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Proposal for an intelligent control system for energy saving in a home automation environment.

Propuesta de un sistema de control inteligente para el ahorro de energía en un entorno domótico.

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Abstract.

Smart grids and their growing application to establish intelligent systems for monitoring energy consumption require the incorporation of proposals in the field of control and electronics. One of the global trends in energy is the use of hybrid generation systems in homes. These consist of the combination of traditional electricity consumption, shared with production models in homes. This entails the need to generate decision-making systems that allow the optimal and real-time combination of owned and commercial energy generation systems. In this way, an intelligent control system was created that allows two energy sources to be combined: a commercial and a domestic one. The objective is to exchange the stored electricity for electricity from the electricity grid in a home automation environment depending on the environmental and consumption conditions. To this end, a database was created consisting of four attributes: current consumption, percentage of load of the storage system of the non-commercial system, presence of sunlight, wind speed, feedback of the status of the previous output. In the output you have a class with two values: non-commercial system connection and commercial network connection. Different models of decision-making tools were evaluated, and it was obtained that the best performance in the tests was given by an Artificial Neural Network (ANN) trained through supervised learning. The result is an intelligent system that allows the power supplies of a house to be intelligently switched and that is typical of smart grids that were evaluated in a simulated environment and then implemented in a physical system.

Key words: Artificial neural networks, home automation, smart networks, intelligent control.

Introduction.

The technological advancement in Smart Grids and power generation systems, as well as the relationship they have with home automation, allow us to visualize a new panorama in the global electricity industry. The idea is to ensure the continuous energy supply in homes with the highest possible quality. Smart grids seek to create mechanisms for monitoring and controlling the variables of electricity grids (Dewangan, Abdelaziz, & Biswal, 2023). This allows the incorporation of emerging technology from smart systems with a sustainable perspective and the transition to renewable energies (Khalid, 2024).

This concept can be integrated into household electricity grids where there is a need to guarantee the supply of electricity continuously and with the highest possible quality. In such scenarios, the possibility of combining commercial energy sources with some on-site production sources is considered (Rangarajan, et al., 2023).

Therefore, the design and implementation of control systems that allow the combination of both sources of energy production is required. That is, systems that allow the exchange of power sources considering the consumption conditions of households, as well as the environmental conditions that participate in domestic energy production systems.

Smart grids are a case of application of the technological advances that constitute Industry 4.0. In other words, these are cyber-physical systems, which produce data within their operation. But they also make it possible to establish models based on such data and automate different tasks (Amin & Kazmi, 2024).

This last feature makes it possible to visualize the need for energy management system schemes that allow energy efficiency to be maintained while demand changes. It also optimizes costs and energy use to control polluting emissions and allow the operation of hybrid systems (Muqet, Liaqat, Jamil, & Khan, 2023). These systems require data acquisition, transfer, and management stages, as well as decision-making stages, based on the intention, interest, understanding, and commitment of users when adapting to modern technologies (Llanez-Caballero et al., 2023).

These types of monitoring and control systems are based on Artificial Intelligence (AI) tools used for classification such as Bayesian Networks (Hossain & Shah, 2023), Decision Trees (Banerjee & Bhowmik, 2023), Artificial Neural Networks (Khan et al., 2023), Fuzzy Logic (Singh & Annapoorna, 2024), support vector machines (Alassi et al., 2023), among others. Most of these tools are adjusted through databases that reflect knowledge of the environment in which the systems are immersed and in which different variables that model energy consumption is involved (Schreiber et al., 2023).

There are success stories in control systems for smart microgrids to reduce energy consumption costs (Guan et al., 2010). Or the control of electrical loads for the optimal use of renewable energies (Vandoorn et al., 2011). Regarding control systems in smart grid environments, there are several examples. One of them is the prediction of energy stability based on a multilayer artificial neural network (ANN) that receives data from consumers and generators as inputs (Mohsen et al., 2023). The grid can detect different states such as stability, instability, overproduction, overconsumption, and average in an electrical system. Another example is the use of a neural network to control the entry into operation of a power generation system under emergency conditions (Fotopoulou, Rakopoulos, Petridis, & Drosatos, 2024). There is also an artificial neural network employed for centralized monitoring of a set of microgrids that combine different power generation mechanisms and databases with time series (Wesley, Babu, & Kumar, 2024). There is even the combination of different AI tools such as fuzzy logic and proximity-based classifiers that serve to predict the stability of electricity grids and their interconnection with Internet of Things (IoT) systems (Önder, Dogan, & Polat, 2023).

