

# IoT applied to irrigation systems in agriculture: A usability analysis

## IoT aplicado a sistemas de riego en agricultura: Un análisis de usabilidad

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**Abstract.** The Internet of Things favors using technological tools in rural environments thanks to the ability to connect to the Internet between devices that facilitate daily tasks. The research aims to evaluate the usability of the decision support system for irrigation in agriculture, AgroRIEGO, through the development of an IoT-based device. The sponsors of this project were the Ministry of Information and Communication Technologies and the Center of Excellence in the Internet of Things Appropriation (CEA-IoT) in Colombia. Among the methods used is the use of the heuristic evaluation technique, structured into 15 categories and 62 subcategories of assessment. This analysis was complemented by the contribution of a group of experts in the design and development of IoT applications and devices and agriculture to assess the system's attributes.

**Keywords:** Heuristic evaluation, Usability testing, User interface, Decision Support Systems, IoT, Irrigation systems.

**Resumen.** El Internet de las Cosas favorece el aprovechamiento de las herramientas tecnológicas en ambientes rurales, gracias a la capacidad de conexión a Internet entre dispositivos que facilita el quehacer diario. El objetivo de la investigación es evaluar la usabilidad del sistema de soporte para la toma de decisiones de riego en el agro, AgroRIEGO, que se tiene desde el desarrollo de una aplicación de un dispositivo basado en IoT. El patrocinador de este proyecto fue el Ministerio de Tecnologías de Información y Comunicación y el Centro de Excelencia de Apropiación en Internet de las Cosas (CEA-IoT) en Colombia. Dentro de los métodos usados se encuentra el uso de la técnica de evaluación heurística, estructurada en 15 categorías y 62 subcategorías de valoración. Este análisis se complementa con el aporte de un grupo de expertos en el diseño y desarrollo de aplicaciones y dispositivos IoT y el agro para valorar los atributos del sistema.

**Palabras clave:** Evaluación heurística, Evaluación de usabilidad, Interfaz de Usuario, Sistemas de soporte a la toma de decisiones, Internet de las Cosas, Sistemas de irrigación.

**Paper type:** Research paper.

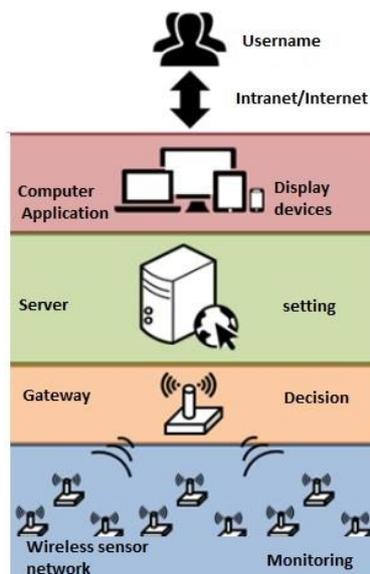
## 1 Introduction

Usability is a highly relevant topic in the Human-Computer Interaction (HCI) literature. Over time, HCI research results have determined that the study of human factors is a key factor for success in the design and applicability of technological devices (Turk, 2014). In that sense, and to address the objectives of HCI, it has been identified that phenomena such as the design of programming languages have been addressed by several researchers (Rautaray & Agrawal, 2012), as well as the errors caused using alternative modeling approaches (Gil-Quintana et al., 2021), and the usability of operating systems such as UNIX (Agarwal & Venkatesh, 2002). Bastien (2010) indicates that "the most important issue facing both utility researchers and practitioners is the construction of the utility itself." This issue of utility has been theoretically defined,

operationally applied, and measured in multiple ways. Utility assessment has been applied to medical, technological, and agricultural devices (Romero-Riaño et al., 2021), using various approaches and methods.

