Title:

Advancing Entomological Research: Exploring Electronic Measurement Systems with a Case Study on Mapping Geometric Points of Beetle Elytra

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Introduction:

Electronic measurement systems in entomology utilize various methodologies to capture and analyze the behavior, movement, and morphology of insects. These methodologies include Radiofrequency identification, Acoustic monitoring, Inertial measurement units, Video tracking systems, Laser triangulation, Ultrasonic sensors, Computer vision and image analysis, Wireless sensor networks, Telemetry systems, Odometers and rotary encoders, and Environmental DNA.

In the literature, there are several articles related to these methodologies, wherein the authors elucidate their strategies primarily aimed at identifying the movements of insects [1, 2, 3, 4, 5].

The interdisciplinary group led by Dr. Dina Rochman from Metropolitan Autonomous University campus Cuajimalpa comprises experts in robotics, computer science, mechatronics, mechanics, 3D printing, and descriptive geometry. Together, they propose the development of two innovative measurement systems designed to map the geometric points of insects in two dimensions. The first system utilizes an encoder sensor, while the second system employs a rotary encoder.

The main objective of this research is to integrate new and advanced electronic measurement techniques to provide a meticulous and precise understanding of insect morphology.

The morphological analysis of beetle elytra serves as a focal point in our entomological study, delving into the intricate details of these forewings and utilizing electronic measurement systems for comprehensive exploration.

The morphological analysis of beetle elytra holds significance not only within the realm of entomology but also in broader ecological and evolutionary studies. Understanding the intricate features of these forewings contributes to our knowledge of adaptation, biodiversity, and evolutionary processes shaping beetle morphology.

Main Sections:

The evolution from odometers to the contemporary use of rotary encoder systems and encoded sensors underscores the pivotal role of technology in the advancement of distance measurement throughout history.

One of the most well-known odometers was designed by Leonardo da Vinci in the late 15th century. Also known as "Da Vinci's wheel," this ingenious gear mechanism was conceived to measure the distances traveled by wheeled vehicles.

Unlike odometers, which are measurement instruments designed to calculate the total or partial linear distance traveled by an object or vehicle, expressed in configured length units (such as meters or miles), and whose application is versatile, commonly used to evaluate fuel performance, estimate speed through brake marks, make perimeter measurements, guide the laying of cables or pipelines, and contribute to workspace design, rotary encoders are electromechanical or electronic devices designed to measure the rotation of a shaft and convert it into electrical signals representing angular position.

In the context of our project, the rotary encoder serves as a key electronic component that detects and measures the rotation of the wheel. The overall setup, including the encoder, is part of a measurement system designed to determine the distance traveled by the wheel, as the signals from the rotary encoder are electronically processed to calculate the distance based on rotation information, using Arduino.

Another measurement system we are proposing to map the geometric points of the beetle's elytra is an encoder sensor. An encoder sensor is a device designed to measure the position, rotation, or displacement of an object and convert this mechanical information into electrical signals. In our project, we have designed a button for the encoder sensor that incorporates a tip. When pressing this button, the tip comes into contact with the tracks printed on a board, indicating on the LCD screen the X coordinate of each of the geometric points of the contour of the beetle's elytra.

Systematic procedure:

The systematic procedure followed to achieve the intended results is detailed below: (1) Configuration and 3D modeling and printing of components: The creation and design of the base, posts, rails, buttons, table, and wheel were carried out using 3D modeling techniques. Special attention was paid to tolerances during assembly, especially in the toothed rail and wheel, to ensure that the structure was sturdy and functional. (2) Button calibration: A detailed comparison of the position and distance in placing the buttons on each of the rails, both toothed and non-toothed, was performed to ensure the accuracy of distance measurements. (3**)** Interval selection: The measurement intervals to be programmed into Arduino for each of the measurement systems were determined. This selection was based on specific considerations of each component and the purpose of the measurements. (4) Data collection: Experimental tests of the two electronic measurement systems were initiated to record distance readings from both buttons at each stopping point. (5) Code validation: The code used in Arduino was verified and validated through various tests to ensure its correct operation. (6) Graphical representation: During the tests with the beetle's elytron on the proposed structure, the measurements of the beetle's elytron were verified, and graphical representations were made to analyze the results obtained.

Structural design:

For both measurement systems, a structure consisting of a base, two prisms, a worktable, a cylinder, a toothed rail, a non-toothed rail, a wheel, and four buttons was designed, 3D printed, and assembled.

In the design of button 1, two key considerations were taken into account. Firstly, the placement of a needle used for insulin injection at the end of the button was anticipated. Secondly, a spring-loaded movement system was incorporated, characterized by an internal cone that, when pressed, makes contact with the plate of the encoder sensor system.

Similarly, to button 1, in button 2, an insulin injection needle is incorporated into its base. Button 2 consists of an intermediate hole to place the wheel inside the cylinder of the rotary encoder and a cylinder that enters the final part of the rotary encoder, serving as a button to return the encoder measurement to zero.

