Universidad Continental

FACULTAD DE INGENIERÍA

Escuela Académico Profesional de Ingeniería Mecatrónica

Tesis

Mechatronic Design of a Modular Artificial Honeycomb for the Automatic Extraction of Honey from Apis Melliferas Bees in Huancayo, Peru

Jose Alfredo Paitan Cardenas
Vrigel Kenty Povez Nuñez
Frank William Zarate Peña

Para optar el Título Profesional de
Ingeniero Mecatrónico

Huancayo, 2024

INFORME DE CONFORMIDAD DE ORIGINALIDAD DE TRABAJO DE INVESTIGACIÓN

A	:	Decano de la Facultad de Ingeniería
DE	:	Frank William Zarate Peña Asesor de trabajo de investigación
ASUNTO	:	Remito resultado de evaluación de originalidad de trabajo de investigación
FECHA	:	30 de Julio de 2024

Con sumo agrado me dirijo a vuestro despacho para informar que, en mi condición de asesor del trabajo de investigación:

Título:
Mechatronic Design of a Modular Artificial Honeycomb for the Automatic Extraction of Honey From Apis Melliferas Bees in Huancayo, Peru

URL / DOI:
10.1088/1742-6596/2522/1/012020

Autores:
1. Jose Alfredo Paitan Cardenas – EAP. Ingeniería Mecatrónica
2. Vrigel Kenty Povez Nuñez – EAP. Ingeniería Mecatrónica
3. Frank William Zarate Peña – EAP. Ingeniería Mecatrónica

Se procedió con la carga del documento a la plataforma "Turnitin" y se realizó la verificación completa de las coincidencias resaltadas por el software dando por resultado 12 % de similitud sin encontrarse hallazgos relacionados a plagio. Se utilizaron los siguientes filtros:

	SI	NO
• Filtro de exclusión de bibliografía		X
• Filtro de exclusión de grupos de palabras menores Nº de palabras excluidas **(en caso de elegir "SI")**:		X
• Exclusión de fuente por trabajo anterior del mismo estudiante	X	

En consecuencia, se determina que el trabajo de investigación constituye un documento original al presentar similitud de otros autores (citas) por debajo del porcentaje establecido por la Universidad Continental.

Recae toda responsabilidad del contenido del trabajo de investigación sobre el autor y asesor, en concordancia a los principios expresados en el Reglamento del Registro Nacional de Trabajos conducentes a Grados y Títulos – RENATI y en la normativa de la Universidad Continental.

Atentamente,

Mechatronic Design of a Modular Artificial Honeycomb for the Automatic Extraction of Honey from Apis Melliferas Bees in Huancayo, Peru

Jose A Paitan Cardenas[1], Vrigel K Povez Nuñez[1] and Frank W Zarate Peña[2]

[1]EAP Mechatronics Engineering, Universidad Continental, Huancayo, Perú
[2]Engineering Research Unit, Universidad Continental, Huancayo, Perú

E-mail: 75925569@continental.edu.pe
E-mail: 44574626@continental.edu.pe
E-mail: fzaratep@continental.edu.pe

Abstract. This research develops the mechatronic design of an artificial honeycomb for Apis Melliferas bees, which allows the automatic extraction of honey in the farms of the province of Huancayo, Peru, since Junin produces 208.26 tons of honey annually with traditional and obsolete techniques. This design was executed under the German VDI 2221 standard and contemplates the mechanical, electronic and control system, which are dimensioned according to the theories and laws of: distortion energy, polynomial 3 4 5, involute curve gears, Kirchhoff, Ohm, on-off control, among others. It was possible to design, in Inventor, the honeycomb structure whose cells have a 19° slope for the honey gravity flow, a gear-rack-gear system for the transmission of torque from the servomotor to the cam shaft to move the grid, which opens the flow duct; also, it was possible to design, in Proteus, the electronic system made up by the Arduino UNO, a servomotor of 2. 5 Kg-cm servomotor with rotation restricted to 110° and the 15mm force sensor; finally, the actuator control and the monitoring of the weight according to the on-off logic were programmed in Arduino IDE. According to the simulations performed, the design is technologically feasible.
Keywords: Artificial honeycomb, automatic honey extraction, gravity flow, Apis Mellifera honey bee.