From the perspective of promoting educational actions that have relevance and national impact on innovation and competitiveness, the Ministry of Information Technologies in Colombia has defined actions aimed at developing Centers of Excellence and Appropriation in emerging technologies that can, in turn, generate technology-based enterprises. One of these bets has materialized in the Center of Excellence and Appropriation on the Internet of Things (CEA-IoT), led by the Autonomous University of Bucaramanga (UNAB) in the east of the country. The CEA-IoT has managed to connect the interests of the government, universities in different regions of the country, technology leaders in the Internet of Things worldwide, and companies in the productive sector that see in these technologies an opportunity for innovation towards competitiveness (Guerrero & Rico-Bautista, 2020; Parra Valencia et al., 2017; Rico-Bautista et al., 2019, 2020).

This article takes as the object of study a decision support system for irrigation, which takes advantage of the various phases of plant growth, using sensor network technology integrated with the Microsoft AZURE platform, connected through a web server to communicate with Android system devices, understanding that one of the most important factors for the success of agricultural production is the existing irrigation system (Caro et al., 2020). The conceptual architecture of the AgroRIEGO System consists of four components: i) Monitoring, ii) Decision, iii) Configuration, and iv) Visualization, (see [Figure 1](#)).



**Figure 1.** Conceptual architecture of AgroRIEGO. Source: CEA-IoT

The system, called "AgroRIEGO," monitors the volumetric content of water in the soil through sensors placed at certain points in the area to be irrigated. These sensors are located close to the root, within an effective depth according to the level of development of the plant, to increase their accuracy and efficiency. The data from the sensors on water content is transmitted via ZIGBEE to the sink or brain node and by GPRS to the cloud, with intervals of 5 minutes for it to send the data and 15 minutes for its visualization on the platform and subsequent communication to an Android-based cell phone (see [Figure 2](#)). Based on the data obtained, the AgroRIEGO seasonal precision irrigation system defines the amount of water required by the plants at each stage of their growth. The energy required by the system is supplied by photovoltaic solar energy with battery backup. The system can be controlled by smartphones, which increases its usefulness.

The objective of this research is to develop an analysis of the AgroRIEGO decision support system interface from the HCI perspective using heuristic evaluation techniques. AgroRIEGO has been developed in the context of emerging economies, specifically in Colombia. Due to the characteristics of the rural population in this type of country, an examination of the usability of the current prototype is proposed to improve its next market entry. To this end, 62 variables associated with the design and operation of the prototype are selected to identify the advantages and disadvantages of the context.

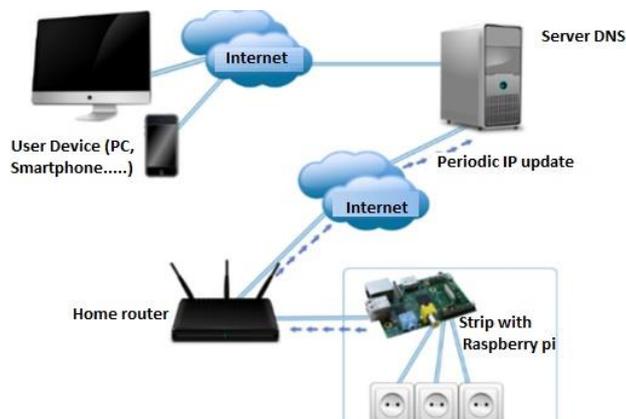


Figure 2. System architecture. Source: CEA-IoT

As a methodology, a review of the frameworks for the study of usability and testing of prototypes is proposed to develop a tool that allows contrasting the critical variables in the design of the prototype. By applying the framework to the prototype, an evaluation of its advantages and disadvantages will be obtained, allowing for adaptation and the generation of improvements in its usability. The sections of the document are (i) introduction, (ii) method, (iii) results, and (iv) conclusions.

## 2 Method

### 2.1 Human-Computer Interaction (HCI)

HCI is defined as the manipulation of graphical objects in an interface using some artifact that makes it possible (Martinez-Toro et al., 2019; Seufert et al., 2015). Moreover, according to ISO 9241, usability refers to a system, service, or product that can be used by users with defined characteristics to achieve specific objectives with efficiency, effectiveness, and approval in each context of use. The human-centered design approach to system design and development aims to improve the usability of interactive systems by focusing on system use, ergonomics, technique, and knowledge. The increased attention to problems identified in user experience (UX) research (Flandoli & Romero-Riaño, 2020) can be explicitly demonstrated by taking as a basis the increasing trend in the number of publications in the area of user-centered design within the Scopus database, which tripled articles between 2003 and 2008 and doubled between 2009 (300) and 2018 (600).

