

Experimental Study for the Development of a Wireless Communication System in a Solar Central Tower Facility

Victor H. Benitez, Ramon V. Armas-Flores, Jesus H. Pacheco-Ramirez

Abstract—Systems transforming solar energy into electrical power have emerged as a viable source of clean, renewable energy. Solar power tower technology is a good example of this type of system, which consists of several mobile mirrors, called heliostats, which reflect the sun's radiation to the same point, located on top of a tower at the center of heliostat field, for collection or transformation into another type of energy.

The so-called Hermosillo's Solar Platform (Plataforma Solar de Hermosillo, PSH, in Spanish) is a facility constituted with several heliostats, its aim and scope is for research purposes. In this paper, the implementation of a wireless communication system based on intelligent nodes is proposed in order to allow the communication and control of the heliostats in PSH. Intelligent nodes transmit information from one point to another, and can perform other actions that allow them to adapt to the conditions and limitations of a field of heliostats, thus achieving effective communication system.

After deployment of the nodes in the heliostats, tests were conducted to measure the effectiveness of the communication, and determine the feasibility of using the proposed technologies. The test results were always positive, exceeding expectations held for its operation in the field of heliostats. Therefore, it was possible to validate the efficiency of the wireless communication system to be implemented in PSH, allowing communication and control of the heliostats.

Keywords—Solar energy, heliostat, wireless communication, intelligent node.

I. INTRODUCTION

IN recent decades, solar energy systems have emerged as a viable source of clean, renewable energy, so its use in domestic and industrial applications is growing. The function of these systems is to collect energy from the sun and to transform it into another type of energy, such as electrical or thermal [1]. An example of a transformation system for solar energy to thermal energy is the solar power tower technology, which consists of several mobile mirrors, called heliostats, which reflect the sun's radiation directly to a single point, located at the top of a tower that is at the center of the heliostat field. At this point, components inside the tower, convert the solar energy into heat and then into electricity [2].

Due to the abundance of solar radiation that exists in the region, the University of Sonora, along with other institutions,

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conducted a project where the Plataforma Solar de Hermosillo (PSH, formerly known as heliostats field tests) was built [3]; the PSH is located in the city of Hermosillo, Sonora, Mexico. This research facility accounts with a growing number of heliostats developed by the same University and other research institutions and a central tower for power generation pilot and prototype testing (Fig. 1).



Fig. 1 Hermosillo's Solar Platform

PSH is an infrastructure that allows the evaluation of heliostats applied to solar power generation plants based on central tower technology. Its main objectives are [4]:

- Encourage the formation of a national network of researchers working on the development of solar concentrator technology
- Form high-level human resources in the area of solar concentration and solar chemistry
- Advance the development of solar technologies, generating scientific and technological knowledge.

Currently the heliostats in PSH lacks the necessary sensors and instrumentation to analyze or determine their performance considering the operation conditions that are present. This represents a problem for the heliostat field performance, because the variables in which they operate are not measured properly, and that may affect the operation thereof, such as temperature, wind speed, humidity, among other variables. Without such information on these factors, the development of technologies, studies, experiments and operation of the units, are compromised, and the development of new technologies is difficult.

The architecture and layout of the network in PSH makes it expensive and practically impossible to incorporate sensors to

the units. In order to make the heliostats' instrumentation, the design of a low cost wireless communication system is proposed, which can transfer information in an efficient way, and that can be implemented in PSH, taking in account all the factors that can interfere with the communication in this location, like: environmental factors, electric interference and noise, interference caused by obstruction, etc.

II. FRAMEWORK

A. Solar Power Tower Technology

Two main mechanisms of capturing sunlight and delivering useful energy have been developed and commercialized: photo-thermal and photovoltaic systems [5]. Photo-thermal systems transform solar radiation in useful thermal energy, while photovoltaic systems are able to produce electricity directly from sunlight.

In photo-thermal systems, the thermal energy collected from the sun can be utilized directly or be transformed in other kind of energy, like electric or chemical energy [6]. Although energy in these systems is generated only during the day, it is possible to recollect and store additional thermal energy [7]. This heat can be used during the night to produce energy.

