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Method Article

Measuring the force of the tip of the elephants trunk

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A B S T R A C T

Forces that animals can exert is of great interest in biology. Regarding the elephant trunk, the maximum mass that an elephant can lift with its trunk is known, but the pinching force of the trunk tip is unknown. We here present an original system to measure this force for an organ much coveted in soft robotics for example.

It consists of:

- A wooden box protecting the elephants and the measuring system with no protruding parts except the sensor. This box has an opening at the back to fill it with apples and a trap door at the front to release the apples.
- Two load cells protruding from the box connected to an electronic system controlled by an Arduino card that records and sends the pinch force via Wi-Fi to a laptop while releasing a reward apple.
- Depending on the threshold chosen, the elephant must pinch harder than the previous time to release the next apple. The repetition of this action allows us to approach the maximum force it can achieve.

The system, tested on elephants at the Beauval Zooparc (France), has demonstrated that it is effective in measuring the pinching force of the tip of the trunk.

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A R T I C L E I N F O

Method name: A device for measuring the pinching force of the trunk tip of elephants

Keywords: Muscular hydrostat, Pinching force, Functional study, Proboscis, Force sensor

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Specifications table

Subject Area:	Agricultural and Biological Sciences
More specific subject area:	Morpho-functional studies of the elephant trunk
Method name:	A device for measuring the pinching force of the trunk tip of elephants
Name and reference of original method:	N.A.
Resource availability:	N.A.

Introduction

Numerous morpho-functional studies have been performed using different sensors. For example, they focused on bite force (e.g. on carnivorous [1], on insectivorous [2], on lizards [3] but also on pulling or pinching force with no endoskeleton system (e.g. on arthropods coconut crabs claws [4] or octopus arms [5]). The elephant's trunk is at the center of many fields of research, from evolutionary biology [6] to biomechanics [7] or soft robotics [8]. It is a multitask organ capable of combining high precision in the distal part and high power in its entirety and performing many tasks in a large working space. It is also strongly involved in the olfactory system of elephants. Considered as a muscular hydrostat composed of about 150 000 muscle bundles [6] these opposing actions are performed without any rigid structure [9]. Depending on the size, weight and delicacy of the object, elephants will use three different main approaches to grasp it: (I) for small and slight objects, the elephant will use the tip of its trunk composed of two kind of fingers for African savannah elephant (II) for larger objects, the elephant will use all or parts of its trunk, wrapping it around the object and (III) for particles and water, the elephant will use suction to grasp the objects in its trunk [10].

The whole trunk is capable of lifting up to 350 kg [6] and data on the force of the trunk when grasping small objects exist [11]. But the force developed with the tip of the trunk during pinching is still unknown. Thanks to the keepers indications, we know that the strength of the tip of the trunk was much less than that generated by a human hand. Knowing that the grip strength of the human hand strength is comprised between 257 N for women and 420 N for males [12], this allowed us to choose the sensor.

In a context of bio-inspiration (e.g. [13]) this biological force data is of major interest for robotics for example but also in evolutionary biology in the context of morpho-functional studies linking performance (e.g. bite force [14], grip force [15]) and the morphology of the organ or the animal.

Our device has been designed to take into account the multiple constraints related to the dangerousness of elephants, the colossal force they can deploy, their willingness to pinch the sensor and of course the safety for the animals. Elephants, through their colossal strength even in captivity, remain indeed potentially dangerous for those who approach them. Safety measures for the personnel therefore constrain the design of our biological studies. In addition, devices must not harm the elephants by injuring them or stressing them. Finally, the equipment must be able to withstand the sometimes brutal manipulations of these animals. These constraints, specific to elephants, offer an original scientific and technical challenge.

General functioning of the device (Fig. 1)

A load cell protruding from a large wooden box is offered to an elephant. The elephant explores the box with no other protruding features than the sensor, pinches the sensor and releases an apple. The force in Newtons (N) of the pinch is performed, recorded thanks to an Arduino micro-controller card [16,17] and sent via Wi-Fi to a laptop.