Thus, one of the main open challenges in the field is to create control systems that favor the incorporation of clean energy sources, which have the capacity for autonomy and control for energy management with a vision of integration into grids and micro-grids (Gallegos, Arévalo, Montaleza, & Jurado, 2024). This perspective also includes the rational management of non-renewable energies and the contribution to reducing the impact on the environment of energy production through non-renewable sources (Panzavecchia et al., 2025). In addition, there is a contribution to the improvement of the economy of families (Ogundipe et al., 2024).

The research question that originated this research is: What decision-making structure in the field of Artificial Intelligence can function as a control element of a smart system for the energy management of a smart home?

Therefore, the objective of this research was to design an intelligent system to manage energy consumption in a home, combining a domestic energy production system and the commercial energy system. The system has as its central element real-time decision-making based on an AI tool. To determine the most appropriate classification tool to solve the problem, an experiment was designed where the performance of different options was compared, and the most appropriate one was chosen. The results were validated in a simulated environment and finally an electronic system was built that gives physical support to the proposed intelligent energy management system.

This article presents an introduction to the problem in the first section. The second shows the details of the proposed solution. The third section presents the results. In the fourth section, the contribution of research and its relationship with existing literature is discussed. Finally, the last section details the conclusions of this research.

Proposed solution.

The aim of the research was to design an intelligent energy management system contained in an electronic development board. This system must be operated in a home to ensure electrical connectivity between two generation sources: the commercial grid and a local production system. The system must have the capacity for autonomy for decision-making and communication capacity to transmit data and communicate with the user.

In this way, a system was proposed in four sections: Perception, communication, administration, and control (see figure 1). The perception sub-system is made up of all the sensors necessary to measure energy consumption, the percentage of the accumulator where the energy produced by a photovoltaic and a wind system is stored, the solar light intensity, the wind speed and the information of the energy generation scheme connected to each calculation that works as a kind of feedback. An IoT communication model was used to send data using Wi-Fi and a local area network.



Figure 1. System signal flow: The sensors send measurement information to the perception subsystem, which pre-processes the data. This information is then sent by the communication subsystem (IoT) to the manager. The manager receives the data and uses an ANN to make real-time decisions. The output returns to the control subsystem via the communication system. The control subsystem then adjusts the signal to the final actuator.

The communication sub-system allows the exchange of data between the system's sensors and the management sub-system. In the same way that it allows the flow of information from the administrator to the final control elements. In addition, it allows the user to remotely control the autonomy of the control system. It is also responsible for sending reports through a mobile application and an SMS message scheme. To do this, it uses an interface in the form of a mobile application made in MIT App Inventor 2. The interface allows the user to manually select between the commercial power grid and the home power production system. In addition to receiving reports on the operation of the system and the times in which each of the systems was interconnected (commercial and domestic). There is also interconnection with a communication

system based on the XBEE protocol, so that in the event of failure of the SMS module, it allows remote control of the system.

The management subsystem is responsible for the preprocessing of the measurements as well as for calculating the output of the intelligent control element. To this end, four feedforward (multilayer perceptron) artificial neural network architectures were evaluated: two layers, three layers, four layers, five layers. All control schemes were trained in Weka using a database of 152 instances created by the system's operating conditions (see table 1). A Cross validation ten folds was used and the AI tool with the best performance in the classification of the database was chosen.

Table 1. Database Organization. It contains the variable name, the data type used (attribute - input or class - output) and the number of possible values for the attributes or class.

Variable	Type	Values
Solar radiation	Attribute	3: Absences, Low, High
Wind intensity		3: Absences, Low, High
Battery level		3: Low, Medium, High
Power consumption		3: Low, Medium, High
Feedback		2: Commercial, Domestic
Energy source	Class	2: Commercial, Domestic

The control sub-system allows the interconnection of the two energy supply schemes. The information is delivered through the communication sub-system to a set of solid-state relays that allow the interconnection of the power stages. This proposed system was evaluated in the Simulink computing environment, where the operation of the entire database was verified (see figure 2). A communication scheme based on the software's data bus was used in the simulation, as well as programming blocks to simulate information processing. Finally, it was taken to an Arduino Mega ADK card where the final functional tests were conducted.

