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DEVELOPMENT OF A DIGITAL TELEVISION SET TOP BOX FOR MULTIPLE TELEVISION RECEIVER CONTROL AND ACCESS THROUGH A PERSONAL AREA NETWORK

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Abstract

Digital Television set-top boxes are now a standard supplementary appliance to the television set of Filipinos. Although internet video sharing applications and streaming services provide a challenge to free television broadcasts, Free Television is still the primary access of entertainment for those who still have no internet access.

The purpose of the study is for the researcher to prove the possiblity that through a device prototype, a digital television set-top box can multi-connect at least four television sets with independent user control. This is accomplished with the combination of Bluetooth, Infrared, Mircro-controller and Radio Frrequency technologies which enable the independent control for the infra-red signal and the independent reception of IDSB-T signals to each connected sets. This device is intended for households and lodging establishments that have multiple television units.

The researcher used a mixed research method in this study. The specific research design is the exploratory sequential design. This design is applicable for studies which use prototypes and mixed testing of qualitative and quantitative data outputs. For the test instruments, the researcher developed two kinds. The first instrument is used for the functional test of the prototype. This is based on how the device would be operated by the user in terms of control signal response of the set-top box, and the quality of the received video and sound on the television unit. The second instrument is a user evaluation survey with criterions based on five of the eight characteristics of the ISO/IEC 25010 standard which measures the acceptability of the prototype set-up box in terms of functional suitability, usability, reliability, portability, and maintainability. The researcher recorded a video presentation of the prototype in action. This video is included in the user evaluation on-line survey. The initial survey lasted for 2 weeks and gained 35 respondents.

The researcher's statistical treatment for the gathered data is weighted averages for both instruments.

ISSN Print: 2984-8288
ISSN Online: 2984-8385

The results of the functional test, the demonstration, and the user's evaluation support the hypothesis of the study. The functional test findings show that there is normal response to the control signals within the Bluetooth's 10-meter range. The video and audio signals are rated high to good quality. Moreover, there is a noticeable degrade of video and audio quality beyond the 10-meter range. In addition, the control signals are no longer working in the mentioned range.

The respondents for the on-line user evaluation are mostly from the Electronics Engineering discipline and are faculty and students of the said specialization. There were also respondents who have expertise in other fields of Engineering and Applied Technologies like Computer Engineering and Information Technology. These respondents, after viewing the demonstration, have given the prototype an overall adjectival rating of "excellent" based on a 4-point Likert scale. With this, it is considered that the prototype has achieved the objective of this study.

For the improvement of the device, the researcher proposes several recommendations. Among these recommendations are the use of smaller available components to reduce its size, and the use of other wireless means to transmit the audio-video signals to distant units.

Introduction

People's need for information and entertainment is essential in today's information-driven culture. This continually manifests and is traceable with the historical development of the electronic devices which begun from the vacuum tube used in the early broadcast radio to today's video streaming applications in smartphones.

Nowadays, information can be easily accessed by anyone through the use of a smartphone. However, the limitations of on-line access in some regions in the country, which ranges from slow to none, is still undeniable (Jennings, 2016). There is nothing more publicly available, trustworthy, and which provides free electronic information and entertainment other than television (TV).

Television technology started with an electro-mechanical system in the early 1930s. It was followed shortly by the analog electronic radio broadcasting system right after the Second World War. In 1941, United States of America (USA) started the National Television System Committee (NTSC) Standard. This television standard only provided non-chroma or black and white image to be broadcasted. In 1953, the NTSC standard was improved such that the color information includes 6 megahertz (MHz) bandwidth per TV station signal.

The Philippines, being a former colony and exposed to the USA market specifically to US TV equipment at that time, adopted the 1953 NTSC Standard. Consequently, Analog television

ISSN Print: 2984-8288
ISSN Online: 2984-8385

became the dominant mode of free-to-air TV broadcast in the Philippines for almost seventy (70) years.