To do so a threshold is chosen: 10 N for example. The elephant must pinch with a force of at least 10 N or more to trigger the release of the apple. If this first action is done, the threshold is added and the elephant must pinch with a force of at least 20 N to get its reward. Then 30, 40 N and so on until the elephant can no longer release an apple. The last obtained value corresponds to the maximum possible force or at least close to it. The repetition of this action should lead to the recording of the maximum force that the elephant can deliver with the tip of its trunk thanks to its two fingers.

Table 1
List of components.

Component	Description	Quantity
Arduino Nano 33 IoT	Micro-controller	1
SparkFun Load Cell Amplifier SEN-13879 - HX711	Load Cell Amplifier	2
Micro Load Cell CZL635 (50kg)	Force sensing module	2
Servo Motor MG 995	Rotary actuator	1
Goldbat 5200mAh Li-po Battery	External battery / Servo alimentation	1
Poweradd-EnergyCell 10000mAh power bank	External battery / Arduino alimentation	1
Breadboard	Solderless construction base	1
Jumper Cables	Connection wires	30

Material and methods

Specimens

For the development of this device, we worked at the Zooparc de Beauval (France) which has seven African savannah elephants, *Loxodonta africana*, six females and one male. The latter, being in the process of acclimatisation in its new environment, did not participate in the experimentation. Each day, in turn, the animals have individual training with their caretakers in order to monitor their state of health and to accustom them to possible veterinary care. A few minutes at the end of this training were dedicated to this experiment. Observations and experiments already carried out with these same elephants ([18,19,20]) have enabled us to see that the first behaviour when faced with a large box is to explore it by laying the tip of the trunk flat and then to palpate the protruding parts. Following this principle, we chose to build a large and solid wooden box, without any grips other than the sensor.

Manufacture of the box

The choice of wood rather than another material met the safety requirements for the elephants. In case of breakage, wood is not dangerous for the elephant, unlike metal for example. In addition, wood is relatively strong, heavy and opaque so that the elephant cannot see the measuring devices inside nor the presence of apples. The box is composed of five plywood panels measuring 80 cm X 80 cm X 2.1 cm, four of which form the sides of the box and the other the cover (Fig. 2A). The box was reinforced from the inside with wooden battens and eight internal metal brackets. An opening is located at the back of the box for recharging the apples and an exit trap is located at the front for the distribution of the reward apple.

Force sensor

The force sensor is made by utilizing two CZL635-50 micro load cells (Phidgets Inc., Canada) [21] facing each other in order to measure the pinching force (Fig. 2B). These load cells convert the load applied to them into electrical signals via strain gauges. The strain gauges deform when a weight is applied and send an electrical signal proportional to that load. These micro load cells are widely used in various fields such as biology (e.g. bite force [22], hand grip force [23,24], plant growth [25]) or engineering (e.g. [26,27]) for their excellent cost / accuracy ratio.

Electronic device, equipment and assembly

All components are listed in Table 1. As schematized with Fritzing software [28] in Fig. 3, the Micro Load Cells CZL635 [21] (Load cell 1 & 2) are connected to the SparkFun Load Cell Amplifiers SEN-13879-HX711 [29] (Load cell amplifiers 1 & 2) via the cables: red/E+, black/E-, green/A+ and white A- (Table 2) to amplify the signal of the load cells. Then the Load cell amplifiers 1 & 2 are connected to the Arduino Nano 33 IoT Microcontroller card [16,17] that collects the data and programs