This growing body of literature outlines several challenges for research on how to measure usability and empirically compare subjective and objective measures of usability and for usability testing studies (Maguire, 2001). Among the most important challenges that emerge for usability are extending satisfaction measures beyond post-use questionnaires; studying correlations between usability measures as a means of validation; focusing on the development and use of learning and retention measures; and finally, validating and standardizing the large number of subjective satisfaction questionnaires used (Hornbæk, 2006).

Methods to support user-centered design have been the focus of interest in usability testing. Usability is now widely recognized as critical to the success of an interactive system or product (Rico-Bautista et al., 2021). When a user has difficulty using and learning a system, it is inefficiently designed. As a result, they may be underutilized, misused, or abandoned, leading to frustration among users who continue to insist on maintaining their current working methods. These failures come at a high cost to the organizations using the systems, as well as affect the reputation of the developers (Maguire, 2001).

A usability evaluation assesses the degree to which a system is effective (that is, it accomplishes the tasks for which it was designed) and efficient (that is, the number of resources, such as time or effort, that are required to use the system in order to perform the tasks for which it was designed) (Bastien, 2010).

Given that the objective of this study is to evaluate the GeoToroTur geoservice with respect to that of the Geoserver, this study is comparative (A. Díaz, 2009). It is also experimental because tests were carried out in the laboratory to obtain the data. This research is classified as prospective because, from the point of view of planning the collection of data, these were obtained specifically for the writing of this article. Likewise, due to the number of measurements of the variable, the study is longitudinal since each geoservice was analyzed with 75 different consultations in 35 repetitions. In addition, the study is univariate because only one response variable is analyzed, and it is balanced because the treatments have the same number of repetitions. Likewise, the research is classified as analytical since the behavior of the geoservices was examined with the purpose of detecting possible relationships among them. Finally, the level of this research is explanatory since it is oriented to establishing the cause-effect relationships between the variables analyzed from the results obtained through the experiment.

## 2.2 User testing tools for the user

There are several approaches to usability testing. Table 1 shows a summary of the usability testing tools identified.

Table 1. Usability testing tools.

Description	Method
Software tools	Data capture and analysis
Graphical comparison tools	Desktop environment
Mobile application tools	Mobile usability studies

## 2.3 Usability testing and heuristic evaluation

There are several approaches to analyzing the user experience and usability of artifacts. From the HCI perspective, these approaches are heuristic evaluation and observational usability testing (Granollers, 2018). Heuristic evaluation became the most popular user-centered design (UCD) approach in the 1990s; this technique is an effective method for evaluating user interfaces by making recommendations based on UCD principles (Granollers, 2018).

Different approaches have been applied in usability evaluation. Jacob Nielsen's (1994) framework identifies eight approaches: guideline review, consistency inspections, heuristic evaluation, standards inspections, pluralistic walkthroughs, formal usability inspections, cognitive walkthroughs, and feature inspections. In an alternative taxonomy, user experience analysis includes approaches such as heuristic evaluation (Jacob Nielsen, 1994), cognitive walkthroughs (Kowalczywska & Turnhout, 2012), guidelines (Blanck, 2014), and GOMS (goals, operators, methods, and selection). Observational usability testing refers to all methods generally referred to as "user testing."

In 1991, an evaluation proposal was developed by applying four different techniques: heuristic evaluation, software guides, cognitive walkthroughs, and usability tests (Hornbæk, 2006). In this sense, the importance of considering several aspects, such as the problems that people encounter when performing information retrieval tasks and of evaluating the evaluation methods taking into account the approach to the problem, the quality of the results, and the cost-effectiveness of each method is emphasized (Maguire, 2001).