Solar power tower technology is a type of collector that follows the movement of the sun for the collection of thermal energy. It is useful for high levels of solar radiation. A group of mobile mirrors, or heliostats, is used to reflect solar rays to a common target for its recollection [8]. The target is located on the top of a tower at the center of the heliostat field, where great amounts of thermal energy can be collected to be used or transformed (Fig. 2).

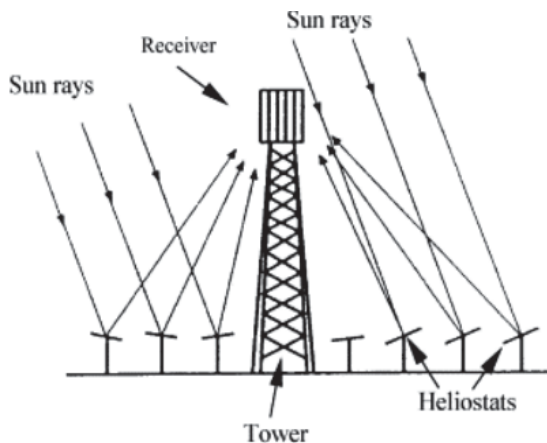


Fig. 2 Scheme of a solar power tower system

The heliostats in a solar power tower system need to move accordingly to the sun trajectory, so they can reflect the sunlight to the same point in the tower at all times. To achieve this goal, the heliostats need sensors and controllers to regulate their movement, which communicate with a central computer that controls them. There are several studies that approach solar tracking problem from different perspectives, to attain the systems' best performance [9]. However, all these

works are only focused on the heliostats' individual control.

B. Wireless Communication Networks

Wireless communication networks have widely developed in recent years, due to its benefits and unique features, such as self-configuration, low cost, easy deployment and multi-hop routing [10]. This kind of network can be used to obtain and distribute information from sensors in real time, process it in collaborative tasks and propagate control signals based on the data and system operation [11].

A Wireless Sensor Network (WSN) is created when multiple sensors monitor a large physical environment in a cooperative manner, using wireless communication [12]. The different nodes in the network communicate with each other, but also communicate with a Base Station (BS) through their wireless radios, allowing them to spread the detected data so it can be processed, viewed, analyzed and stored. In Fig. 3 two different WSN schemes are shown, that are used to monitor separate physical environments, but that are also interconnected via the Internet.

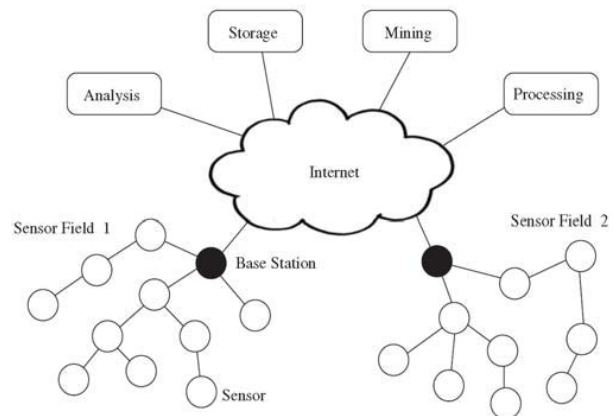


Fig. 3 Wireless Sensor Networks

Intelligent nodes are defined have features or capabilities not only limited to data collection and transmission, but can also perform other processing tasks or other actions [13] and [14]. According to this definition, the implementation of a communication network with intelligent nodes is an option that can be considered to be implemented in a field of heliostats, to enable effective communication and control of the system.

C. ZigBee

ZigBee is one of the most currently implemented wireless technologies. It is a communication technology designed based on the IEEE 802.15.4 standard, in order to be used for wireless control and sensor networks. The name ZigBee comes from the zigzag movement that bees make to communicate with others in the hive [15].

ZigBee is one of the most widely used wireless communication standards with low power, low data rate, low cost and short time delay in communication [16]. Some of the advantages of using ZigBee are:

- Reliable and self-healing mesh
- Supports large number of nodes
- Easy to deploy
- Very long battery life
- Secure
- Low cost
- Can be used globally
- Open standards protocol with no negligible licensing fees
- Remotely upgradable firmware
- Low power (ability to operate on batteries measured in years)
- Low maintenance (meshing, self-organizing)

In Fig. 4 the different radio bands that ZigBee can use are shown, as well as some of its specifications [17].

