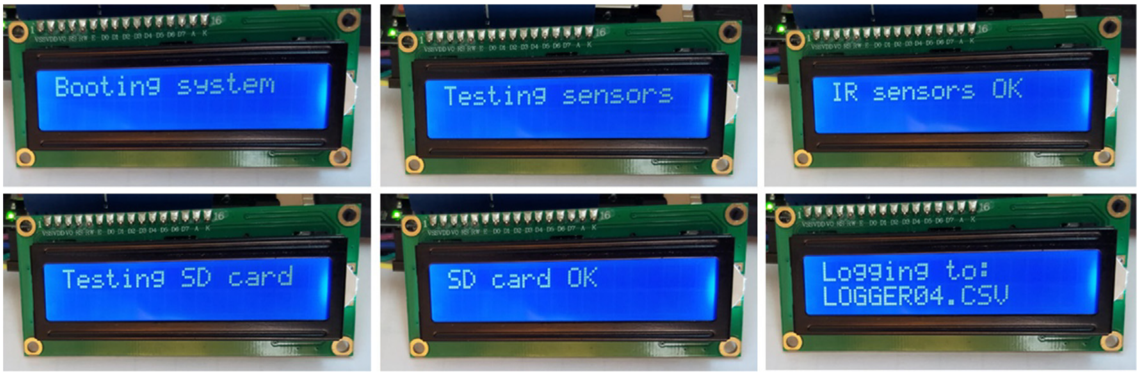


**Fig. 16.** Initialization stages of Actifield.

**Table 1**
Troubleshooting guide.

| Error Message | Problem | Possible reasons | Solution |
|---|---|---|---|
| IR Sensors Faulty | At least one of the IR phototransistors is reading values below expected | An object could be obstructing the IR phototransistors | Remove any object that may be obstructing the IR phototransistor in the test chamber before initialization. |
| | | An IR phototransistor may be faulty | Run diagnostic code to identify specific sensor (https://osf.io/8yw5t/). |
| | | An IR LED may be faulty | Identify and replace any defective IR LEDs by beeping with a digital multimeter or viewing through a mobile phone camera (Fig. 8). |
| SD Card failed | The SD card could not be detected | No SD card has been inserted | Insert an SD card into the SD Card shield. |
| | | The SD card has not been inserted properly | Check to ensure the SD card has been properly inserted. |
| | | The SD card has not been formatted | Ensure the SD card has been formatted to FAT32/FAT. |
| | | The SD card is full | Free up some space on the SD card. |
| File not created | A data file could not be created | The write-protection on the SD card is set to on | Ensure the write-protection on the SD card is off. |

purposes (Directive 2010/63/EU). Ethical approval of the study was granted by the Ethics Committee of the Department of Pharmacology, Kwame Nkrumah University of Science and Technology.

### *7.2. Locomotor activity recording*

The experiment was conducted as follows. After assembling Actifield, a camera, (Everio$^{TM}$, model GZ-MG1300, JVC, Tokyo) was secured 30 cm above the test chamber to record the mice. Each mouse was gently placed into the test chamber and the activity counts recorded while simultaneously videoing the mouse for five minutes. After this the test chamber was wiped completely with 20% ethanol to remove any olfactory cues before testing the next mouse. The Arduino was reset after every run to ensure the data of each mouse was logged to a separate file on the SD card. Eight mice were used in all with each mouse being tested only once. After the experiment, the data was retrieved from the SD card on Actifield.

Subsequently, the videos obtained were processed and analysed for the total distance traveled by each mouse using ANY-Maze® and ICY to compare results. First, the mice profiler tracker plugin [15] on Icy was used to analyse the videos. Next, the videos were analysed with ANY-Maze® Video Tracking System v5.28 (Stoelting Co., Wood Dale, IL, USA). The data obtained from Actifield, ANY-Maze® and ICY was analysed for correlation using Pearson's product-moment correlation test. All statistical analyses were performed with GraphPad Prism for Windows version 6.01 (GraphPad Software, San Diego, USA). P values $< 0.05$ were considered statistically significant.


**Fig. 17.** Live results from a running experiment.

**Table 2**
Comparison of results obtained from Actifield and video tracking software.

| Data Source | Parameter | Mean ± SEM (n = 8) |
|---|---|---|
| Actifield | Activity count | 514.25 ± 33.64 |
| ICY | Distance travelled (m) | 9.82 ± 0.76 |
| ANY-Maze® | Distance travelled (m) | 9.93 ± 0.87 |

### 7.3. Results and discussion

The results obtained from the experiments are summarized in Table 2. There was a positive correlation between activity counts obtained from Actifield and distance traveled as obtained from ICY ($r = 0.87$, $P = 0.0045$). Similarly, there was a positive correlation between activity counts from Actifield and the distance travelled from ANY-Maze® ($r = 0.81$, $P = 0.0148$). The results indicate that Actifield provides reliable results comparable to video tracking software.

## 8. Conclusion

Actifield presented in this paper is a reliable, low-cost and open source alternative for rodent locomotor activity recording. The IR motion detection system employed in Actifield has been evaluated for recording rodent locomotor activity and performs comparably to both commercial and open source video tracking software.

Since Actifield is powered by the open source Arduino microcontroller, researchers can benefit from a vast repertoire of open Arduino projects and the large DIY community support to further modify the design for other applications.

## Ethical Statement

All procedures and techniques used in the experiment were in accordance with principles regarding the protection of animals used for experimental purposes (Directive 2010/63/EU). Ethical approval of the study was granted by the Ethics Committee of the Department of Pharmacology, Kwame Nkrumah University of Science and Technology.

## Conflict of interest statement

None.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ohx.2018.e00047.

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