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# Prototyping the graphical user interface for the operator of the Cherenkov Telescope Array

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## ABSTRACT

The Cherenkov Telescope Array (CTA) is a planned gamma-ray observatory. CTA will incorporate about 100 imaging atmospheric Cherenkov telescopes (IACTs) at a Southern site, and about 20 in the North. Previous IACT experiments have used up to five telescopes. Subsequently, the design of a graphical user interface (GUI) for the operator of CTA involves new challenges. We present a GUI prototype, the concept for which is being developed in collaboration with experts from the field of Human-Computer Interaction (HCI). The prototype is based on Web technology; it incorporates a Python web server, Web Sockets and graphics generated with the `d3.js` Javascript library.

**Keywords:** The Cherenkov Telescope Array, graphical user interface, Web technology.

## 1. INTRODUCTION

The Cherenkov Telescope Array (CTA)<sup>1-3</sup> is a planned observatory for very high-energy ( $> 100$  GeV) gamma-rays. Gamma-rays induce particle cascades in the atmosphere. These are accompanied by Cherenkov radiation, which is emitted by the charged particles in the cascade. The Cherenkov light may be detected by imaging atmospheric Cherenkov telescopes (IACTs).<sup>4</sup> Using multiple telescopes in concert, Cherenkov showers can stereoscopically be sampled, allowing to reconstruct the properties of the primary gamma-ray.

CTA will include three different telescope types, sensitive to different gamma-ray energy ranges. The telescopes will be deployed in two sites, Northern and Southern, which will respectively include about 100 and about 20 telescopes. Currently running IACT experiments such as H.E.S.S.,<sup>5</sup> MAGIC<sup>6</sup> and VERITAS,<sup>7</sup> are restricted to up to five telescopes. Compared to these instruments, the large number of CTA telescopes will improve the sensitivity and the energy coverage of gamma-ray measurements by at least an order of magnitude.

The large number of telescopes has implications for the development of a graphical user interface (GUI) for the operator of a CTA site. The complexity of the system presents new and interesting challenges, requiring innovative design. In the following, we detail the development process of the operator GUI. We discuss the requirements we have derived for the GUI, and describe our prototype implementation.

## 2. DEVELOPMENT PROCESS AND REQUIREMENTS FOR THE GUI

In order to develop an effective user interface, we have drawn upon the lessons learnt from the Atacama Large Millimeter/submillimeter Array (ALMA).<sup>8</sup> ALMA is an astronomical interferometer of radio telescopes in the Atacama desert of northern Chile. It will be comprised of up to 66 radio antennas, and so will be comparable to CTA in complexity.

During the early stages of ALMA, conventional user interfaces were developed. Early experience operating the ALMA array with only a few antennas, indicated that the latter were not adequate. The initial interfaces required many unnecessary interactions to access relevant information. This resulted in extraneous cognitive

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40 load, and was not efficient for quick diagnosis of system problems. The implementation was therefore improved,  
41 taking into account advances in the field of Human-Computer Interaction (HCI).<sup>9</sup>

42 For creating the GUI for the operator of CTA, we are following the design process used for ALMA. The  
43 GUI is being developed by involving experienced telescope operators and astroparticle physicists on the one  
44 hand, and experts from the field of HCI on the other. In contrast to ALMA, we have been able to adopt this  
45 model at the start of the design process for CTA. We will therefore be able to apply HCI input to all aspects  
46 of the operator interface. The development process includes practical face-to-face meetings, in tangent with  
47 brainstorming workshops with representatives of the relevant stakeholders. To date, we have held two such  
48 participatory design workshops. The outcome of the meetings is twofold. For one, the workshops helped us  
49 to refine the scope of the operator GUI, i.e., answer the question, “what should the GUI enable users to do?”.  
50 Additionally, we have defined a preliminary set of panels for the GUI. That is, we have begun to address the  
51 question, “how should the GUI be designed?”.

52 With regards to the first question, we first note that on-site operations related to observing with CTA will  
53 normally be automated. Consequently, the GUI for the operator of a CTA site will nominally be used to perform  
54 the following tasks:

- 55 1. initiate and end observations;
- 56 2. override the automated scheduled operations in order to perform a specific task, or for safety reasons, which  
57 might require manual control over a given telescope or group of telescopes;
- 58 3. monitor the state of the array during data acquisition, which includes monitoring of low-level hardware  
59 components, of software processes, and of the output of a near real-time data analysis;
- 60 4. identify and diagnose problems with specific sub-systems or processes, in order to solve minor problems or  
61 notify technical experts, as needed.