Operation and results of measurement systems:

The basic operation of a rotary encoder involves converting rotary motion into electrical signals.

In our project, we utilize the rotary encoder to accurately measure distances and map the geometric points of the beetle's elytron. This encoder is integrated into a button that we manually move along a toothed rail from the right, where the insulin needle makes contact with the beetle's elytron, to the left until the tip of the button.

When rotating the wheel using the rotary encoder along the toothed rail, the distance traveled by the wheel is displayed on the LCD screen and the serial monitor (Fig. 1). The same process is repeated with a second button, whose travel is from right to left. By subtracting the two distances obtained from the total measurement of the table, we obtain the measurement of the width of the beetle's elytron starting with a distance of 4 mm on the "y" axis. This procedure is repeated as necessary until the total length of the beetle's elytron is.

```
Distancia = 0     2
Pasos = 0
Elitro = 25.44
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Distancia = 3.46 |Pasos = 1.00
Distancia = 6.91 |Pasos = 2.00
Distancia = 10.37 |Pasos = 3.00
Distancia = 13.82 |Pasos = 4.00
Distancia = 17.28 |Pasos = 5.00
Distancia = 20.73 |Pasos = 6.00
Distancia recorrida = 20.73 |Pasos totales = 6.00
Botón pulsado |Distancia comienzo = 0 |Pasos comienzo = 0
Distancia recorrida = 20.73 |Pasos totales = 6.00
Botón pulsado |Distancia comienzo = 0 |Pasos comienzo = 0
Distancia = -3.46 |Pasos = -1.00
Distancia = -6.91 |Pasos = -2.00
Distancia = -10.37 |Pasos = -3.00
Distancia = -13.82 |Pasos = -4.00
Distancia recorrida = -13.82 |Pasos totales = -4.00
Distancial guardada = Botón pulsado |Distancia comienzo = 0 |Pasos comienzo = 0
Distancia élitro = 25.44
Distancia recorrida = -13.82 |Pasos totales = -4.00
Distancial guardada = Botón pulsado |Distancia comienzo = 0 |Pasos comienzo = 0
Distancia élitro = 25.44
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Fig. 1: Displayed on the LCD screen and the serial monitor distance traveled by the wheel.

The rotary encoder we use, the KY-040, has a resolution of cycles per revolution. This means that the encoder produces 15 pulses for each complete revolution of the shaft.

Using the formula [3] (3.1), where D is the distance traveled by the rotary encoder, π is approximately 3.14159, R is the radius of the wheel (in our case, the wheel measures 11 mm), and N is the number of cycles per revolution (in our case, it's 15), we calculate that the distance per step is approximately 4.608 mm.

$$D = \frac{2\pi R}{N} \tag{3.1}$$

The results presented in Table 1 represent the distance the rotary encoder wheel would travel in each step, considering the radius of 11, 8, 7, and 5 mm. Each step increases the distance traveled, up to 15 steps.

steps	radius 11	radius 8	radius 7	radius 5
1	4.608	3.351	2.932	2.094
2	9.215	6.702	5.864	4.189
3	13.823	10.053	8.796	6.283
4	18.431	13.404	11.729	8.378
5	23.038	16.755	14.661	10.472
6	27.646	20.106	17.593	12.566
7	32.254	23.457	20.525	14.661
8	36.861	26.808	23.457	16.755
9	41.469	30.159	26.389	18.850
10	46.077	33.510	29.322	20.944
11	50.684	36.861	32.254	23.038
12	55.292	40.212	35.186	25.133
13	59.900	43.563	38.118	27.227
14	64.507	46.914	41.050	29.322
15	69.115	50.265	43.982	31.416

Tab. 1: Distances traveled by the wheel, values are given in mm.

The operation of an encoder sensor involves detecting a physical phenomenon, which in this case would be distance, and converting this information into an electrical signal, either analog or digital.

