Hydrogen Line Telescope

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**Functional System Requirements**

REVISION – Draft

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Functional System Requirements

for

Hydrogen Line Telescope

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T/A Date

**Change Record**

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# Introduction

## Purpose and Scope

Currently, viewing the galaxy by detecting hydrogen line emissions is not a study that is easily accessible. Educators and students who are interested in this topic typically rely on building a DIY version of a hydrogen line telescope. The purpose of the Hydrogen Line Telescope (HLT) project is to provide an intuitive and reliable tool that educators and students can use to view hydrogen line emissions from the galaxy. The HLT will provide users with an interface that enables them to choose from four different modes of data collection. When the user selects the desired option, the telescope will rotate as needed to collect the appropriate data. This data will be analyzed and cleaned before being sent to an image processing software. Finally, a final image of the hydrogen emissions will be displayed to the user overlaying a sky map image of that same are. The HLT will make it easy for any interested user to easily view and study hydrogen emissions from the galaxy.

Figure : Project Conceptual Image

## Responsibility and Change Authority

Both team members, Warren and Johanna, will be responsible for verifying that all requirements for this project are met. The requirements outlined in this document can only be changed with the approval of both team members and Professor John Lusher.

|  |  |
| --- | --- |
| **Subsystem** | **Responsibility** |
| Antenna | Warren Herrington |
| Motorized Mount | Warren Herrington |
| Image & Signal Processing | Johanna Hein |
| Graphical User Interface | Johanna Hein |

Table : Subsystem Responsibilities

# Applicable and Reference Documents

## Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

|  |  |  |
| --- | --- | --- |
| **Document Number** | **Revision / Release Date** | **Document Title** |
| IEEE 802.15 | 09/11/2009 | Wireless Specialty Networks (WSN) |
| USB 2.0 | 07/01/2021 | USB 2.0 Specification |
| TIA-568-C.4 | 07/01/2011 | Broadband Coaxial Cabling and Components Standard |

Table : Applicable Documents

## Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

|  |  |  |
| --- | --- | --- |
| **Document Author(s)** | **Revision / Release Date** | **Document Title** |
| Lulu Liu  Chris Chronopoulos | 09/03/2008 | The Hydrogen 21-cm Line and Its Applications to Radio Astrophysics |
| Kamal M. Abood  Anmar M. Kitas | 2018 | Background Radio emissions observation at 1.42 GHz |

Table : Reference Documents

## Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

# Requirements

## System Definition

Neutral hydrogen line emissions are a very useful tool for astronomy and can be a more accessible way to look at fascinating parts of the universe. This hydrogen line telescope will take what is normally a fringe and unintuitive process and streamline it for the user. The user will be able to select from several different modes allowing them to choose areas of the night sky. The system will then return intuitive and useful photos and data to the user. The Hydrogen Line Telescope has four subsystems: Antenna Design, Motorized Mount, Image & Signal Processing, and Graphical User Interface.

*Diagram

Description automatically generated*

Figure : Block Diagram of System

Graphical user interface will take the sky selection input from the user and turn it into positional commands and a path for the telescope to follow. The controller will read this in from the software running on the laptop. Then the controller will instruct the motorized mount to point the antenna where it needs to go. At each point the controller will read in data from the antenna and aggregate it into an appropriate format to be sent back to the user's laptop for data processing.

The controller will connect and interface with the motorized mount using g-code. The g-code will use trigonometry to calculate the length of each linear actuator. The results of this calculation will then be extrapolated into how many steps the stepper motors need to take to get to the correct position. This antenna position would then be held until the controller had received enough data. The motorized mount would then move the antenna on to the next position to gather more data.

Graphical user interface, application

Description automatically generated

Figure : HLT Data Flowchart

The dataflow starts at the graphical user interface. The user selects a mode of operation and runs the program sending the positional information to the Raspberry PI. The Raspberry PI converts the positional data into g-code which is then sent to the motorized mount controller. At this point, the motorized mount rotates as needed to point the helical antenna towards the correct location chosen by the user. When the helical antenna receives the hydrogen emissions, it passes the data through a low noise amplifier to a software-defined radio. The Raspberry PI takes the SDR output, calculates the magnitude and frequency of that area, and compiles that data into a csv file. This process is repeated until the entire selected section of sky is scanned by the antenna. The csv file is then sent to the image processing software on the user’s laptop via a Bluetooth connection. Finally, the image processing software creates a heatmap type image of the hydrogen line emissions to display to the user.

## Characteristics

### Functional / Performance Requirements

#### Antenna Beam Width

The HPBW of the antenna shall be equal to or less than 10 degrees.

*Rationale: This is to make sure the resolution of the image the telescope outputs is sufficiently high to form an image where the arms of the galaxy are distinguishable*

#### Accurate Antenna Positioning

The motorized mount will position the antenna to within 5 degrees of the desired scanning location.

*Rationale: The HPBW of the antenna is 10 degrees and in order to get an image that matches what the user desired it will need to be within 5 degrees of the desired projection.*

#### Data Processing Accuracy

The data processing shall have less than a 30% inaccuracy rate when outputting the frequencies and magnitudes calculated from the SDR output.

*Rationale: This tolerance ensures that the majority of data received by the image processing software accurately represents the raw data detected by the helical hydrogen line antenna.*

#### Graphical User Interface

The graphical user interface shall be intuitive and user friendly. All HLT modes of operation and data results shall be easy to view and understand.

*Rationale: The system needs to be able to be run by a student or educator. Using the tool should be relatively straightforward for someone with minimal technical knowledge. To interpret the results, the user will need to have a small amount of technical knowledge.*

#### Antenna Routing

The positional system shall be able to correctly route the antenna at least 90% of the time.