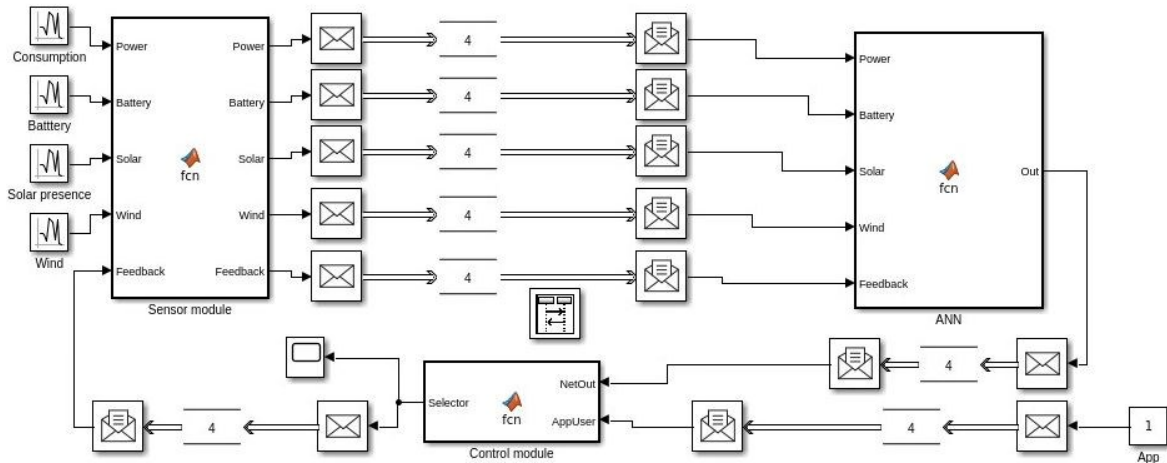


Figure 2. Evaluate environment in the simulation. Made up of the control, communication, sensing, and control modules. In addition to connectivity from the APP.

Results.

The process to select the most appropriate ANN structure to make decisions in the environment where the system operated showed that all the networks evaluated had the highest classification percentage during the cross-validation stage (see figure 3).

