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Tesis

Automated System of Pre-Hispanic Camellones to Reduce Crop Damage Due to the Extreme Weather Event of Frost

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Automated System of Pre-hispanic Camellones to Reduce Crop Damage Due to the Extreme Weather Event of Frost

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***Abstract*—This research develops the design phase of an automated system which can reduce the effects of frost, as this causes many negative effects in the high Andean communities of Peru, destroying crops and thus generating large economic losses, so the main objective is to develop an automated system of *camellones* against the effects of extreme weather event of frost to reduce crop losses. In the proposed methodology of the study was conducted in a field crop in a rural location in the highlands, the methodology of the VDI 2221 will be presented for the electronic design based on Arduino Uno, temperature sensors and control of two solenoid valves; as well as the mechanical design of the gates containing the valves and the *camellones* for the field crop that is able to maintain a constant flow and volume of water. The results obtained are a schematic design of the circuit, as well as a 3D modeling of the gates and *camellones*; also, through calculations the estimation of the amount of incoming and outgoing flow of water controlled by the valve, the amount of heat absorbed and released by the mass of water in the system is obtained. The design of the system of the *camellones* related to flow control, capacity and thermal conductivity is also feasible to execute because it is adapted to the conventional irrigation systems of the rural locality of study.**

Keywords—frost, camellones, solenoid valve, flow rate, VDI 2221 and Arduino uno

I. INTRODUCTION

The damage caused to agriculture by frost is very frequent and high worldwide, In Mexico, they monitored the standardized vegetation index (NDVI) and analyzed minimum temperatures to determine frost losses, resulting in the loss of up to 3511 hectares of agricultural production [1]. In Chile they used a tool to prevent frost damage to flower buds, using and evaluating the effectiveness of a PVA-based polymer on cherry trees [2]. Large losses were generated by this phenomenon.

In Peru, agriculture is one of the main productions of the country, but the frost generated abrupt losses, mainly in the Andean Region, since its geographical conditions make the danger of frost persist throughout the year, preventing agricultural activity a high-risk feature [3]. In the locality of Leonor Ordoñez this phenomenon occurs and there is no system that can reduce losses, so it is proposed to generate an automated system which will help mitigate the effects of this phenomenon to achieve improvements in production and management of water resources. The system will automatically operate the water supply because the solenoid valve module will be connected to a portable gate that is based on the instituted parameters [4].

They developed a water valve control system, which utilizes the ATmega 328 microcontroller on the Arduino Uno development board using PWM technology for opening and closing speed control, as well as the LM 7805 voltage regulator [5]. Other similar features in the construction of the proposed system are the use of a solenoid actuated valve with a transistor circuit with relay for electromechanical actuation and the implementation of the DHT 11 environmental sensor [6]. The incoming velocity to the system is regulated and stabilized by a truncated pyramid shaped diffuser with degree of inclination [7].

In the differences to the operation of the anti-freeze system for crops, it is not opted for a closed greenhouse solution with water distribution and a connection of the systems with IoT technologies [8]; but what is proposed is the use of pre-Hispanic techniques known as the camellones or Waru Waru, from the dialect of Altiplanic cultures of Peru, modernizing them and integrating a control system of water input and output as well as temperature monitoring. The proposed water flow control system is implemented by the commercial PU225 solenoid valve with DC 12 V power supply, as opposed to an original low-cost remote control design [9].

The methodology used is VDI 2221 because the research carried out is a systematic development of mechatronic products and the design of this system will be developed applying the guidelines of the standard. We will present as results the 3D molding of the gate that will contain the water flow control system, the flow diagram of the complete system, the monitoring system and reception of temperature data, finally the system is developed in an arable land obtaining the frost control data.

II. MATERIALS AND METOHODS

A. Methodology VDI 2221

The methodology used is the VDI 2221 for the mechatronic systems that will be used in the research, which will allow to develop the system in an optimal way in which the seven stages are developed to elaborate the complete system and to obtain the mechanical and electrical design of the traffic lanes so that it can be used correctly in the field as can be seen in the following Fig.1.