*Rationale: The system must consider incorrect boundary selection from the user through the GUI as well as the possible inability to track an area of sky given that area’s current location and the location in the sky at the end of the scan time given the rotation of the earth.*

#### System Run Time

The system shall be able to position the antenna and collect data for up to 6 hours.

*Rationale: By looking at the maximum area the user could select which would be 360 degrees around and 80 degrees from vertical. This would have a maximum of 288 “pixels”. If the HLT can move between positions and take data at each pixel at a rate of 1 per minute, it will take 4.9 hours to complete the whole image.*

*Using the 2-D terrestrial sweep metrics, the HLT would be able to at least cover a 160 degree by 75 degree image assuming it used the same power.*

*Using the 1-D terrestrial sweep, the HLT would be able to cover at least 75 degrees of the night sky within 5 hours.*

*By waiting in between point analysis the repeated point analysis would consume much less power and be able to run for 12 hours.*

#### Battery Operating Time

The system shall be able to function on battery power for a period of 6hrs.

*Rationale: The system needs to have enough power to calibrate the telescope at the beginning of the set-up and scan the sky to produce an image. The scan time of the system could take up to six hours depending on the size of the area selected.*

### Physical Characteristics

#### Mass

The system shall be made up of separable parts that are less than or equal to 25 kg per component.

*Rationale: The system needs to be transportable by two average adults. The entire system shall be separated into parts for transportation, each of the parts shall be less than the defined mass for ease of transportation.*

#### Volume Envelope

The antenna and motorized stand shall each stand less than or equal to 1 meter cubed.

*Rationale: Each part of this system must be able to be transported by two adults and a vehicle.*

#### Mounting

The antenna shall be mounted on a motorized stand that may rest on any stable, relatively level surface.

*Rationale: The antenna will be movable to the user’s desired location. The antenna and motorized mount will be connected and can rest on any stable surface for celestial viewing.*

### Electrical Characteristics

#### Inputs

1. The presence or absence of any combination of the input signals in accordance with ICD specifications applied in any sequence shall not damage the Search and Rescue System, reduce its life expectancy, or cause any malfunction, either when the unit is powered or when it is not.
2. No sequence of command shall damage the Search and Rescue System, reduce its life expectancy, or cause any malfunction.

Rationale: By design, should limit the chance of damage or malfunction by user/technician error.

##### Power Consumption

The maximum peak power of the system shall not exceed 45 watts.

*Rationale:  This requirement is to ensure the proper operation of all subsystems within the Hydrogen Line Telescope.*

##### Input Voltage Level

The input voltage level for the Raspberry Pi 4 shall be 5V, the input voltage level for the DC stepper motors shall be less than or equal to 24V.

*Rationale:  The Raspberry PI 4 is designed to run off of 5V while the DC stepper motors are designed to run off of a voltage less than 24V.*

##### External Commands

The Hydrogen Line Telescope shall document all external commands in the appropriate ICD.

*Rationale:  The ICD will capture all interface details from the low-level electrical to the high-level packet format.*

#### Outputs

##### Data Output

The Hydrogen Line Telescope will include a graphical user interface (GUI) for the user to view the telescope's progress and resulting image.

*Rationale: The Hydrogen Line Telescope data will be readily available to the user through a GUI.*

##### Diagnostic Output

The Hydrogen Line Telescope may include a diagnostic interface for control and data logging.

Rationale:  Provides the user with a tool for manual debugging.

### Environmental Requirements

The Hydrogen Line Telescope shall be designed to withstand and operate in the environments and laboratory tests specified in the following section.

*Rationale: The Hydrogen Line Telescope should be able to function properly in an outdoor setting similar to the Bryan, TX / College Station, TX area.*

#### Pressure (Altitude)

The Hydrogen Line Telescope may be able to function properly at altitudes ranging from sea level to 500 feet above sea level.

#### Thermal

The Hydrogen Line Telescope may be able to function properly in an environment with temperatures ranging from 32°F to 120°F.

*Rationale: The system will be able to operate in temperatures reasonable for extended outdoor exposure by the system and the user(s).*

#### Humidity

The Hydrogen Line Telescope may be able to function properly in relative humidity ranging from 0% to 70%.

*Rationale:  The system way be able to operate in moderately humid conditions.*

### Failure Propagation

The Hydrogen Line Telescope shall not allow propagation of faults beyond the Hydrogen Line Telescope interface.

#### Failure Detection, Isolation, and Recovery (FDIR)

The Hydrogen Line Telescope may have failure detection in the calibration that is run at startup. The calibration process, which levels and positions the system appropriately, may detect any faults in the motorized mount, antenna, or Raspberry PI. If any faults are detected, the system will send an alert to the user and shut down the appropriate subsystems. The system will recover after the user receives the alert informing them of the issue(s) allowing the user to fix the problem and proceed to calibrate and setup the system as usual.

# Support Requirements

The Hydrogen Line Telescope requires a laptop with Bluetooth capability in order to connect to the Raspberry PI for data transfer. The user must provide power to the laptop if needed, the rest of the HLT system will be powered by a portable battery. The user must have access to a vehicle for transportation and an open, flat area for hydrogen line emission viewing.

# Appendix A: Acronyms and Abbreviations

GUI Graphical User Interface

ICD Interface Control Document

MHz Megahertz (1,000,000 Hz)

W Watt

V Volts

A Amp

mA Milliamp

HLT Hydrogen Line Telescope

HPBW Half Power Beamwidth

dBi Decibels Compared to Isotropic

SDR Software-Defined Radio

LNA Low Noise Amplifier

RPA Repeated Point Analysis

# Appendix B: Definition of Terms