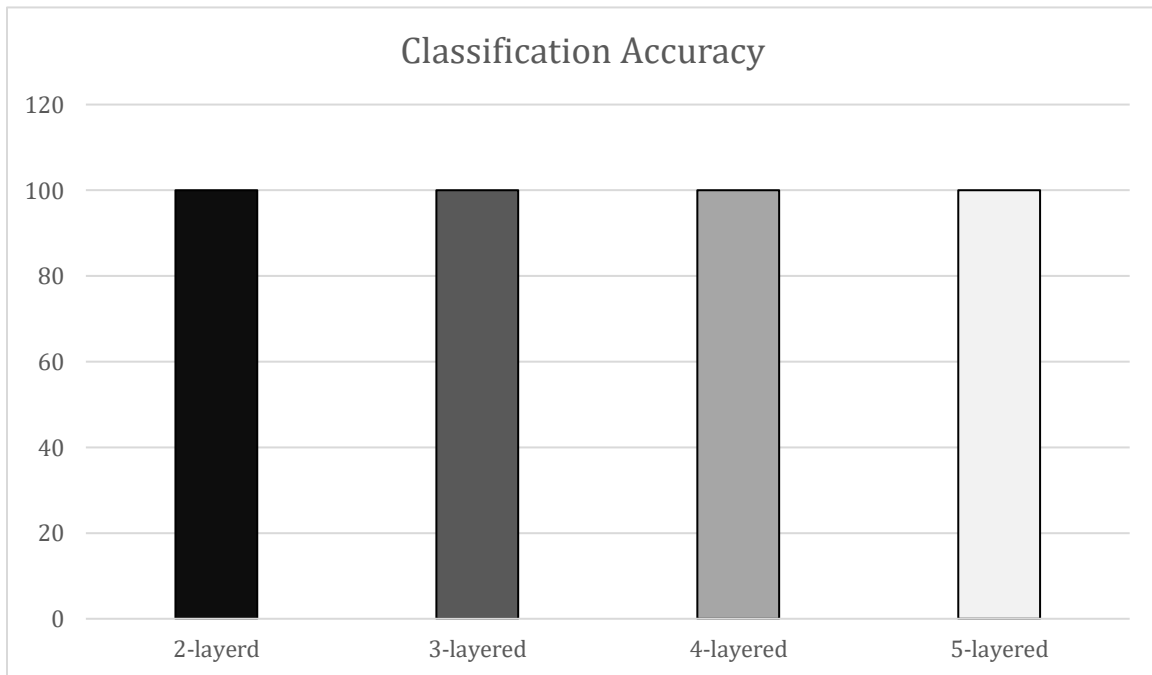


Figure 3. Classification of trained artificial neural networks. The classification accuracy for the four ANN models tested was the maximum possible in validation stage. Therefore, it was decided to use the simplest model to reduce the size of the final program.

For this reason, the simplest network was chosen, in this case the one with two neurons in the input layer (see Figure 4). This reduces the size of the code on the Arduino card.

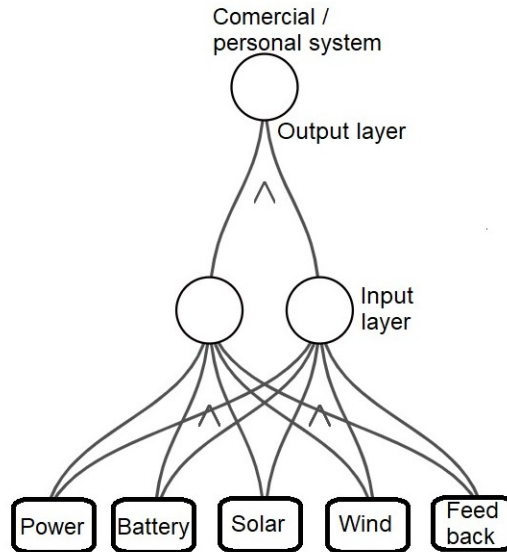


Figure 4. Artificial neural networks are used as a control element of the solution. A two-layer reactive network was used. The neurons in the input layer receive information from the four sensors and feedback. The output layer determines whether the household's energy consumption is connected to the commercial grid or to the domestic energy production system.

The size of the final program was 7,386 kB, which included the information acquisition and processing mechanism, as well as the ANN and communication mechanism. Once the network was programmed, the prototype of the system was built, which included the Arduino card, the RF, and SMS communication extensions, as well as the XBee transmission module (see figure 5). The system operates in real-time, performing a processing cycle every 50uS. The cost of the physical implementation of the complete model is around \$100 USD.

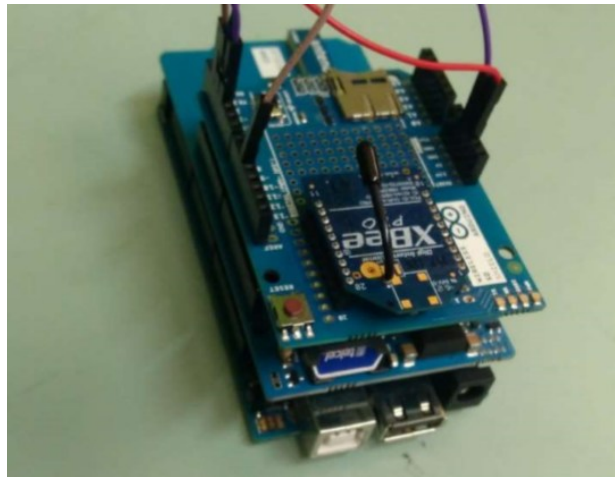


Figure 5. Electronic prototype of the control system. The system is based on an Arduino Mega ADK board. It also features a GSM module that allows it to interact with the user via SMS, and a XBEE module for connecting devices and the Internet extension.

The size of the application is 171 kB, compatible with mobile devices of the Android operating system (see figure 6). The application made it possible to manually select, when necessary, the source of electrical current flow in the home, in addition to requesting and

visualizing the data from the system in the form of a 24-hour report. The selected communication model (SMS) avoids network latency problems and update restrictions of MQTT servers used in this type of development.