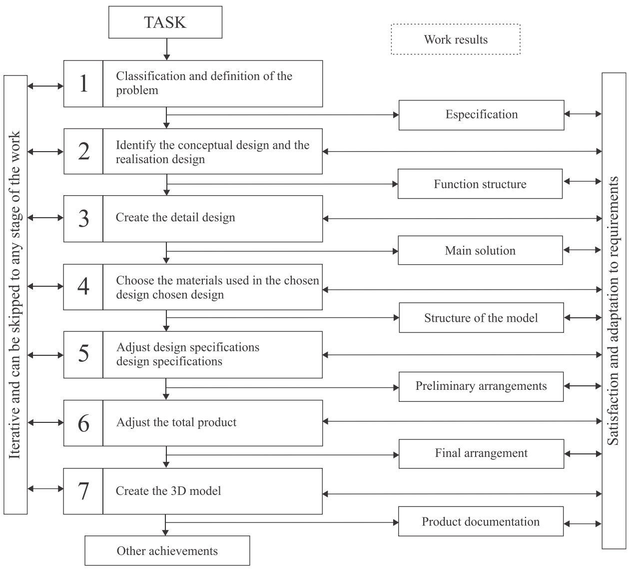

Fig. 1. Methodology VDI 2221.

B. Organizers of Ideas and Concepts

Mind maps are those which represent learning strategies, they help us to understand in a better way, since they organize and acquire more precise ideas, helping us to understand all the information transforming it into knowledge [10].

The mind map uses the analogy of a neuron which has ramifications that are related to the nucleus or main idea, this gradually diversifies until it branches, this is done graphically which puts an image in the center, this is known as the trunk and the ramifications evidence the bright thoughts [11].

A mental map is elaborated in which the main topic is an automated system of pre-Hispanic *camellones* for the reduction of frost damage, in which its ramifications are the type of control, controllers, valve container gates, the design of the *camellones*, the sensors and actuators that the system will have, as can be seen in the following Fig.2.

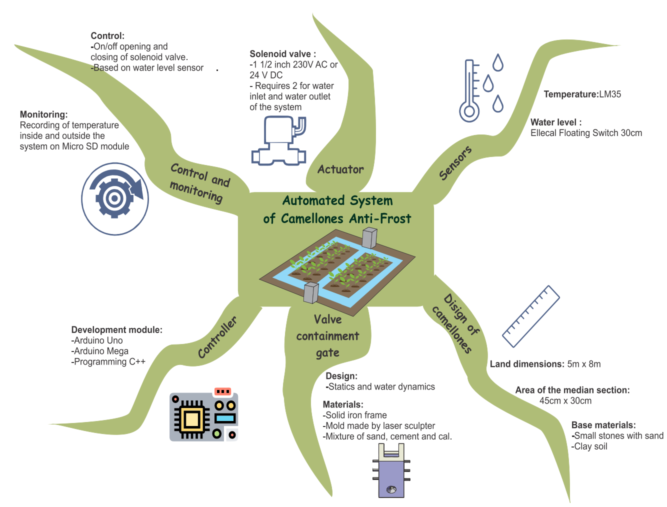

Fig. 2. Mind map.

The lotus diagram allows us to organize our ideas by generating grids, the organizer is very good and effective, since it allows you to order from the main topic with its subtopics around it, the diagram always links a relationship with the main topic generating proposals and critical ideas that will be discussed later.

The diagram is analyzed and generated with the type of designs, gates, monitoring systems through sensors and the functionality that it will have, thus generating the following lotus diagram with the main theme of the automatic system, anti-freeze and all the most effective elements that are generated from the sub-themes as shown in the following Fig.3.

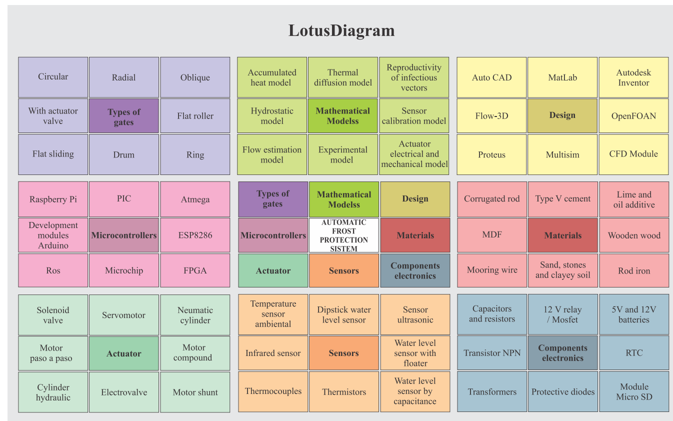

Fig. 3. Lotus Diagram.