Variant	2.4 GHz	868 MHz	915 MHz
Frequency Band	ISM		ISM
Location	Worldwide	Europe	Americas
Transfer Rate	250 kbps	20 kbps	40 kbps
Channels No.	16	1	10

Fig. 4 ZigBee baseband variants

The devices in a ZigBee network can take three different roles that determine the tasks they perform [18]:

- *Coordinator* is in charge of coordinating the network, so there can be only one coordinator in each ZigBee network. It is responsible of initializing the network and choosing its parameters, such as the channel, network ID, among others. It can also store network information, like security keys.
- *Router* is a configuration that can act as a coordinator. It works as an intermediate node, acquiring and passing on information to other devices. A router can connect to an existing network, accept connections from other devices and can be used to extend a ZigBee network.
- *End device* has the least memory size and fewest processing capabilities and features. It is usually in charge of recollecting information from sensors and switches. It has enough functionality to communicate with the devices that control it (router or coordinator), but can't give information to other devices.

III. NODE DESIGN

The first step in designing a wireless communication system for the heliostats of PSH was the analysis of the different types of technologies that could be implemented. Taking into account the characteristics and limitations that are present in the heliostat field, the ZigBee wireless communication technology was the one chosen for the project. This is due to the various advantages provided such as low cost, ease of implementation and robustness, also because of ZigBee's

transmission ranges which can go from 100 meters to several hundred meters in open space, depending on the model used, which is more than enough to meet the needs of the field.

ZigBee has a very low interference with WiFi technology [19], which is present in PSH. The heliostats can cause a noticeable interference or obstruction of wireless communication, which can be solved with ZigBee's multi-hop routing. These are some additional reasons why we opted for the use of this technology for the design of the nodes to the communication system.

The Arduino IDE environment was selected with ZigBee for the nodes design. This was due to the ease with which both technologies can be integrated, their ease of access, and the characteristics and processing capabilities of the Arduino microcontroller, which can meet the requirements to be taken into account in the field.

Based on the selected technologies, and taking into account the resource constraints for this project, the following devices were selected for the development of the communication nodes:

- *Arduino UNO*: The microcontroller used is the ATmega328. Arduino UNO is a microcontroller board that operates on this microcontroller and allows its use in a simple manner, because it contains all the necessary elements so it can be used quickly.
- *XBee S2 Module*: This is the XBee XB24-Z7WIT004 module produced by Digi International, which belongs to the second series of ZigBee. It has a better hardware than the first series, and is designed for larger wireless networks, improving the power output and data protocol over previous versions. These modules allow a very reliable and simple communication between microcontrollers, computers and any device with a serial port.
- *Arduino XBee Shield*: The XBee Shield for Arduino allows the Arduino environment to communicate wirelessly using ZigBee. This device allows easy integration of the Arduino UNO with the XBee S2, since it can be used as a replacement of the serial / USB port that is required for ZigBee radio configuration. It also includes sockets that allow the use of various outputs provided by the Arduino UNO, enabling better use of the microcontroller.

The designed nodes were implemented, after integrating the described technologies (Fig. 5), and then tests were performed to determine their effectiveness.

IV. IMPLEMENTATION

To perform tests to the designed nodes, the X-CTU and Arduino software were used, for the measuring of wireless signal intensity and for programming the microcontrollers respectively.

Different tests were performed on the heliostat field, in order to show whether the technologies selected for the nodes could be used without being affected by the interference of the heliostats or information transfer distances.

A diagram of the heliostats distribution in PSH is shown in

Fig. 6.



Fig. 5 Node for communication system

A. First Test

Firstly, a simple test in which 100 data packets were sent between two nodes, positioned at an increasing distance between the heliostats, was performed to determine the distances in which communication is effective, and observe the behavior of interference caused by the heliostats.

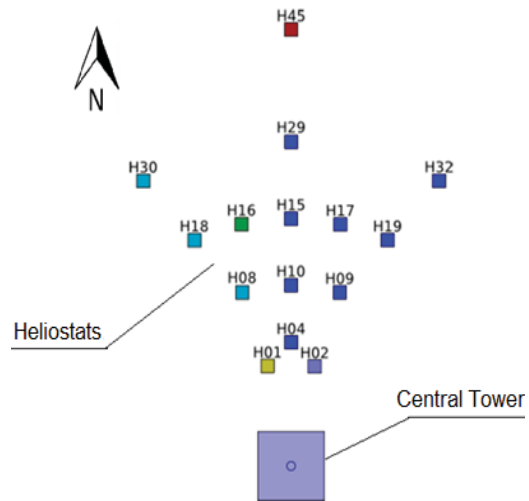


Fig. 6 Heliostats distribution in PSH

The intensity of the wireless signal between nodes was measured by means of the Received Signal Strength Indicator (RSSI), as well as the packet error rate, i.e. the percentage of packets sent between nodes successfully. The X-CTU software was used for this, as shown in Fig. 7.