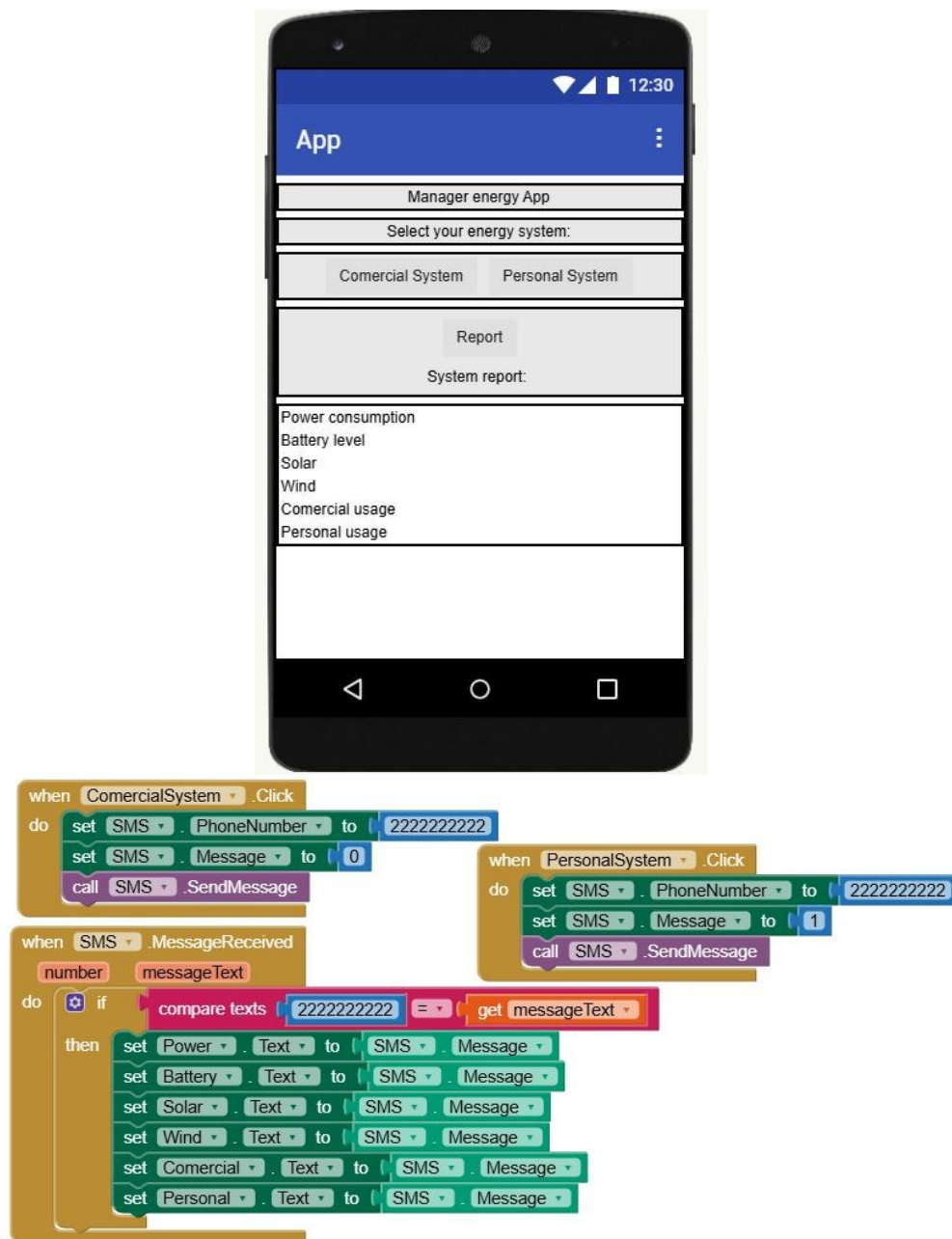


Figure 6. Mobile application for monitoring the proposed system. The application was programmed in MIT App Inventor 2. It can exchange information with the communication subsystem using SMS messages.

Discussion.