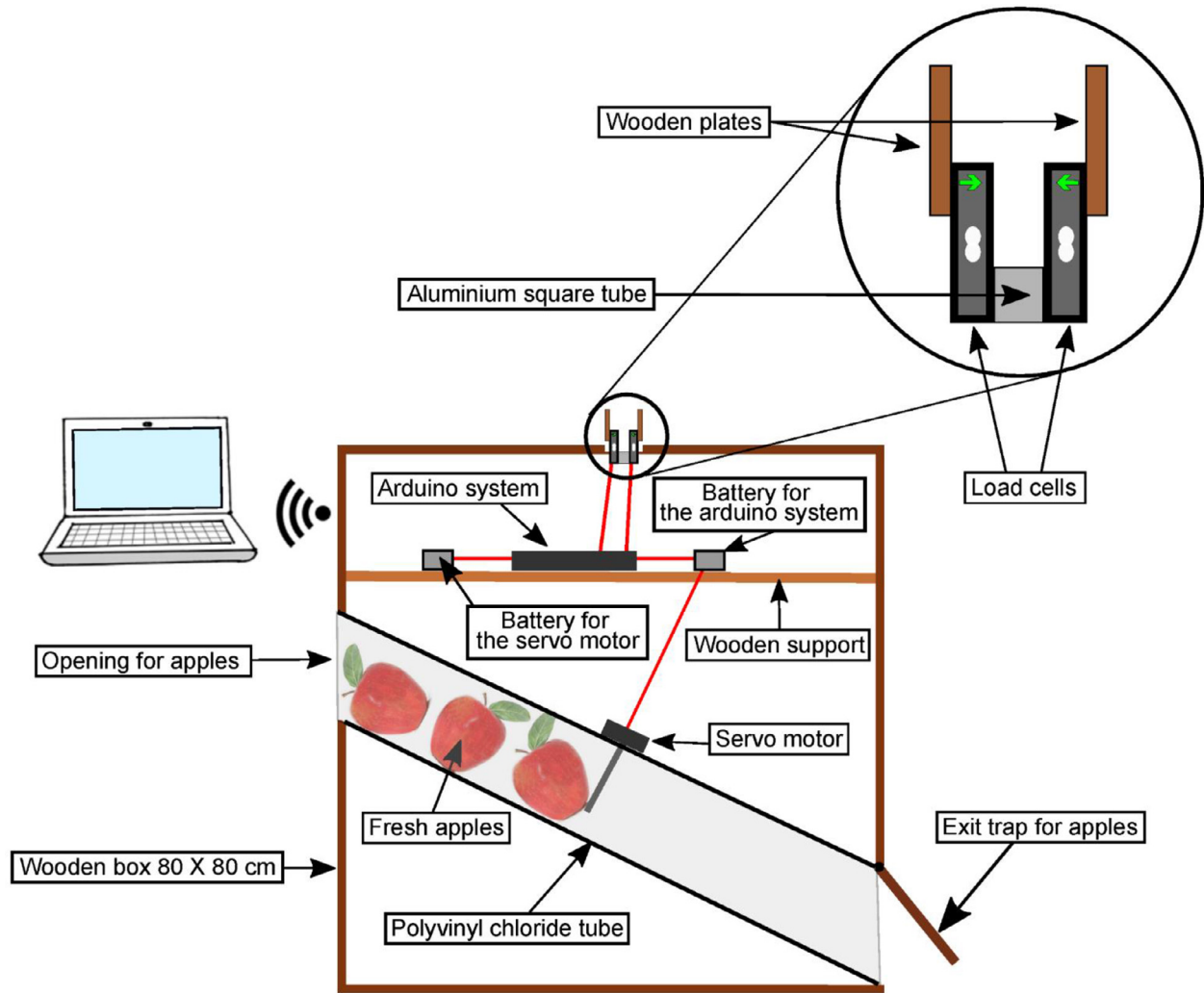


Fig. 1. Scheme of the global design of the device.

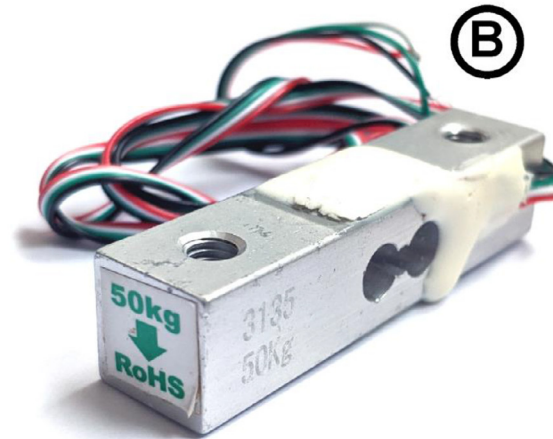


Fig. 2. **A** Photo of the wooden boxe seen from behind with the opening for recharging the apples; **B** Photo of Micro Load Cell (0-50kg) - CZL635 (Phidgets Inc., Canada) [15].