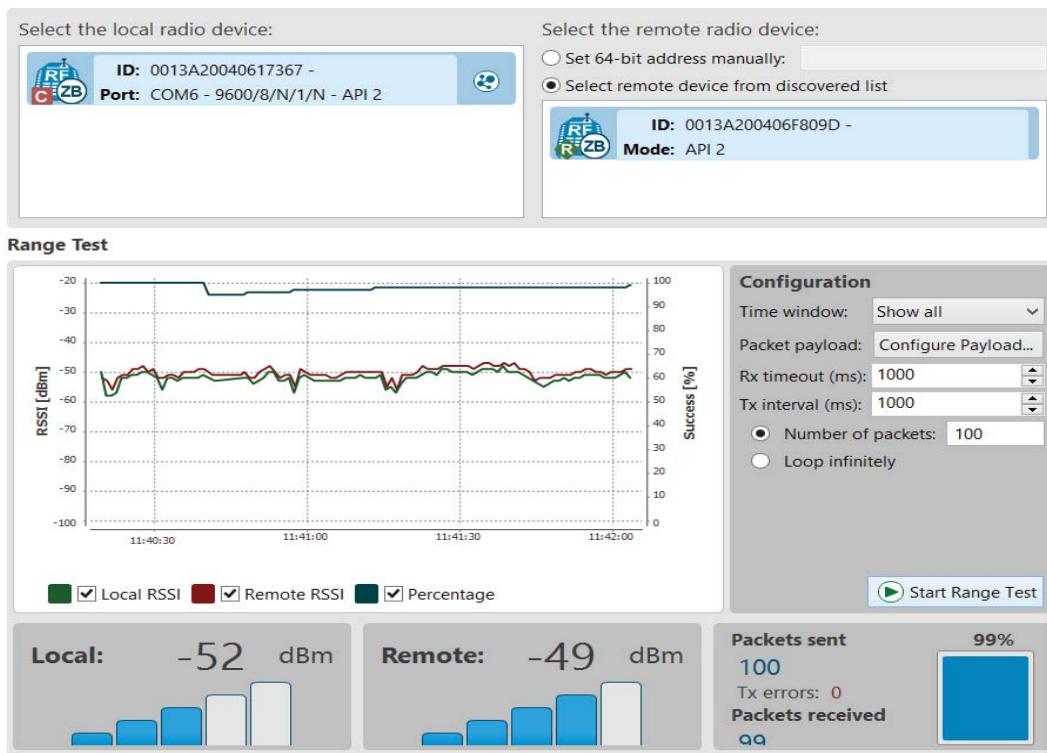


Fig. 7 Software X-CTU

In the results obtained in this test, the levels of signal strength and packet error rates were always very close to one hundred percent, indicating that the nodes used were able to establish communication between the heliostats in the field.

The heliostats consist of large mirrors placed on steel structures, so they were expected to cause a noticeable obstruction or interference in the transfer of wireless signals. However, since the realization of the first test, it was noted

that the ZigBee technology was strong enough to establish wireless communication in PSH, unaffected by the heliostats, which greatly facilitated the implementation of the communication system.

B. Second Test

In the second test the microcontroller was added to the nodes, in order to test the data transfer from this device using ZigBee. A test similar to the previous one was performed, transmitting information between two radios and separating them increasingly. One of the nodes was placed outside the control room (CR), which is located on one side of the central tower, and from which the operation of the heliostats is monitored, while the second node was placed at an increasing distance towards the heliostats we intended to communicate (Fig. 8).

The objective of this test was to control a servomotor in one node from the other via a PWM signal. This allowed testing the communication with a higher amount of data transfer, while observing the presence of noise in the communication that could affect system performance.