The idea organisers provide an overview of the number of functionalities and topics to be covered by the design, which in turn will serve as a guide throughout the life of the project.

C. Morphological Matrix

This methodology was used, since it helps us a lot to be able to decipher what is the best solution to the problem that we are having, a very effective technique is used to present many solutions through the established parameters creating a morphological box where the combinations are made and thus determining the most suitable solution to develop the most appropriate way to develop the problem posed.

Likewise, the morphological matrix is very useful to perform an optical and adequate conceptual scheme, it supports engineers to be able to solve types of uncertainties that they have because the initial stage of their design is not the most appropriate and more suitable designs are generated in which when using the combinations of these types and stages of designs through the correct evaluation having a much clearer approach thus achieving to meet the objectives set out having a much clearer approach [12].

As part of the design from the functions and solutions, the use of the morphological matrix was made, from which four possible solutions are obtained for the system that is proposed to be implemented.

Therefore, the morphological matrix is elaborated to be able to choose the best components to be used for the elaboration of the automatic frost control *camellones* system, divided by the nine functionalities and the components that are more adapted to the type of solution that we want to realize as show below in Table I.

TABLE I. MORPHOLOGICAL MATRIX

N	Functionalities	Function carriers			
		1	**2**	**3**	**4**
1	**Type of gate**	Conventional 🔵	Radial 🟢	With solenoid valve 🔴	Circular 🟡
2	**Floodgate sealing system**	Capillary crystallization 🟢	Pore sealing gel 🔵	Flexible mortars 🟡	PVC Edges 🔴
3	**Control system**	ON - OFF 🔴	PID 🟡	FUZZY 🟢	Predictive 🔵
4	**Temperature sensors**	Thermistor 🔵	Thermocouple 🟢	LM35 🟡	DHT11 🔴
5	**Development board**	Arduino Uno 🔴	Arduino Mega 🟢	Arduino mini 🔵	Raspberry Pi Pico 🟡
6	**Programming language**	C++ 🟢 🔴	Python 🟡	Block program 🔵	
7	**Sensor data acquisition**	GSM module 🟢	Wi-Fi module 🟡	Micro SD module 🔵 🔴	
8	**3D model program**	AutoCAD 🔴	Inventor 🔵	SolidWorks 🟢 🟡	
9	**Anti-filtering structure of the windrows**	Earth clay 🟢 🔴	Stones and sand cemented		
10	**Mold for gate concrete**	Conventional 🔵 🟢 🟡	Laser cutting on MDF 🔵 🟡 🔴		

Once the morphological matrix has been generated, combinations are made, looking at and analyzing prices and effectiveness of the component as show in Table II.

TABLE II. SOLUTION BY COLOR

Color	Solution
🔵 Blue	S1
🟢 Green	S2
🔴 Red	S3
🟡 Yellow	S4

a. S1: 1.1 - 2.2 - 3.4 - 4.1 - 5.4 - 6.3 - 7.3 - 8.2 - 9.2 - 10.1
b. S2: 1.2 - 2.1 - 3.3 - 4.2 - 5.2 - 6.1 - 7.1 - 8.3 - 9.1- 10.1
c. S3: 1.3 - 2.4 - 3.1 - 4.4 - 5.1 - 6.1 - 7.3 - 8.1 - 9.1 - 10.2
d. S4: 1.4 - 2.3 - 3.2 - 4.3 - 5.4 - 6.2 - 7.2 - 8.3 - 9.2 - 10.1

Therefore, the combinations are made so that the solution is optimal and valid for the system that complies with the established standards and parameters.

D. Technical and Economic Evaluation

To obtain the best solution from the four solutions, a weighting process was used for each of the solutions, based on project variables to quantify how good each solution is.

The technical and economic evaluation was carried out based on the VDI 2225 methodology which, through the following tables, expresses the criteria used to quantify the feasibility of each of the solutions obtained in the morphological matrix. The morphological matrix of the technical evaluation is obtained as shown in Table III.