1. Introduction

Beekeeping is an important activity worldwide due to its direct impact on food and agriculture [1]. Among the direct benefits are pollination, which promotes biodiversity, as well as products such as pollen, wax, propolis and honey [2] with its high nutritional and medicinal value [3]. Peru produces about 2,314 tons of honey annually from more than 40,000 beekeepers with 300,000 hives [4]. The department of Junín has 19874 hives in production, ranking third in national production [5]. The research was carried out in the province of Huancayo, where beekeepers witness the negative factors affecting beekeeping, such as swarming [2], climate variability, excessive use of agrochemicals [6], pests and diseases, monocultures and unsustainable agricultural practices [1]. These practices are a stress factor for bees and the main reason for hive loss [7]. Therefore, it was considered necessary to develop modern techniques and technologies to modify these practices efficiently.

There are studies and patents on the subject, such as the artificial honeycomb patented by C. J. Anderson and S. R. Anderson [8]; as well as a prototype developed by Caisaguano León et al. [9] that includes aspects of Industry 4.0, and finally a hive capable of collecting honey without exposing Kwon's honeycombs [10].

The objective of this project is to develop the mechatronic design of a honeycomb for Apis Melliferas bees, using the VDI 2221 methodology, which will allow the automatic extraction of honey on farms in the province of Huancayo. The modular artificial honeycomb will allow the extraction of honey by gravity flow through the honeycomb's ducts when its weight has reached the programmed limit and the beekeeper is present at a safe distance for the transfer of the storage containers to a collection center. Automation of the honey harvesting process has a direct benefit in that it reduces beekeepers' exposure to poisonous stings and optimizes the economic, time and energy resources involved in manual monitoring and extraction.

2. Materials and methods

The design follows the guidelines of the German VDI 2221 methodology, whose stages are specified in figure 1 and detailed in the appendix. The software used for the design and simulation are Autodesk Inventor Professional 2023, Proteus 8 Professional and Arduino IDE.

3. Development

3.1. Mechanical system

First, the artificial honeycomb module is sketched, see figure 2, which contemplates a pair of polyethylene honeycombs and a stainless steel grid between them.

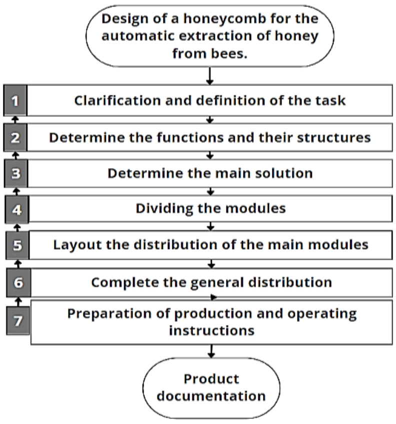


Figure 1. VDI 2221 Methodology.

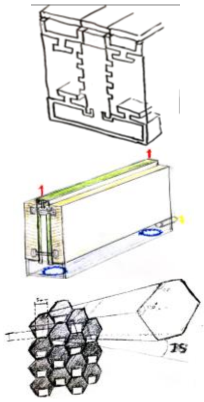


Figure 2. Sketch of the proposed design.

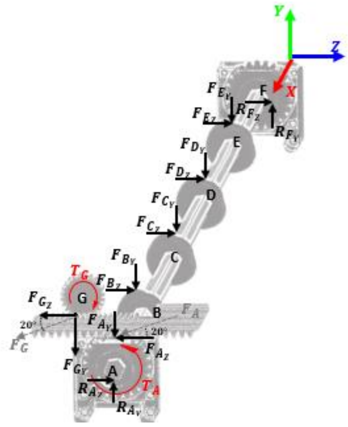


Figure 3. Free body diagram.