It was possible to establish an effective communication and control of the motor through the nodes used, between the CR and the heliostat H01, which represents a distance of over 50 meters between nodes. Beyond this point, communication was lost or was less stable, which was useful to determine the communication capabilities of the designed nodes.

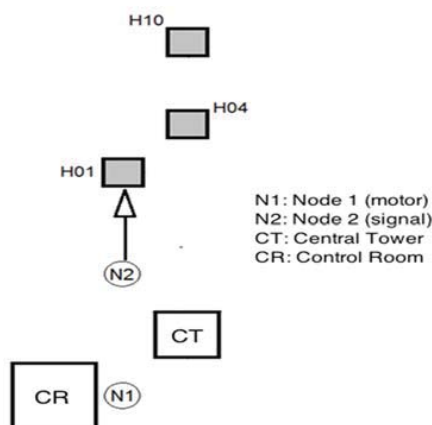


Fig. 8 Node location for second test

C. Third Test

The next step in testing the effectiveness of the nodes was to add another node to the system, in order to increase the transmission distance capabilities. This third test was similar to the previous one, controlling a servomotor with a signal generated from another node, with the only difference being the addition of a new node, placed north of the other two (Fig. 9).

The first two nodes were located in the same positions as the previous test results, using the greatest distance at which effective control of the servomotor was held. The third node was placed at an increasing distance towards others heliostats. The motor control was established between the farthest nodes,

while the middle node transmitted the signal between them.

When deploying the nodes this way, it was observed that the distance at which effective control of the servomotor was held increased significantly, much higher than it was with only two nodes, since it was possible to establish communication between the CR and the heliostat H15, which represents a distance of almost 100 meters. These results showed that the implementation of several nodes with ZigBee technology is a viable option for establishing a wireless communication system in the PSH facility.

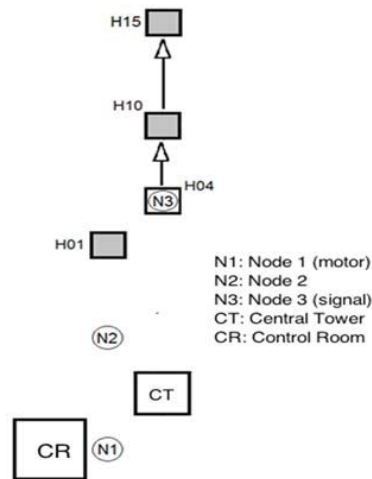


Fig. 9 Node location for third test

D. Final Test

The results of the preliminary tests served to validate the effectiveness of the proposed communication system, so it was possible to carry out tests where the heliostats' motors were controlled and receive feedback from them, showing that a communication and control system was achieved that allows the transfer of information from sensors and actuators between the heliostats and the CR.

Fig. 10 shows the way in which this test was performed. The nodes placed in the H04 and H10 heliostats controlled servos, based on a signal from the node in the CR. The motors were instrumented with sensors that measured the position they were in, to send this information to the control room, so it was possible to control and monitor the motors from this place.

The communication was delimited to these two heliostats due to limitations in resources had for this project; however, this was enough to demonstrate the effectiveness of the proposed system

The results of this test can be seen depicted in Fig. 11. These graphs show the data obtained from the first node, where it is shown how the movement of each motor varied, compared with the control signal that was sent from the first node.

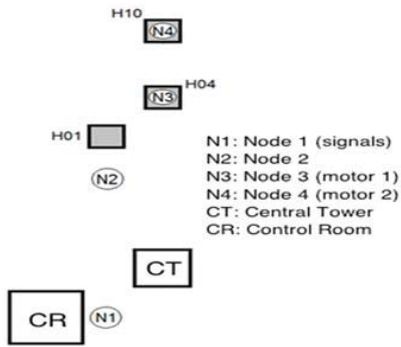


Fig. 10 Node distribution for final test

As shown in the graphics the motors moved as it was expected, according to the control signal sent to them. This is due to that, as seen in preliminary testing, no data is lost in the communication between nodes placed as was done in this test. It is also shown that there is a delay between the data signal and the position. The cause of this is the way the nodes of the system were programmed. The data in the graph was obtained from the first node, which was programmed to read the feedback value of the motors just after sending the value of the position to which they should move next, i.e. the value read is the one from the previous position, not the new one, because this signal has not yet reached the motor.