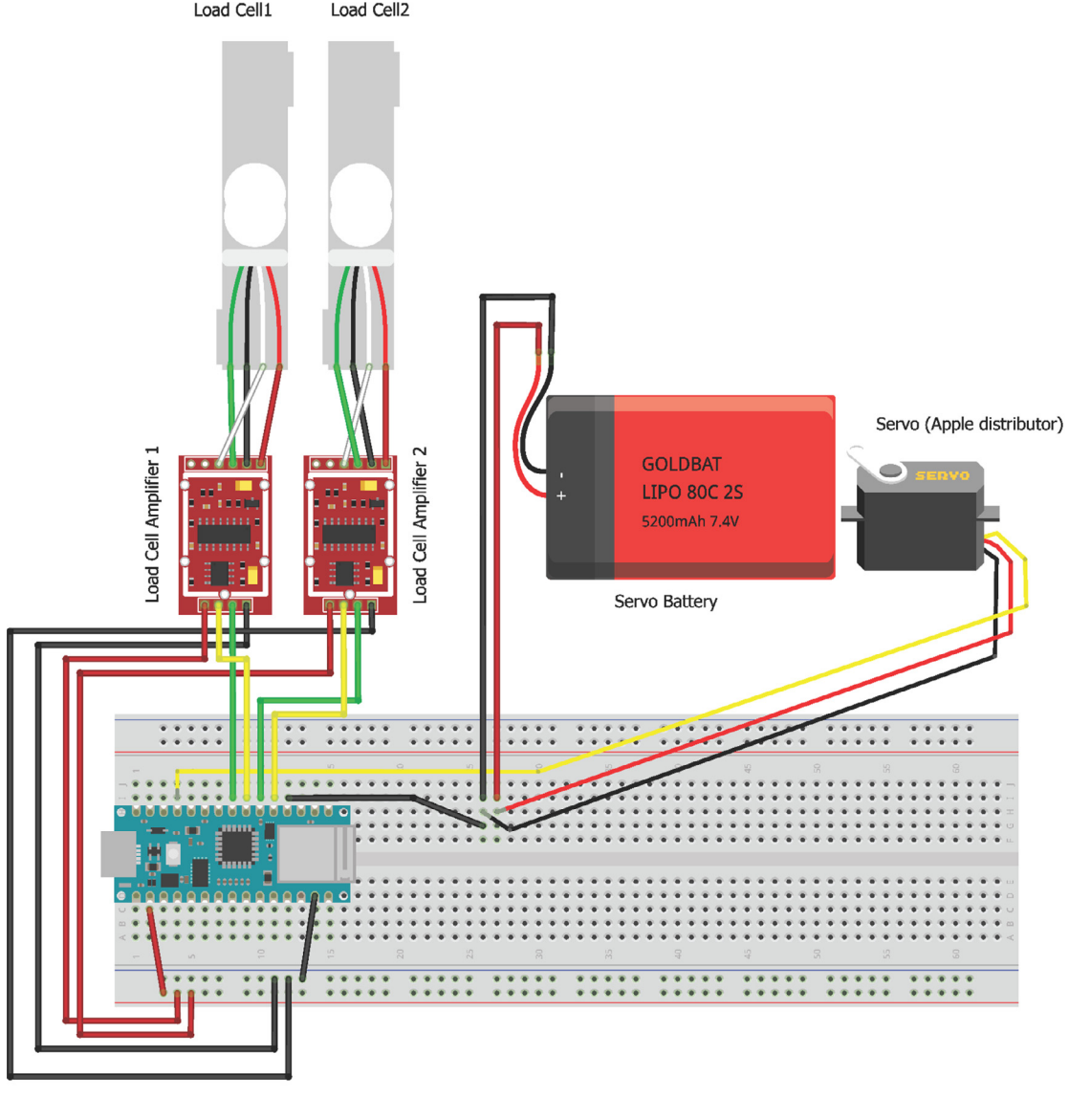


Fig. 3. Scheme of the electronic device. This scheme has been performed thanks to Fritzing software [22].

fritzing

Table 2

Load cells to HX711- load cell amplifier module connections.

Load cell 1&2	HX711_ADC
E+	RED
E-	BLK
A+	GRN
A-	WHT

Table 3

HX711- load cell amplifier module to micro-controller connections.