TABLE III. THECNICAL VALUE

MECHANICAL DESIGN - PRELIMINARY PROJECT EVALUATION													
TECHNICAL VALUE (X_i)													
Project: Automated system of pre-Hispanic ridges to reduce crop damage due to the extreme weather event of frost.													
p: score from 0 to 4 (Value scale according to VDI 2225) 0 = not satisfactory, 1 = tolerable, 2 sufficient = Good, 4 = Very good (ideal) g: weighted weight according to the importance of the evaluation criteria (from 1 to 5).													
Project variants			Solution 1		Solution 2		Solution 3		Solution 4		Solution ideal		
N.	Criteria	g	p	gp	p	gp	p	gp	p	gp	p	gp
1	Design	4	1	4	3	12	3	12	2	8	4	16
2	Function	3	2	6	2	6	3	9	2	6	4	12
3	Automation	3	2	6	3	9	3	9	2	6	4	12
4	Assembly	4	3	12	2	8	3	12	3	12	4	16
5	Size	4	2	8	2	8	3	12	2	8	4	16
6	Accuracy	3	1	3	3	9	3	9	2	6	4	12
7	Adaptability	5	2	10	2	10	3	15	2	10	4	20
8	Resistance	3	3	9	3	9	2	6	3	9	4	12
Maximum score		29	16	58	20	71	23	84	18	65	32	116
Technical value X_i			0.50		0.63		0.72		0.56		1.00	

From the technical evaluation, the solution that obtains the highest score is the third one, getting closer to the ideal score.

TABLE IV. ECONOMIC VALUE

MECHANICAL DESIGN - PRELIMINARY PROJECT EVALUATION												
ECONOMIC VALUE (Y_i)												
Project: Automated system of pre-Hispanic ridges to reduce crop damage due to the extreme weather event of frost.												
p: score from 0 to 4 (Value scale according to VDI 2225) 0 = not satisfactory, 1 = tolerable, 2 sufficient = Good, 4 = Very good (ideal) g: weighted weight according to the importance of the evaluation criteria (from 1 to 5).												
Project variants			Solution 1		Solution 2		Solution 3		Solution 4		Solution ideal	
N.	Criteria	g	p	gp	p	gp	p	gp	p	gp	p	gp
1	Maintenance	3	2	6	2	6	3	9	2	6	4	12
2	Technology costs	5	3	15	2	10	3	15	2	10	4	20
3	Material	5	2	10	2	10	3	15	2	10	4	20
4	Manufacturing	4	2	8	1	4	2	8	1	4	4	16
5	Accessories	4	2	8	2	8	3	12	2	8	4	16
6	Lifetime	4	3	12	3	12	3	12	3	12	4	16
Maximum score		25	14	59	12	50	17	71	12	50	24	100
Economic value (Y_i)			0.58		0.50		0.71		0.50		1.00	

From the economic evaluation as show in Table IV, the solution that obtains the highest score is the third one, getting closer to the ideal score. Finally, the evaluation diagram de la

Fig. 4 shows that solution S3 coincides with the characteristic line, concluding that it is the most optimal.

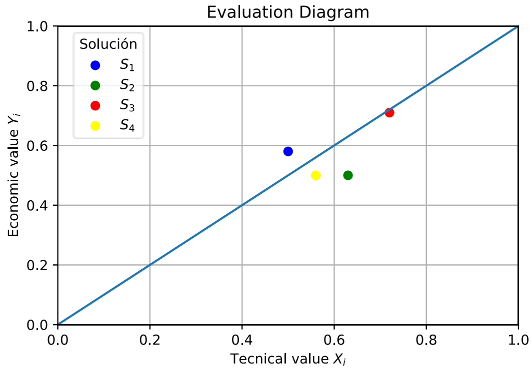

Fig. 4. Technical and economic evaluation diagram.

E. Electronic Design

The proposed solution involves an electronic design based on the Arduino Uno development board and the final actuators, which are the solenoid valves. It is considered that it must be within reach of farmers able to electrically control the opening and closing of these, in turn there is a communication between the sensors, the controller and the modules [13].

The external power supply is provided by a domestic network near the test plot, which through a voltage transformer circuit will supply 5V power for the microcontroller, the DTH 11 temperature sensors and the module for receiving and recording sensor data in a MicroSD module.

Also, the power supply circuit will provide 12V to an actuator circuit designed specifically for the system, which fulfills the function of receiving the control signals, based on interruptions with push buttons of the Arduino Uno, with this reception can activate or deactivate the solenoid valves as shown in detail in Fig. 5.