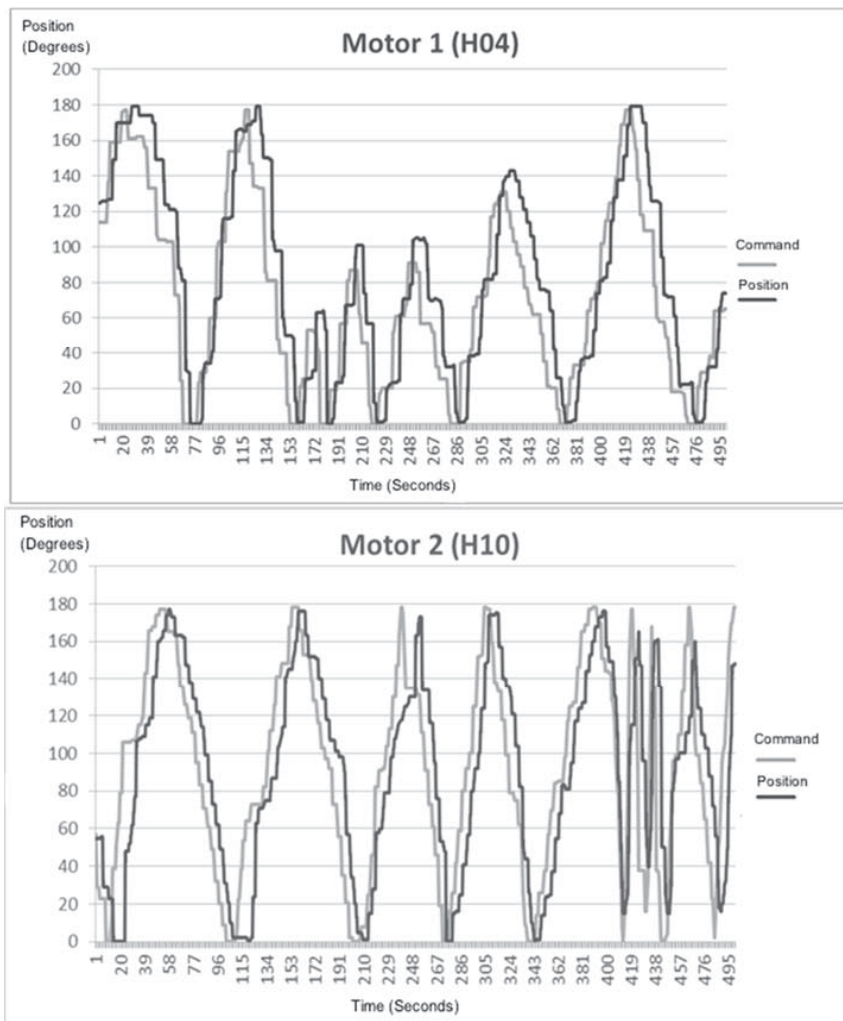


Fig. 11 Motors movement compared to the control signal

The other reason for the shift between signals is the time the motor takes to move to the desired position after receiving the control signal, so the value obtained from motor position is time delayed. These results are satisfactory for the project, since they show that it is possible to control the movement of motors located in the heliostats from the control room through

wireless communication. All this in compliance with the operation requirements of the heliostats, since they don't require a high speed motion and the information transfer of the system is sufficient for implementation in the field, for control and communication purposes.

V. CONCLUSIONS

This research was conducted in PSH, so that this facility can continue to improve and to continue with the research related with the development of solar technologies and skilled human resources.

A proposal was made for the implementation in PSH of a wireless communication system that can be used in the field, to improve the operation and to collect data related with the performance of the heliostats. The use of intelligent nodes was proposed because these can meet the communication and control capabilities that are intended to implement in the field.

Once the proposed methodology was implemented, the objectives set at the beginning of this work were achieved, since it was designed, implemented and validated a wireless communication system that meets the requirements of the heliostat field, and also validate the posed hypothesis. Therefore, it can be concluded that the communication system based on the selected technologies can be implemented in PSH for communication and control of the heliostats.

The development of this work opens the door for future research and projects that could be carried out in PSH. Future research work may be to take the same methodology proposed in this document, and apply it to the other heliostats in the field. This methodology can also be applied in other heliostats fields, adapting it to the specific characteristics of each one.