Alto Broadcasting System and Chronicle Broadcasting Network (ABS-CBN) Corporation was the first analog TV Broadcast station in the country, followed by another analog private broadcast station like Global Media Arts (GMA) Network. The Philippine government also established and maintained at its peak three (3) analog broadcast TV stations: People's Television (PTV) 4 Network, Radio Philippines Network (RPN) 9, and Intercontinental Broadcasting Corporation (IBC) 13. As of 2010 there are seven (7) Very High Frequency (VHF) and eleven (11) Ultra High Frequency (UHF) bands still being used in the analog TV standard, which the National Telecommunications Commission (NTC) is due to turn-off by December 31, 2023.

The next development in television technology is spawned by the advent of Digital Media Technologies and Computers in the late 1970s. The Moving Pictures Entertainment Group or MPEG established MPEG-1 standard in 1988 and MPEG-2 in 1994. MPEG standards provide the means of storing analog content like music and movies into a non-magnetic type of compact media (referred to as "optical media"), via the encryption of the video and audio signals into digital bits. The first big break was the laserdisc or LD. LD has an early successful run versus the Video Home System (VHS) or Beta formats. The LD being too big and expensive, soon faded out. A smaller version of LD, called the compact disk or CD, later evolved to Digital Video Disc or DVD, became the successful version of MPEG-2 standard. "In 1999, the MPEG-4 standard was introduced and marked nothing less but a revolution of the video sharing online. It has been adopted as the de-facto standard for online videos and has remained such ever since" (NTC Hosting, 2002).

There are four known technologies of Digital Television (DTV) (Yao, 2003,2005). The first one is the Digital version of NTSC called the Advanced Television Systems Committee or ATSC for North and Central America. The second one is what Europe, Australia, South Asia, and Africa have which is the Digital Video Broadcast-Terrestrial or DVB-T. Third in line is China's Digital Terrestrial Multimedia Broadcast or DTMB. Lastly is what Japan, South America, and the Philippines have adopted which is the Integrated Services Digital Broadcasting-Terrestrial or ISDB-T (NTC, 2018). Moreover, the MPEG-2 standard is the technology used for the signal content of ISDB-T.

In the Philippines, DTV broadcast was pioneered by ABS-CBN (Inquirer, 2007) and received through their DTV decoder box or was marketed as the "magical black box". This is in concurrence with the government's effort through the National Telecommunications Commission (NTC) to have an all free-to-air television broadcast which migrated from 2021 to 2023 to the UHF band. In addition, the Japanese DTV Standard ISDB-T is adapted for the country's standard of digital television broadcasting (DICT, 2017). This move intended to take Philippine Television at par with the world's digital television standard.

ISSN Print: 2984-8288
ISSN Online: 2984-8385

The NTC has allocated the Ultra High Frequency (UHF) broadcasting range in general and 470 MHz to 698 MHz for DTV. Currently, the DTV in the Philippines utilizes UHF channel 14 with bandwidth starting from 470 MHz to 476 MHz going up to the last channel 51 with bandwidth of 692 MHz to 698 MHz (NTC, 2018).

Since 2012, there has been an increasing demand and use for the DTV decoder boxes (ABS-CBN, 2017), which enables the user's standard TV to view DTV broadcast. The main lure is that the image quality, MPEG-2 of DTV, is much clearer compared to its analog counterpart. The standard DTV decoder box kit contains a separate remote control, a small indoor antenna, RCA cables or jacks and an AC-to-DC power adaptor. The DTV decoders are produced and sold by multiple companies including ABS-CBN, CDR-King and WOW. Exclusive channels are encrypted and can only be accessed by sending special codes which is charged to the user through Short Message Service (SMS) in cellular phones, as in the case of ABS-CBN's TV-Plus (ABS-CBN, 2017).

These DTV decoders are intended only for a single television set. However, establishments with multiple television sets, like hotel rooms and hospital suites, need to have one DTV decoder per TV set. The present available DTV decoders do not allow multi-television unit access. One could use an existing regular antenna splitter to share the output signal, but this would only allow two or more different users to watch the same station and program. In the aspect of control, only the user holding the main remote control can turn-off the TV or change the station, and that other users will have no control.

The objective of this research is to develop a Digital Television Set Top Box that would be able to provide service to more than one digital television set. With this objective, the features to enable the users to watch different stations and programs, and to independently control the TV are made available. The proposed device uses Bluetooth technology to transmit IR control signals; and High Frequency RF signals to transmit decoded DTV signals. The target users for this proposed DTV set top box are households that have multiple rooms and establishments similar to hotel rooms and hospital suites.