HX711_ADC	Arduino Nano 33 IoT
VCC	3v3 port
DAT	D5 & D3 GPIO ports
CLK	D4 & D2 GPIO ports
GND	GND port

Table 4

MG995 Servo Motor to battery and micro-controller connections.

MG995 Servo Motor	Goldbat 5200mAh	Arduino Nano 33 IoT
VCC	Type-T connector red + port	
GND		GND port
PWM		D9 GPIO port

the distribution of an apple using the Servo Motor. The Voltage Collector Collector (VCC) in red, is connected to the 3.3V port, the Ground (GND) in black to the GND. The Data (DAT) in green and Clock (CLK) in yellow on the General Purpose Input/Output (GPIO) are connected to ports D5 & D3 and D4 & D2 of the board respectively (Table 3). The Servo Motor MG 995 [30] is powered by an external battery, Goldbat 5200mAh Li-po battery. The GND is connected to the micro-controller and the Pulse Width Modulation (PWM) used for motor control, yellow wire, is connected to GPIO port D9 of the Arduino card (Table 4).

Calibration

Each sensor is fixed independently with a screw on a flat surface and the unloaded offset is recorded on the Arduino card in the calibration code thanks to the open-source Arduino Software (IDE) [16,17]. Three objects with known masses (1, 3 and 5 kilograms respectively) are then weighed on each sensor and the measurements sent to the card. Based on these three weighings and the unloaded offset, the Arduino calibration code returns the calibration value. This calibration value is then transferred to the Arduino weighing code.

Method validation

The validation was carried out on one specimen, Tana in this case, and proceeded as follows.

The movement of the elephant trunk tip and the recording of the forces were filmed synchronously throughout the experiment for a duration of 5 minutes. This recording allows us to check whether the force value in Newtons corresponds to a correctly performed pinch. Correct execution means that both fingers pinch simultaneously and only with the tip of the trunk (Fig. 4A). Other unwanted movements result in incorrect measurements. For example, the elephant may trigger a single sensor (Fig. 4B) or it may make a movement by rolling up the sensors with its trunk.

The first apple had to be delivered with a force of at least 10 N and the elephant therefore had to apply at least a force of 20 N to get a second apple and so on. The box was positioned in front of the elephant at about one meter from the bars. The two synchronised videos (movement and



Fig. 4. **A** Photo showing a correctly performed pinch involving only the tip of the trunk; **B** photo showing an incorrect pinch.

force measurement) were started. As expected from our previous studies [18,19,20] the elephant was curious and explored by touching the box and pressed the sensor, the only external feature of the box.

The video sequence coupled with the live force recording gave the following results.

- After 2 min 23 s of exploring the box without touching the sensor, the elephant touched the sensor in front of it with a force of 2.94 N and so did not release an apple as the threshold is 10 N.
- At 2 min 25 s, it incorrectly pulled the sensor towards itself using only one finger (Fig. 4B) with a force of 10.17 N which resulted in an apple being released.
- At 3 min 56 s, there was a first correct pinch which resulted in a force of 8.84 N without releasing an apple because the elephant must now apply a force of at least 20 N to trigger the reward.
- At 4 min 22 s, the elephant incorrectly pulled the sensor towards itself once again and a force of 4.05 N was recorded without releasing an apple.
- At 4 min 36 s, a pinch is correctly performed (Fig. 4A) and is recorded at 32.79 N releasing a second apple.
- At 4 min 55 s, it incorrectly pulled the sensor towards itself again, resulting in a force of 16 N. The elephant did not receive a reward because the applied force was less than the previous maximum value (32.79 N). 40 N was needed to get another apple.
- At 5 min, the experiment ended.

This sequence validates the method by showing that (I) the box is effective while respecting the safety guidelines (II) the elephant focuses its attention on the sensor and triggers it (III) the distribution of apples encourages the elephant to repeat the task (IV) the threshold system constrains the elephant to perform pinches of increasing force. As a first result, we obtained that the elephant Tana can apply a force of at least 32.79 N when pinching with the two fingers of its trunk.

Conclusion

To conclude, our system proved to be functional and efficient while respecting the numerous constraints linked to this species. Thanks to this system, we have begun to measure trunk tip grip force for each elephant with repetitions and varying extrinsic parameters such as sensor distance. These biological data will be used as a basis for a soft robotics bio-inspired project.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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