The design and construction of a control system for a smart micro-grid that allowed the control of the flow of electrical energy that powers a home is presented. Unlike other solutions that use expensive algorithms for energy management based on fuzzy logic and multi-objective optimization (Mohammadi, Shakouri, & Kazemi, 2022), (Jafari, Malekjamshidi, Zhu, &

Khooban, 2018), (Mansouri, et al., 2021), the designed solution is low cost and low computational complexity, which can be integrated into home automation systems. It incorporates clean energy production schemes, which is a desirable feature of smart grids (Hussaian Basha, et al., 2024). This has the consequence of reducing the cost of the bill, if the domestic energy generation systems are functional in the climatic conditions of the locality.

One of the advantages of this system is that it can be adapted to various power generation mechanisms as is desirable in smart microgrids (Vincent, Le & Gupta, 2022). This can be done by adding or changing the monitored environmental variables and a neural network retraining process. To this end, it is necessary to conduct a knowledge engineering process that classifies all the possible circumstances to which the control system may be subjected, which has been proposed in other similar solutions (Lee, et al., 2023). This provides assurance that the response of the neural network is adequate in each case.

Another advantage of using the proposed system is that the number of sensors is lower than similar devices (Chacón et al., 2017), where they are proposed to monitor the different loads found throughout the house. This makes the initial investment higher and therefore makes the installation more expensive. Which does not occur in the solution system. In addition to the fact that instead of deactivating loads and depriving the use of said device, it makes an exchange of where it is convenient to supply all the loads in the house (Bharti, Singh, & Singh, 2022).

The model presented uses environmental variables for decision-making. But it also incorporates two important variables that make the system operate as a closed loop. The percentage of the battery or accumulator works to know if there is stored energy that can be consumed by the home. Therefore, low battery levels imply the use of current from the commercial connection. The other feedback variable is the previous decision made by the system, which functions as a short-term memory that allows the stabilization of decision-making at operating points where it can be easily switched between the two power supply options. If the system identifies that continuously changing feed flow does not improve the response of the system, it can be maintained for a longer period in the same state. That is, it incorporates mechanisms of consumption history into the system's decision-making as in other energy management schemes (Bolurian, Akbari, Mousavi, & Aslinezhad, 2023).

From the point of view of control engineering and feedback control, the choice of an artificial neural network implies shorter response times than other types of controllers such as fuzzy. And it represents an improvement over traditional control architectures such as PID, since an ANN allows the use of more than one input to power the controller (Molina-Garrido, Aldana-Franco, Camarillo-Montero & Aldana-Franco, 2026).

The proposed system incorporates the use of communication with the user. This through a mobile application and a couple of Arduino modules (Android and Wireless). This allows the system to operate autonomously but does not rule out the option of making it work manually. This provides greater security for users. In addition, a mechanism was incorporated that allows receiving reports via SMS of the last 24 hours of operation of the system at the request of the user. Therefore, energy consumption can be monitored at various times and with this information the operation of the system can be complemented.

Among the main limitations of the proposed model is that now it does not consider the latency of the network to interconnect the application, the control card and the elements of action. This is an important variable in Internet of Things systems, as it regulates speed of communication. However, when working with an SMS-based system, the system's latency is linked to the service provider's communication network. In addition, the Internet of Things connection system used

avoids the use of intermediate servers because it establishes direct communication between the modules.

Conclusions.

The proposal of the designed solution can be applied to a smart microgrid home automation environment as it is a solution for the automation of energy management. The tests conducted demonstrate the ability of artificial intelligence tools to manage this type of control scheme. The training was conducted using a database created through knowledge engineering on the different circumstances in which the system is immersed. These variables can be environmental or system state and can be easily extended in the event of system modifications or additions.

The system has the advantages of using few sensors that do not have an excessive cost. In addition, it uses the Arduino system with its modules at low costs. The estimated cost of the system (USD 100) is lower than some commercial options that cost around USD 900. However, it's important to note that our system does not include the power stage associated with the inverter. Another advantage is the option of manually monitoring and controlling the system through a mobile application.

The control proposal can be reconfigured and allows the energy sources with which it operates to be exchanged. In the test example, a solar and a wind power source were used. But it can incorporate any energy source through sensors. This operation forces the database to be modified through knowledge engineering and to retrain the network. Resulting in an uncomplicated process.

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Claro. Aquí están las referencias sin numeración, manteniendo las correcciones en APA 7:

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