Statement of the Problem

The general problem of this study is: "How to develop a specialized digital television (DTV) set top box that can wirelessly and simultaneously accessed by multiple television receivers, and that can view independent channels on separate television sets?"

Specifically, this study answered the following questions:

1. What will be the system design of this proposed digital television (DTV) signal

ISSN Print: 2984-8288
ISSN Online: 2984-8385

decoder, in a way that a single DTV can receive signal then distribute it into at least four individual television sets which has independence of channel selection?

2. What are the necessary hardware, software and development tool(s) required to allow the remote TV units to communicate with the main DTV set top box, vice-versa?

3. What are the stages of development for the device to verify its functionality?

4. How will the testing of the device, using a prototype, be carried out to verify its performance?

5. How will the proposed system be evaluated when compared in function and performance with the current digital TV set top boxes which uses ISDB-T as standard?

Methods

This chapter presents the research method, design and technique taken by the researcher in the development of the proposed device This chapter covers the research methods and techniques used as outlined in the previous chapter to address the study concern. It also includes the study population, sampling, research tool, research procedures, ethical considerations, data collection procedures, data processing, and statistical data analysis.

The researcher uses the mixed method research approach. This method is applied due to the use, collection, and interpretation of both quantitative and qualitative data. The specific design used is the exploratory sequential design which is a mixed method that is applicable for instrument design and testing (Creswell, 2012).

The technique applied for the study starts with the quantitative data collection, through the functional testing of the developed prototype. The prototype device is demonstrated at operation and this session is recorded as visual proof and support for the collection of the qualitative data through descriptive survey questionnaire which served as the user's evaluation of the device prototype. Data from both quantitative and qualitative sources are analyzed and then unified as a set of final conclusions at the end of the study.

The researcher uses purposive sampling to determine the sample population for the on-line survey. The majority of respondents for the on-line survey have electronics engineering background -- electronic engineering students and faculty. The researcher also sent links for evaluation of the prototype to respondents that have backgrounds in information technology, computer engineering, and other engineering fields. The samples for the user evaluation came from Bulacan Province. The respondents are also considered as household members. The researcher was able to reach a total of thirty-five (35) answered on-line questionnaires.

ISSN Print: 2984-8288
ISSN Online: 2984-8385

For this mixed-method study, there are two types of research instruments: one is qualitative and the other is quantitative. The result of the qualitative test are recorded on the prepared functional test sheet.

In the qualitative test, two sets of functional tests are performed on the device and its components. This is to verify that the deigned application is efficiently carried out. The first part of the functional test measures the control and response efficiency of the system. The second part measures the quality of the audio and video reception.

For the quantitative instrument, a descriptive user-survey questionnaire for the evaluation of the system's level of acceptability is supplied. The questionnaire used the 4-point Likert scale to measure the descriptive interpretation of the users to the device prototype. The reason for using a 4-point Likert scale is to eliminate uncertainty of the response due to the fact the item being evaluated is a device with specific functionalities. In addition, the 4-point Likert scale serves as a good survey for a market research on the device.

The characteristic criterion used in the questionnaire is based on the ISO/IEC 25010 standards. The researcher chose the logical characteristic criteria that is applicable for the prototype. Hence, five among the eight ISO/IEC 25010 characteristics are used in evaluating the device, namely: functional suitability, usability, reliability, portability, and maintainability. This standard is generally used for evaluating properties of a software product, but the five characteristics are logically fit to evaluate the prototype, which is a hardware device with embedded software and custom programmed algorithms within the Arduino, Bluetooth, and ISDB-T boards.

Functional suitability is the characteristic of the device to perform the intended function or application. The evaluation criteria for this characteristic center on the functional aspect of the device. The respondent is asked to rate based on the observed response on the distant television sets, when control signals are sent via remote.

Usability is the characteristic of the device to operate with minimum effort on the part of the user. The evaluation criteria for this characteristic center on the user-friendliness aspect of the device. The respondent is asked to rate based on his or her overall experience in using the device.