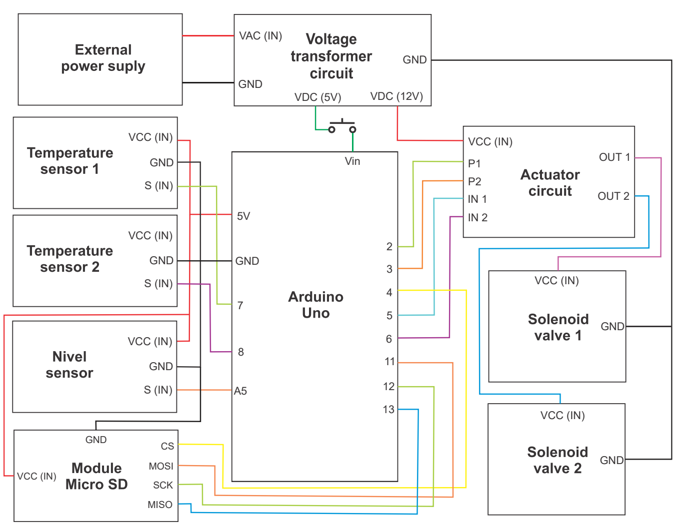

Fig. 5. Electronics design of sistem.

Table V shows the components used for the elaboration of the electronic design, in this case a power supply will be used to obtain the energy, a transformer to regulate the appropriate voltage of the system.

TABLE V. COMPONENT LEGEN

Letters	Components
A	External power supply
B	Voltage transformer circuit
C	Arduino Uno
D	Temperature sensor (1)
E	Temperature sensor (2)
F	Nivel sensor
G	Module MicroSD
H	Actuator circuit
I	Solenoid valve (1)
J	Solenoid valve (2)

A development board which is in charge of controlling the communication between the sensors with the actuators in this case the solenoid valves and finally a MicroSD Module will be used to store the data obtained and as a summary description of each component is shown in Table VI.

TABLE VI. LEGEND AND Description OF Components

Element	Features
External power supply	220V AC power supply.
Voltage transformer circuit	Consisting of a two-winding transformer, diode rectifier, capacitive filter, and direct current regulation.
Arduino Uno	Development board required for its interrupt functions, internal timer, libraries to use the sensors and its data logging.
Temperature sensor (1 y 2)	Thermal sensor DTH11 by thermistor and internal circuit for connection to digital inputs of the Arduino with usual range 0 - 50 °C.
Nivel sensor	It registers the water level in the system.
Module MicroSD	It is a MicroSD memory reader capable of connecting to the Arduino Uno using Serial Peripheral Interface SPI.
Actuator circuit	Composed of transistors, Zener diodes and relays that activate the actuators of the system.
Solenoid valve (1 y 2)	Valve actuated by the magnetic force that originates the passage of current in its solenoid structure.

F. Mechanical Design

This part of the development is focused on designing a solenoidal valve gate system, which fulfills the function of blocking the flow of water for an irrigation canal with control capacity for the user [14]. To obtain a uniform and smooth flow, the use of straightening tubes is considered [15]; this as a viable alternative, it is also possible to opt for a controlled flow system of closing loops [16].

The design of the valve containing gate has as main requirement to be of easy in its setting to the conventional irrigation structures of the locality of the land. Therefore, a concrete design was chosen as shown in Fig. 6. Achieved by a steel frame structure and MDF molds, such molds are obtained by laser cutting. Also shown are the dimensions of the *camellones* whose structure is made of clayey soil abundant in the locality to reduce water losses from the system due to seepage into the subsoil.