REFERENCES

- [1] Chia-Yen, L., Po-Cheng, C., Che-Ming, C. y Chiu-Feng, L., 2009. Sun tracking systems: a review. *Sensors (Basel, Switzerland)*, 9(5), pp.3875–90.
- [2] García-Sobrinos, G., Salvador-Villa, I. y Serradilla-Echarri, J., 2007. Tower of power. *Civil Engineering (08857024)*, 77(October), pp.42–50.
- [3] LACYQS, 2011. Campo de Pruebas de Heliostatos (CPH). (Online) Disponible en: <http://lacyqs.cie.unam.mx/es/index.php/instalaciones/campo-de-pruebas-de-heliostatos>.
- [4] Iriarte-Cornejo, C., 2013. Automatización de Sistema de Control para Campo de Heliostatos. MC. Instituto Tecnológico de Chihuahua.
- [5] Mojiri, A., Taylor, R., Thomsen, E., Rosengarten, G., 2013. Spectral Beam Splitting for Efficient Conversion of Solar Energy - A Review. *Renewable and Sustainable Energy Reviews*, 28, pp.654–663.
- [6] Weinstein, L., Kraemer, D., McEnaney, K., Chen, G., 2014. Optical cavity for improved performance of solar receivers in solar-thermal systems. *Solar Energy*, 108, pp.69–79.
- [7] Krothapalli, A., Greska, B., 2012. Solar Concentrators. En: Chen, W. Y., Seiner, J., Suzuki, T., Lackner, M., ed. *Handbook of Climate Change Mitigation*. Springer US, pp.1263–1294.
- [8] Kalogirou, S. A., 2004. Solar thermal collectors and applications. *Progress in Energy and Combustion Science*, 30(3), pp.231–295.
- [9] Her-Terng, Y. y Chieh-Li, C., 2011. Fuzzy sliding mode controller design for maximum power point tracking control of a solar energy system. *Transactions of the Institute of Measurement and Control*, 34(5), pp.557–565.
- [10] Kamal, A.R.M. y Hamid, M.A., 2013. Reliable data approximation in wireless sensor network. *Ad Hoc Networks*, 11(8), pp.2470–2483.
- [11] Lim, A., 2010. Smart Sensor Networks. En: V. Cutsuridis, A. Hussain y J.G. Taylor, eds. *Perception-action cycle models, architectures and hardware*. Londres : Springer, pp.675–609.
- [12] Dargie, W., Poellabauer, C., 2010. Motivation for a Network of Wireless Sensor Nodes. En: Shen, X., Pan, Y., ed. *Fundamentals of Wireless Sensor Networks, Theory and Practice*. Reino Unido: Wiley, pp.3–15.
- [13] Sachenko, A., Kochan, V., Turchenko, V., Tymchyshyn, V., Vasylykiv, N., 1999. Intelligent Nodes for Distributed Sensor Network. En: IEEE, *Instrumentation and Measurement Technology Conference*. Venecia, 1999.
- [14] Yen Joe, Y., Khuen Ho, W., Wee Lim, K., Qiang Ding, Z., Bing Zhang, J., Voon Ling, K., Romagnoli, J., 2006. Clustering Intelligent Sensor Nodes for Distributed Fault Detection & Diagnosis. En: IEEE, *International Conference on Industrial Informatics*. Singapore, 16-18 de agosto 2006.
- [15] Kühner, J., 2009. *Wireless Communication*. En: *Expert .NET Micro Framework*. Apress, pp.203-208
- [16] Ramya, C. M., Shanmugaraj, M., Prabakaran, R., 2011. Study on ZigBee technology. En: 3rd International Conference on Electronics Computer Technology (ICECT). Kanyakumari, India, 8-10 de abril 2011. IEEE.
- [17] Ondřej, S., Zdeněk, B., Petr, F., Ondřej, H., 2006. ZigBee Technology and Device Design. En: International Conference on Networking, International Conference on Systems and International Conference on Mobile Communications and Learning Technologies. 23-29 de Abril 2006, IEEE.
- [18] Farahani, S., 2011. *ZigBee Wireless Networks and Transceivers*. Newnes.
- [19] Howitt, I., Gutierrez, J. A., 2003. IEEE 802.15.4 Low Rate –Wireless Personal Area Network Coexistence Issues. *Wireless Communications and Networking*, 3, pp.1481-1486.