The cells of each honeycomb have a slope of 15° and have an opening at the back, which coincides perfectly with the holes of the grid when it is vertically displaced 1.9mm. To perform this movement, and based on the distortion energy theory [11], polynomial 3 4 5 [12] and involute curve gears [13], the mechanical transmission system composed of gears, rack, shaft and cams was dimensioned to transform the rotary movement of the servomotor into a vertical linear movement of the grating. Figure 3 shows the free body diagram of the whole transmission mechanism and then the design equations are specified:

3.1.1. Equations for the design of gears by "involute curve". Where "Z" is the number of teeth, "m" modulus, "Dp" pitch diameter, "De" outside diameter, "Di" inside diameter, "Dp" pitch diameter, "De" outside diameter, "Di" inside diameter.

$$Dp = mZ \tag{1}$$

$$De = Dp + 2(m) \tag{2}$$

$$Di = Dp - 2(1{,}25m) \tag{3}$$

3.1.2. Equation for cam design by "polynomial 3 4 5". Where “s” is the outward movement, “h” elevation, “θ” inward movement, “β” cam angle.

$$s = h\left[10\left(\frac{\theta}{\beta}\right)^3 - 15\left(\frac{\theta}{\beta}\right)^4 + 6\left(\frac{\theta}{\beta}\right)^5\right] \tag{4}$$

3.1.3. Equation for shaft design by "distortion energy". Where “d” is the shaft diameter, “m” modulus, “σ'” Von Misses stress, “M” moment, “T” torque.

$$d = \left[\frac{16}{\pi\sigma'}\sqrt{(2M)^2 + 3(T)^2}\right]^{1/3} \tag{5}$$

3.2. Control and electronic system

The control system of the artificial comb is based on an ON/OFF control logic, where the input variable is the weight of the comb (approximately 6.3Kg) and the output variable is the vertical drive of the grid. This allows the automatic extraction of the honey. Figure 8 illustrates graphically the operation of the system by means of a flow chart.

To measure the weight of the honeycomb, a 15mm force sensor will be used. However, a MPX4250 pressure sensor will also be used to simulate the system in Proteus. For this, the pressure will be calculated using equation (6) and considering a mass of 6.3Kg, which includes both the weight of the honeycomb and the weight of the mechanical components.

$$P = \frac{F}{A} = 175KPa \tag{6}$$

To amplify the signal received from the MX4250 pressure sensor, an AD8228 operational amplifier will be used. To set the gain of the amplifier, the gain resistance will be calculated through equation (7), considering the sum of R1 and R2 of 49.4 KΩ, according to the amplifier data sheet, and a desired gain of 6.25. Figure 10 illustrates the electronic circuit of the sensor and amplifier. The output signal will be sent to a microcontroller to execute the control logic.

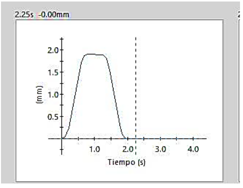
$$RG = \frac{R1 + R2}{G - 1} = \frac{49.4\ k\ ohm}{6.25 - 1} = 9.41k\ ohm \tag{7}$$

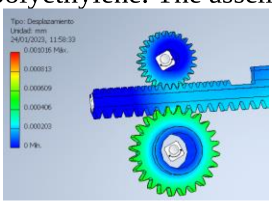
4. Results

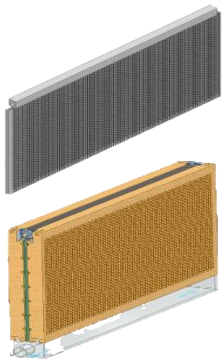
4.1. Mechanics

The cams, gears, shaft and rack were designed according to the theory specified in the methods section. Figure 4 shows the displacement, velocity, acceleration and tapping functions of the cam for an output movement of 70° and with an elevation of 1.9mm, which are continuous, thus verifying its correct dimensioning. The shaft diameter, calculated for a cold drawn UNS G10180 steel, is 7.48757 mm, and the results for the Von Misses stress and the maximum and minimum displacement are shown in figure 5. The diameters of the servomotor and shaft gears for a pressure angle of 20°, a number of teeth of 24 and moduli of 0.7083 and 0.4583 are: for the outside of 11.9167 and 18.4167, for the inside of 9.8542 and 15.2292, for the primitive of 11 and 17 mm, which are shown in figure 6.