Following this evaluation path, Bailey (2013) performs heuristic evaluation and iterative design in software development. The findings reveal the main weaknesses of heuristic evaluations and the importance of usability testing in the design and development of human interfaces (D'mello & Kory, 2015). In 1993, they incorporated think-aloud testing into the prototype of an extended voicemail application. In addition, they follow the line of using heuristic evaluation, in which usability experts question user interface and performance testing (McIntire et al., 2014).

The main differences between the realistic approach to usability testing and the non-realistic approach to heuristic evaluation have been highlighted by Huggins (Huggins et al., 2017). The disadvantages of the time-intensive and cost-intensive evaluation of usability testing are the main conclusions of the work by

Kantner & Rossenabum (1997). Regarding the evaluation methods used for website usability evaluations, Kantner & Rossenabum (1997) indicates that heuristic evaluation and laboratory testing are two of the most used approaches. In search of the best usability research methods, they propose a combination of research methods for user data collection and conclude that the combination of research methods is more likely to increase the strategic penetration of human factors in organizations (Waytz et al., 2014). Research methods include ethnographic interviews; utility research efforts on a limited budget; and contextual inquiries followed by expert group interviews.

Bright et al. (2015) reveal the complementarity and convergence of heuristic evaluation and usability testing. Even though the results from the two methods can be confirmed to some extent, there is no clear explanation for why they don't match up, especially when it comes to the question of whether reported usability problems lead to real-world failures (Corneanu et al., 2016).

It was considered important to use different data collection techniques in determining the needs of medical equipment users. In that sense, Garmer et al. (2002) proposes an approach to evaluate pumps for medical use that is designed based on three methods: an analysis of observations, interviews, and heuristic evaluation. The need to develop feasible techniques that allow medical equipment manufacturers and hospital staff to specify and critically evaluate the quality of use is highlighted.

The heuristic evaluation procedure for measuring usability has been applied to various developments, such as Web sites, identifying from the site design its weaknesses and strengths. Based on a large collection of usability lineages developed by Microsoft, Agarwal and Venkatesh (2002) developed a heuristic evaluation procedure for evaluating web site usability, which invites users to assume the role of a consumer or investor in evaluating usability. Rau & Liang (2003) combine critical variables of internationalization and localization of Web sites and the improvement of Web site usability with user-centered design methods, focusing on scenario utilization techniques, cluster analysis, and performance measurement testing, generating, and highlighting international and local particularities in Web site development for Web site designers (Agarwal & Venkatesh, 2002).

### 3 Results

Microsoft's usability guidelines, which provide a comprehensive basis for heuristic evaluation of Web sites, are organized around five main categories: promotion, content, emotion, usability, and made-for-media. The informational and transactional capabilities of a Web site are evaluated by content. This item has four subcategories: Media usability, the appropriate use of multimedia content; Relevance, related to the relevance of the content to the primary audience; Current and timely information, which captures the degree of timeliness of a website's content; and Depth and breadth, which examines the variety and detail of topics (Agarwal & Venkatesh, 2002).

Ease of use relates to the cognitive effort required to use a Web site. The following are three subcategories for measuring ease of use: Goals, related to clear and understandable objectives; Structure, focused on the organization of the site; and Feedback, which captures the extent to which the website provides feedback on progress to the user. Promotion captures the advertising of a website on the Internet and other media. The fourth category, made for the medium, refers to tailoring a website to fit the needs of a particular user. Made for the medium has three subcategories: Community, which captures whether the website offers users the opportunity to be part of an online group; Customization, which reflects technology-oriented website customization; and Enhancement, related to the special importance given to current trends (Agarwal & Venkatesh, 2002).

When we speak of emotion, we refer to those affective links invoked by a website. The following are four subcategories that comprise emotion: There is a plot referred to arousing user interest, especially with a story; Challenge captures the idea of difficulty, especially in relation to a sense of accomplishment, rather than simply functional complexity or obscurity; Strength of character relates to the credibility conveyed by the site, especially through the individuals portrayed on the site; and Rhythm establishes the extent to which the site facilitates control of the flow of information.