We conducted tests on the model using the corresponding buttons (Fig. 2), and the results were satisfactory. The rail, along with the wheel, operates in such a way that each step of the rotary encoder marks 4.61 mm in the Arduino. The sum of each step provides us with the total distance that each of the buttons travels, in the positive and negative directions. We subtracted these distances from the measurement of the table to obtain the length of the beetle's elytron in the corresponding "y" coordinate.

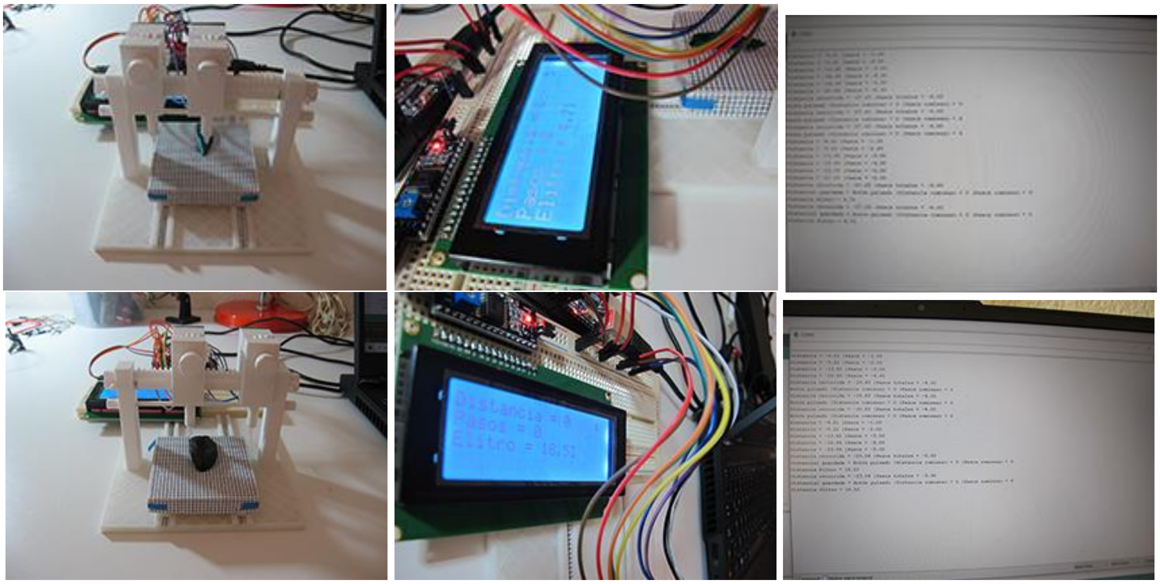

Fig. 2: Tet one and two.

In the context of our project, a "track" refers to a series of markers printed or engraved on a plate at regular intervals. These marks represent reference points or specific positions along the surface. The minimum distance at which tracks can be printed on a plate depends on various factors such as the manufacturing process of the plate, the precision of the printer used, and the printing resolution. In general, in most PCB (Printed Circuit Board) printing processes, track-to-track distances of around 0.1 mm (100 micrometers) or even less can be achieved.

We conducted two simulations to test the operation of the sensor system. The results are available in a video with the MKV extension, which is an open-source and free software container format. Below are screenshots of the two simulations: one with 64 tracks (Fig. 3) and the other with 300 tracks (Fig. 4). Each of the 64 tracks represents a conducting line that is touched or selected at a specific moment. Given the large number of connections involved, the 'Detector' block generates a unique binary code of only 6 bits, which represents the track that has been activated or selected. These 6 bits allow for $2^6 = 64$ distinct combinations and physically consist of only 6 connections going from the Arduino to the 'Detector,' plus a single connection going from the 'Detector' to the Arduino. This connection indicates to the Arduino when to stop the internal counter, which will generate the combination corresponding to the track number.

The circuit of 300 tracks is an extension of the 64-track circuit, with the main difference being that there are now 9 connections going from the Arduino to the 'Track Detector. Similarly, there is a connection from the 'Detector' to the Arduino indicating when to stop the internal counter of the Arduino to generate the code corresponding to the activated track. The 9 connections have the potential to generate up to $2^9 = 512$ track codes. However, due to space limitations, the simulation was limited to 300 tracks, which is the initially anticipated quantity for the measurement system.

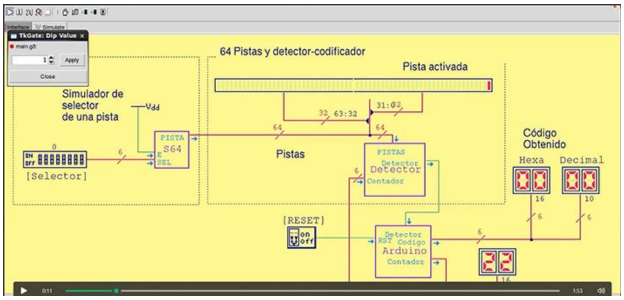

Fig. 3: Simulation with 64 tracks.

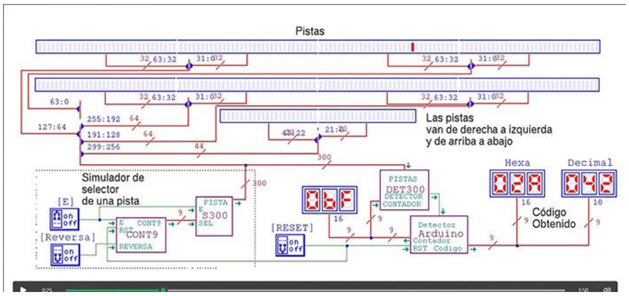

Fig. 4: Simulation with 300 tracks.

Conclusions:

In summary, the interdisciplinary project has successfully integrated new electronic measurement techniques to study insect morphology. Both the encoder sensor and rotary encoder proved effective in measuring distances and physical phenomena. 3D printing has been crucial for adapting components to project needs. While efficient, limitations were identified regarding sensitivity to electromagnetic interference and securing mechanisms. These considerations must be addressed to ensure the reliability and accuracy of the systems.

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