Reliability is the characteristic of the device which refers to the availability or readiness to function properly as needed. The evaluation criteria for this characteristic center on the optimum performance aspect of the device. The respondent is asked to rate based on the device's ability in working properly in the whole time of use.

ISSN Print: 2984-8288
ISSN Online: 2984-8385

Portability is the characteristic of the device to be functional in a variation of environment and to reach the minimum requirement to function. The evaluation criteria for this characteristic center on the operation of the device, if there are changes made in the type of television set, and changes on location of the distant units. The respondent is asked to rate based on the device's ability in working properly within the scope of the device's limitations. The researcher presents the functional test result as a reference to the respondent since this requires actual modifications to the location and television unit to which the respondent may not have access to.

Maintainability refers to the characteristic of the device to stay resilient for long time use. The evaluation criteria for this characteristic center on the structural design, material strength, fault testing and reparability of the device. The respondent is asked to rate based on the earlier mentioned attributes, but also consider that the version of the device being evaluated is just a prototype. The respondent rates maintainability on the basis that the criteria are can be implemented based on the current design.

Data-Gathering Procedure

A. Functional Tests

The functional tests are conducted by the researcher. There are two types of Functional Tests: (1) Practical Test and (2) Extreme Test

The Functional Test conducted by the researcher involves data collected by focusing on the efficiency of the system in correctly controlling the distant devices. This is proven when the correct response was observed from the distant devices. All possible error scenarios like wrong channel change, no response, or hanging are taken note of during the functional testing. The 10-meter distance limit for the IR signal via Bluetooth is also verified. The distances is measured via line-of-sight direct measurement.

B. User's Survey Evaluation of the System's Level of Acceptability

The researcher used an on-line survey form via Google forms to reach the intended population. The total number of samples is dependent on the number of responses that the survey receives within five days of access. A video of the demonstration of the prototype is attached with the online survey link.

Data Processing and Statistical Treatment

ISSN Print: 2984-8288
ISSN Online: 2984-8385

The data from the two different instruments are independent from one another and cannot be directly processed. The use of both instruments is to verify the operational feasibility of the prototype device, however, both are needed to have a unified overall evaluation.

The determination of averages or means is through a statistical treatment applied to the instrument's numerical data. In the first instrument, there are three test sections for raw data, an average for each section is taken. These sectional averages are used to determine the overall average which is used to verbal functional efficiency rating of the prototype device.

In the second instrument, the tally of the ratings gathered from the survey of every characteristic evaluation criterion are treated statistically using weighted mean. The frequency of similar rating is multiplied to the corresponding weight rating. The result is then divided by the overall frequency.

The users use the numerical rating below to evaluate each characteristic criterion based on the guide questions given for each criterion.

The weighted average is obtained per characteristic criterion based on the responses. These are interpreted based on the following ranges of averages.

Significant Findings

A. Test and Evaluation Results

1.1. Data and Evaluation of Functional Test Results

1.1.a. Practical Function Test Data:

Table 1

Practical Prototype Test Results

Unit	Distance from Main Unit	Control Efficiency ε_C	Audio Quality ε_{QS}	Audio Quality ε_{QV}	Overall Efficiency ε_o
DS1	9.77 m	90%	100%	100%	96.67%
DS2	7.52 m	94.38%	100%	100%	97.67%
DS3	9.08 m	93.75%	100%	100%	98.67%

Average Overall Efficiency = 97.67%

Lunday Research Journal
ISSN Print: 2984-8288
ISSN Online: 2984-8385

1.1.b. Evaluation of Practical Function Test Results:

With reference to Table 1, the average overall efficiency of 97.67% has an equivalent verbal rating of “Highly Efficient”. This suggests that the prototype is a practical working electronic appliance when used within the workable rated distance determined by Bluetooth technology. This is expected as the IR signal can be transmitted and received via Bluetooth within the 10m distance. The errors on the pressed buttons were due to human error such as wrong pressing or pointing of the remote to the IR receiver at the distant units.

The picture and sound quality from the observance of the researcher is of the best quality. No noise signal was observed during the testing.