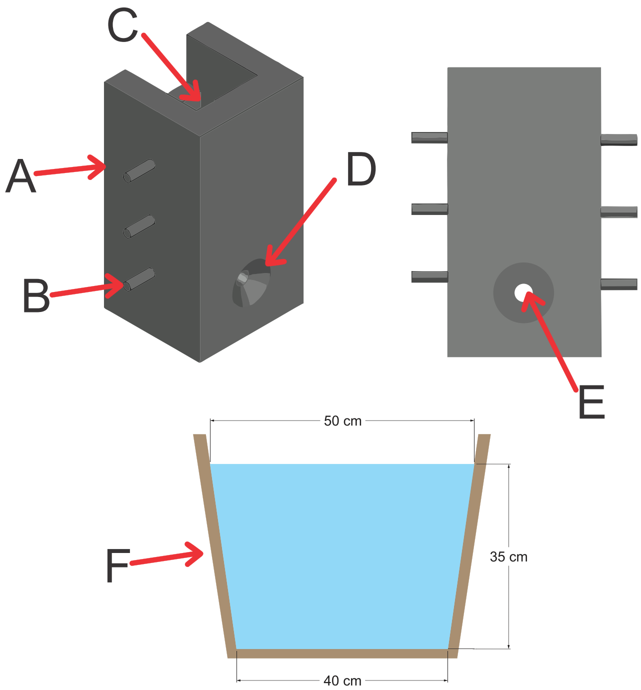

Fig. 6. Mechanical design of gate and *camellones*.

Table VII shows a list of the fundamental parts of the design with a brief description of important features and techniques taken into account.

TABLE VII. PARTS OF THE MECHANICAL DESIGN AND DESCRIPTION

Letters	Parts	Description
A	Gate surface	Waterproofing roofing with PVC blankets.
B	Restraints	These will attach the floodgate to the conventional water inlet of the site.
C	Hollow volume inside the damper	The solenoid valve and piping, water inlet and outlet control actuators are placed in it.
D	Funnel surrounding the orifice	Added to the front of the gate to generate the funnel effect in the water that increases the amount of flow towards the center.
E	Water inlet orifice	From 50.8 mm in diameter, the incoming water passes into the solenoid valve and exits to the *camellones*.
F	*Camellones*, dimensions and structure	These surround the ground and contain the water, with a transverse shape of an inverted trapezoid whose lower base measures 40 cm, upper base 50 cm and height 35 cm.

III. RESULTS

As results obtained, the schematic design is presented based on a modeling in AutoCAD software in Fig. 7. For the estimated experimental plot of 4 x 5 m with two cultivation areas surrounded by the *camellones* that in operation will have a volume of water, 3465 L, the estimated amount of flow during the operation of the valves is 3.4 L/s. Another important result for the research is to obtain a relation of the thermodynamic behavior of the *camellones* system in relation to the volume of water, this relation is shown in Table VIII.

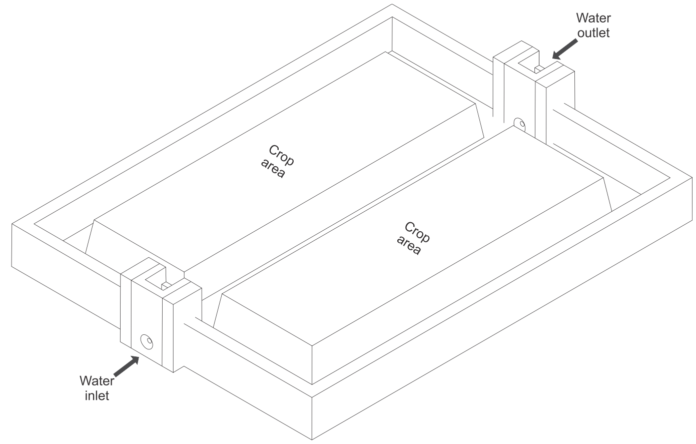

Fig. 7. System design on the field.

TABLE VIII. ESTIMATED THERMAL

	Unit of measurement	Amounts per volume of water in percent				
Water content	%, m^3/m^3	0	20	40	60	80
Thermal capacity	W/mK	0.24	1.39	1.18	0.96	0.85
Thermal conductivity	10 J^{-6}/m^3k	1.26	1.91	2.23	2.75	3.81

From the above table, it can be seen that at 80% of the filling capacity of the *camellones*, which will be the usual average level percentage, an optimum thermal conductivity for heat exchange and a thermal capacity expected with the mathematical model is obtained. A quantification of the temperature gained by the system during the frost phenomenon will require experimental measurements.

IV. CONCLUSION AND FUTURE WORKS

The design of the system of the *camellones* related to flow control, capacity and thermal conductivity is also feasible to execute because it is adapted to the conventional irrigation systems of the rural locality of study**.** An electronic design with easily accessible components, as well as affordable for potential end users, was also achieved.

For future work, an experimental evaluation is performed with the implementation of the electronic and mechanical designs. Also, upon implementation, automation will be sought with all the components mentioned above. In addition, the automated system to be developed will help reduce losses due to crop damage caused by frost in the Andean areas of Peru.

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