The grid, shaft, cams, rack and gears are made of steel; the honeycomb, reservoir, shaft holders and other elements are made of polyethylene. The assembly is shown in figure 7.







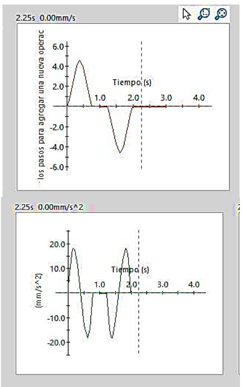


Figure 4. Displacement, velocity and acceleration graphs.

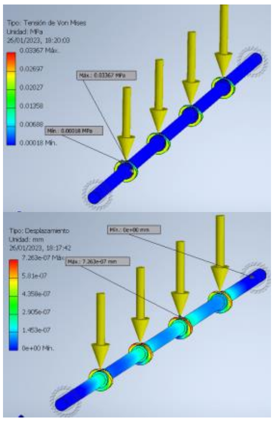


Figure 5. Stress analysis.

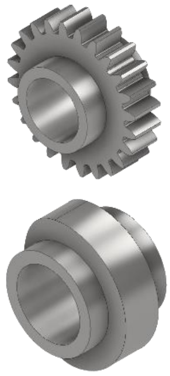


Figure 6. Gears and cam.

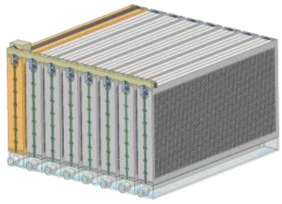


Figure 7. Grid, honeycomb and hive.

4.2. Electronics and Control

Figure 9 illustrates the programming implemented based on the control logic established in the flowchart. An Arduino UNO control board was used to carry out the system tests, which were performed using the Proteus simulation program.

Figure 10 shows the general electronic circuit, where the Arduino, a servomotor and a manual push button can be observed; where the beekeeper can press and the automatic extraction of the bee honey will be performed, without running the risk of being stung or using specialized protective equipment, and a smoker to scare the bees away at the time of harvesting. Figure 10 presents the overall electronic circuit design, which includes the use of an Arduino control board, a servo motor, and a manual button. This system allows the beekeeper to extract the honey automatically, avoiding the risk of stings and the need to use specialized protective equipment, which includes a smoker to keep the bees away during the harvesting process.

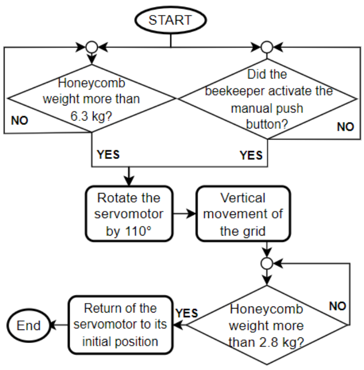


Figure 8. Flowchart of the artificial honeycomb control system.

```
void loop() {
  int valor_leido=analogRead(0);
  int valor_leido1=analogRead(1);
if(digitalRead(2)==LOW || (valor_leido+valor_leido1)>=835.584) {
  myservo.write(110);
  X =1;
  digitalWrite(12, LOW);
  delay(10);
  digitalWrite(13, HIGH);
  delay(10);
}
else
{
if((X==1)&& ((valor_leido+valor_leido1)<835.584) &&
((valor_leido+valor_leido1)>381.95)){
  myservo.write(110);
}
else {
  if((valor_leido+valor_leido1)<381.95 && (X==1)){
    myservo.write(0);
    X=0;
    digitalWrite(13, LOW);
    digitalWrite(12, HIGH);
  }
  else{
    myservo.write(0);
    digitalWrite(13, LOW);
    digitalWrite(12, HIGH);
```

Figure 9. Control logic programming.