1.2.a. Extreme Function Test Data:

Table 2

Extreme Prototype Test Results

Unit	Distance from Main Unit	Control Efficiency ε_C	Audio Quality ε_{QS}	Audio Quality ε_{QV}	Overall Efficiency ε_o
DS1	15.5 m	0%	66.67 %	66.67 %	44.44%
DS2	17.47 m	0%	66.67 %	66.67 %	44.44%
DS3	18.78 m	0%	33.33 %	66.67 %	33.33%

Average Overall Efficiency = 40.74%

1.2.b. Evaluation of Extreme Function Test Data:

Table 2 conveys that due to the longer distance between the main unit and distant unit, the Bluetooth channel for the IR control signals can no longer communicate, hence control of the TV set is not possible. However, the video and audio signals can still be transmitted with the maximum range of the RF transmitters as 2 km, but the quality of the audio and video signals are lesser because of the power attenuation at longer distances. The low efficiency of 40.74% is due to the loss of control and lesser quality of the output audio and video signals, this has an equivalent verbal rating of “Average Efficiency”.

Evaluation of the System’s Level of Acceptability from User’s Survey Form

ISSN Print: 2984-8288
ISSN Online: 2984-8385

A. Functional Suitability

Table 3 presents the results of the survey for the descriptive measure of the system's level of functional suitability.

The overall evaluation criteria weighted mean suggests that the respondents strongly agree that the device has met the basic functional suitability as a digital television set-top box and an extendable ISDB-T receiver.

Table 3

Descriptive Measure of the System's Level of Acceptability in terms of Functional Suitability

Evaluation Criteria	Frequency				Weighted Mean	Verbal Interpretation
	1	2	3	4		
The device and its components are capable to change channels and adjust the sound volume on the distant television units without any issues.	1	0	6	28	3.75	Excellent
The device and its components are capable in providing standard to high sound and video quality.	1	0	11	23	3.60	Excellent
The device and its components are feasible solution to an extendable ISDB-T receiver	1	0	7	27	3.72	Excellent
Overall Evaluation Criteria Mean					3.69	Excellent Functional Suitability

B. Usability

Table 4 reveals the results of the survey for the descriptive measure of the system's level of usability.

The overall evaluation criteria weighted mean suggests that the respondents strongly agree that the device is user-friendly, can be easily set up, and can be used for regular operation as a digital television set-top box.

Table 4

Descriptive Measure of the System's Level of Acceptability in terms of Usability

ISSN Print: 2984-8288
ISSN Online: 2984-8385

Evaluation Criteria	Frequency				Weighted Mean	Verbal Interpretation
	1	2	3	4		
1. The device and its components require less effort for the user to learn, understand and operate	1	1	6	27	3.69	Excellent
2. The distant units provide the user the same experience of using a regular individual set top box.	0	2	10	23	3.60	Excellent
Overall Evaluation Criteria Mean					3.65	Excellent Usability

C. Reliability

Table 5 presents the results of the survey for the descriptive measure of the system's level of reliability.

The overall evaluation criteria weighted mean suggests that the respondents strongly agree that the device responds to the control signal within the provided range of distance, and observes that the correct response is done to the television set when a particular button is pressed.

Table 5

*Descriptive Measure of the System's Level of Acceptability in terms of Reliabil*ity

Evaluation Criteria	Frequency				Weighted Mean	Verbal Interpretation
	1	2	3	4		
1. The device and its components respond correctly to the pressed button in the remote control.	1	0	2	32	3.86	Excellent
2. The device and its components are capable to be powered on/off with the ISDB-T signal access at the distant television sets.	1	0	5	29	3.78	Excellent
3. The distant units provide the optimum operation within less than 10 meter distance from the main unit.	1	0	11	23	3.60	Excellent
Overall Evaluation Criteria Mean					3.75	Excellent Reliability

D. Portability

ISSN Print: 2984-8288
ISSN Online: 2984-8385

Table 6 presents the results of the survey for the descriptive measure of the system's level of functional suitability.

The overall evaluation criteria weighted mean suggests that the respondents strongly agree that the device is very portable. The distant units are design to be portable from the onset of this study. In addition, the RCA enables connection to allow analog TVs to be accessible by the proposed device.