The user experience evaluation approach developed in this work is based on the application of heuristics. This technique is relevant because of its ease of application through expert focus groups. Additionally, it facilitates the evaluation of devices that are at the prototype development level (the current stage of development of the AgroRIEGO application). This technique is based on the complementarity of the

integration of two approaches and is used for the analysis of the usability of websites and devices. This approach implements an evaluation composed of 15 categories and 60 subcategories, see [Table 2](#).

**Table 2.** Categories and subcategories for heuristic evaluation.

Categories	Subcategories
System visibility and status	5
Reduction of latency	2
Helping users to recognize, diagnose and recover from errors	4
Default	3
Help and documentation	5
Preventing errors	6
Consistency and standards	3
User control and freedom	3
The connection between the system and the real world, the use of metaphors, and human objects.	4
Flexibility and efficiency of use	5
Autonomy	3
Recognition instead of memory, learning, and anticipation	6
Saving the state and protecting jobs	3
Aesthetic and minimalist design	4
Color and readability	4
Total	60

The results of a preliminary evaluation, based on the heuristic of 6 categories, are presented in [Table 3](#). A discussion group composed of a team of five professionals in the areas of telecommunications, engineering, and design was carried out for its elaboration. Of the total of 62 subcategories, 54 were evaluated, answered, and computed to obtain the percentage of total use of the application. The remaining eight subcategories were not applied due to the state of development of the AgroRIEGO prototype.

**Table 3.** Results of the heuristic evaluation.

Results	Values
Color and readability	2.5
Recognition instead of memory, learning, and anticipation	2
System visibility and status	3.5
Flexibility and efficiency of use	1.5
User control and freedom	0.5
The connection between the system and the real world, the use of metaphors, and human objects.	1.5
Autonomy	0.5
Preventing errors	1
Help and documentation	2
Helping users to recognize, diagnose and recover from errors	0
Saving the state and protecting jobs	1
Reduction of latency	0
Aesthetic and minimalist design	3
Default	0
Consistency and standards	3
Total	40.70%

As a result of the heuristic application, the main strengths, and weaknesses of the AgroRIEGO application interface are identified. A total usability percentage of 42.7% was obtained as a product of the evaluation within the focus group. The main strengths are visibility, connection to the real world, design, color, and readability. As main weaknesses in the usability of the application, the categories of defaults, latency reduction, error aids, and user freedom and control are identified.

Based on the results of the evaluation heuristics, AgroRIEGO is identified as a user-friendly technology system that enables the measurement of deficiencies or excesses in soil moisture levels within crops. AgroRIEGO makes it possible to receive information quickly and efficiently within an intuitive interface, from which the order to activate the irrigation system is enabled by sending a text message. In addition to these features, it is also possible to work with a local network in the absence of wireless networks or data availability. These attributes make it possible to implement this type of system in crops located in isolated areas.

## 4 Conclusions

The main objective of this research is to develop an analysis, from the HCI perspective, of the AgroRIEGO decision support system interface, using heuristic evaluation techniques. For this purpose, 54 categories were evaluated, answered, and computed through a focus group workshop to obtain the percentage of total usability of the application. The results of the heuristic evaluation highlight visibility and system state as the main strengths of the interface. In addition, several weaknesses are removed from the evaluation, such as user control, defaults, and error support.

Several factors or subcategories for application improvement have been identified. The need for a link to return to the initial state or home page, logical organization of information according to the end-user, keyboard shortcuts for common actions, messages before performing irreversible actions, confirmation messages before acting, visible and easily accessible help options, autosave, options for the visually impaired, keeping the user informed of system status, and a system or device option to return to predefined initial settings

Among the main limitations identified in this evaluation are the size of the sample of the group of experts, the low culture in the use of heuristics and design and usability evaluation processes in the Colombian context, and the difficulty of accessing potential end-users of the product, since it is in the development or prototype phase. Future research may address the combination and contrast of evaluation through heuristics with usability evaluations in the field.

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