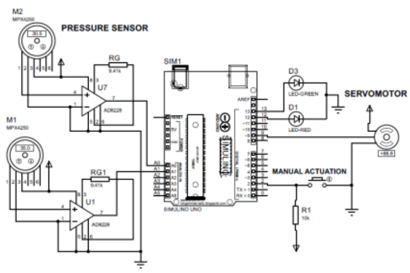


Figure 10. Electronic circuit of the honeycomb.

The input data is collected by two pressure sensors located on each frame, which measure the weight distributed on both frames and add up the total weight of the frame ready to be harvested. The MG905 servomotor, with a torque of 2.5 Kg/cm, is responsible for the vertical movement of the artificial honeycomb grid through a 110-degree rotation. This process continues until the weight of 2.8 kg, corresponding to the empty frame, is reached. In addition, the circuit includes two LED lights: a red one indicates that the extraction process is not being carried out, while a green one indicates that it is being executed.

5. Conclusions

Successfully developed the mechatronic design comprised of mechanical, electrical and control systems for a modular artificial honeycomb for automatic honey extraction. This has the potential to modernize beekeeping in the region and provide an innovative approach to this harvesting process. As a result, beekeepers' exposure to poisonous stings is reduced and the economic, time and energy resources required for manual monitoring and extraction are optimized.

6. Appendix

A Google Drive folder is shared below providing detailed information on the methodology used, including also the dynamic and assembly simulations https://drive.google.com/drive/folders/1UPFh8bkxRRns-rYxjRi8CUVjuDEsvIKR?usp=share_link

References

[1] Food and Agriculture Organization of the United Nations 2020 *FAO celebrates world bee day 2020 with online even*

[2] Baena F *et al* 2022 *Apis mellifera en México: producción de miel, flora melífera y aspectos de polinización. Revisión* **vol 13** (Mexico: Rev Mex Cienc Pecu) pp 525–548

[3] Luis E, Ramon S and Ivonne S 2017 *Situación apícola en México y perspectiva de la producción de miel en el Estado de Veracruz* (Mexico: Rev Estrategia del desarrollo empresarial) **vol. 3** pp 40–64

[4] Ministerio de Desarrollo Agrario y Riego 2021 *En Perú existen más de 40 mil productores apícolas que trabajan la miel de abeja en 300 mil colmenas a nivel nacional - Noticias - Ministerio de Desarrollo Agrario y Riego - Gobierno del Perú*

[5] Ministerio de Agricultura y Riego 2022 *Plan nacional de desarrollo Apícola*.

[6] Comisión Económica para Amérca Latina y el Caribe 2022 *Estadísticas e indicadores: Ambientales - CEPALSTAT Bases de Datos y Publicaciones Estadísticas*

[7] Tiphaine H, Marion L *et al* 2019 *Impact of Stressors on Honey Bees (Apis mellifera; Hymenoptera: Apidae) Some Guidance for Research Emerge from a Meta-Analysis* **vol. 12** (France: Diversity) p 7

[8] Anderson S and Anderson C 2016 *A bee-benign artificial honeycomb* (United States: United States)

[9] Caisaguano L *et al* 2022 *Diseño y construcción de una colmena Flow Hive automatizada mediante la aplicación de aspectos de Industria 4.0 que permita modernizar el proceso de extracción de miel con una mayor rapidez y seguridad* (Ecuador: Universidad de las Fuerzas Armadas ESPE. ESPEL. Carrera de Ingeniería en Mecatrónica)

[10] Kwon J 2020 *a functional honey comb with easy honey collecting* (Korea: Korea Intellectual Property Office)

[11] Budynas R and Nisbett J 2008 *Shigley's Mechanical Engineering Design* Ciudad de México: McGraw-Hill) chapter 5 pp 215-216

[12] Shigley J and Uicker J 2001 *Theory of Machines and Mechanisms* (Naucalpan de Juárez: McGraw-Hill) chapter 6 pp 235

[13] Mott R 2006 *Machine elements in mechanical design* (Naucalpan de Juárez: Pearson Educación) chapter 8