Table 6

Descriptive Measure of the System's Level of Acceptability in terms of Portability

Evaluation Criteria	Frequency				Weighted Mean	Verbal Interpretation
	1	2	3	4		
The device and its components are adaptable to any RCA enabled analog television set.	1	1	7	26	3.66	Excellent
The device and its component can be re-installed in another location.	1	2	6	26	3.63	Excellent
Overall Evaluation Criteria Mean					3.65	Excellent Portability

E. Maintainability

Table 7 reveals the results of the survey for the descriptive measure of the system's level of functional suitability.

The overall evaluation criteria weighted mean suggests that the respondents strongly agree that the device is highly maintainable. Although the presented device is just a prototype, the components used are mostly integrated and modular.

Table 7

Descriptive Measure of the System's Level of Acceptability in terms of Maintainability

Lunday Research Journal
ISSN Print: 2984-8288
ISSN Online: 2984-8385

Evaluation Criteria	Frequency				Weighted Mean	Verbal Interpretation
	1	2	3	4		
The device and its components are rugged and requires low maintenance.	0	3	16	16	3.38	Excellent
The device and its components can be easily tested for faults.	1	4	13	17	3.32	Excellent
The device and its components can be easily replaced in case of failure.	0	5	9	21	3.46	Excellent
Overall Evaluation Criteria Mean					3.39	Excellent Maintainability

Summary of the Results for System's Level of Acceptability

Table 8

Overall Mean and Verbal Interpretation of the System's Acceptability

Evaluation Criteria	Average Mean	Verbal Interpretation
Functional Suitability	3.69	Excellent
Usability	3.65	Excellent
Reliability	3.75	Excellent
Portability	3.65	Excellent
Maintainability	3.39	Excellent
Overall Mean	**3.63**	**Excellent**

Table 8 reflects the respondents' evaluation on the prototype of the device as "excellent" in lieu of the 3.63 points from the 4-point Likert Survey. The individual evaluation for all criterions of the system's evaluation on Functional Suitability, Usability, Reliability, Portability and Maintainability are all "excellent".

Conclusion

Based on the findings of the study, the following conclusions are drawn:

The implemented system design for the device is able to deliver the functions and operations of the multi-access DTV set top box. The device is able to send independent DTV content to three distant units and these distant units do not have any DTV components.

The combination of the presented hardware, software and development tools has allowed the distant TV units to communicate independently with the main DTV set top box.

ISSN Print: 2984-8288
ISSN Online: 2984-8385

The study identified seven stages to develop the prototype or study output device. The intended functionality of the prototype is assured within each stage.

The performance of the device is tested in both the technical and consumer perception aspects. The high positive responses from the test and survey verify the acceptable performance of the study's output device as a viable appliance.

The prototype, when compared to the current digital TV set top boxes based on the result of the functional viability and 4-point Likert test, suggests that in terms of basic functions and operation, it works similarly to a regular ISDB-T set top box. The multiple access is the unique feature and novelty of this device.

Recommendations

Based on the findings of the study and the conclusions that were drawn, the following recommendations are offered by the researcher:

1. The use of Bluetooth for the signaling has some limitations in distance. This can be explored by future researchers and an updated Bluetooth system or another wireless technology like Wi-Fi can be implemented for signaling.

2. The use of drone transmitter and receiver is a bit of an overkill in terms of distance reception as the transmission range is 2km. In this aspect, the possibility of using Wi-Fi technology should be considered in future developments.

3. Instances of IR signal reception bouncing in the main unit may control other distant devices. The researcher covered the IR LED and IR receiver with a black enclosure to solve this issue. Future researchers may consider providing a much smaller singular enclosure for both IR components in the main unit.

4. The ISDB-T cards used in the prototype were large. A development of a single ISDB-T circuit card with output of multiple RCA or data out for DTV output is suggested to be the next iteration for this design. The smaller DTV ISDB-T circuit cards are what is currently available.

5. The researcher urges the future researchers to find other applications for the system. The system design can be altered by replacing the ISDB-T circuit cards while retaining the Bluetooth and the drone RF receiver and transmitter modules.

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ISSN Print: 2984-8288
ISSN Online: 2984-8385

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ISSN Print: 2984-8288
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