62 With regards to the second question, we have defined the following categories, which will be represented by  
63 different GUI panels (some of which may overlap):

- 64 1. **Telescope:** monitor the status of telescopes and their respective sub-systems; manually control single  
65 telescopes and sub-arrays, etc.
- 66 2. **Process:** monitor and modify predefined operation sequences, such as starting up the array at the begin-  
67 ning of the night, and performing a scheduled observing task.
- 68 3. **Science:** monitor the output of a physics analysis on the level of a single telescope or of a sub-array,  
69 including trigger rates, event-reconstruction metrics, science summary reports, etc.
- 70 4. **Infrastructure:** monitor the status of auxiliary systems, such as the power grid, as well as other indicators,  
71 such as alarms and data transfer rates.
- 72 5. **Environment:** monitor environmental systems, such as weather monitors, all-sky cameras, etc.
- 73 6. **Miscellaneous:** provide access to terminals, shift logs, expert call sheets, etc.

74 With these guidelines in mind, we have identified the following set of initial requirements for the GUI:

- 75 1. the GUI will be able to convey information for various levels of telescope multiplicity; on the level of  
76 the entire array ( $\sim 100$  telescopes); the level of sub arrays (between 1 and 32 groups); or the level of a  
77 single telescope and the associated sub-systems. Multi-telescope views for a given sub-system will also be  
78 available, which will take into account differences between telescope types. The various levels of information  
79 will be integrated using semantic zooming, as defined below;
- 80 2. the GUI will need to be highly responsive, where the different panels of the GUI will have the option to  
81 be synchronized;

- 82 3. the GUI will integrate different interfaces to CTA software (databases, live feeds etc.) with various latencies;  
83 4. the different components of the GUI will be modular, allowing for quick updates and for collaborative  
84 development.

85 In the next section, we illustrate the requirements for the operator GUI using a prototype design. At this  
86 stage of development, the prototype by no means addresses the complete scope of the GUI. Instead, it acts as a  
87 proof of concept for those features which were identified as most important.

### 88 3. PROTOTYPING ACTIVITIES

89 Our prototype is based on Web technologies. A Web-based framework has the advantage of being lightweight and  
90 modular. It also naturally allows for remote access, which will enable the GUI to be used for remote monitoring,  
91 and for remote operation. These will be useful both for physicists and for technical experts, who the operator of  
92 the array will need to consult.

93 The back-end of the prototype is a Python server called Pyramid.\* A Python framework has the advantage of  
94 being very versatile, incorporating the ability to use many off-the-shelf libraries for computation, communication,  
95 multi-threading and multi-processing. The front-end is a web browser. The design is responsive, i.e., adjustable  
96 according to the width of the display. It is implemented using Polymer,† a Web Component application pro-  
97 gramming interface (API), developed by Google, based on the Material Design‡ concept. Data are displayed  
98 using an open-source Javascript library, called d3.js.§ The latter is a data-driven framework, with integrated  
99 mechanisms for displaying, updating and animating vector graphics. Communication between the back-end and  
100 the front-end of the GUI is performed using Web Sockets. These allow asynchronous communication, facilitat-  
101 ing quick and robust GUI behaviour. For plotting, we also use dc.js,¶ a library based on d3.js and on  
102 Crossfilter.∥ The latter is a Javascript library, which facilitates exploring large multivariate datasets.

103 Figure 1 shows a representation of the layout of a CTA array, where each circle corresponds to a single  
104 telescope. The relative position of telescopes corresponds to a scaled physical layout on-site, constituting a  
105 pseudo-geographic display of the array. The attached numerical values and the colour scheme of elements  
106 correspond to a *health metric*. This metric may represent different properties according to the *visualization*  
107 *context*. The panel incorporates *semantic zooming*,<sup>10</sup> which defines the context. Semantic zooming is a technique  
108 of assigning different layers of information to a given visual element. This behaviour complements the usual  
109 geometric zooming, where the size of elements changes with the zoom factor. For the type of semantic zoom  
110 implemented in this example, the level of detail associated with an element increases as one zooms-in. The figure  
111 shows the evolution of the display for different zoom factors, as follows.

112 **Zoom factor 1:** Figure 1(a) shows a global view of all telescopes, emphasizing physical positions, as well  
113 as a general health metric. In this example, health corresponds to the combined health of all sub-systems of  
114 the telescope. For illustration, one of these sub-system, the camera, reports reduced health as the percentage of  
115 dead pixels.

116 **Zoom factor 7:** Given this zoom level, Fig. 1(b) shows how the display changes for a given element which is  
117 hovered over. The hover action triggers a transition, where a circle representing a single telescope is replaced by  
118 a more detailed view of the associated sub-systems. The context from the previous zoom level is preserved during  
119 the transition. The health metric, which was previously represented by the full circle, has morphed into the red  
120 circle surrounding the four wedges. Each of the wedges represents one of the sub-systems of a telescope: the  
121 data-acquisition system (DAQ); the camera; the mirror system; and the mount (the structure of the telescope).  
122 Each of the latter now also reports its individual health metric. These are represented numerically, by colour  
123 and by the percentage of filled area within the corresponding wedge.

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\* See <http://docs.pylonsproject.org/projects/pyramid/> .

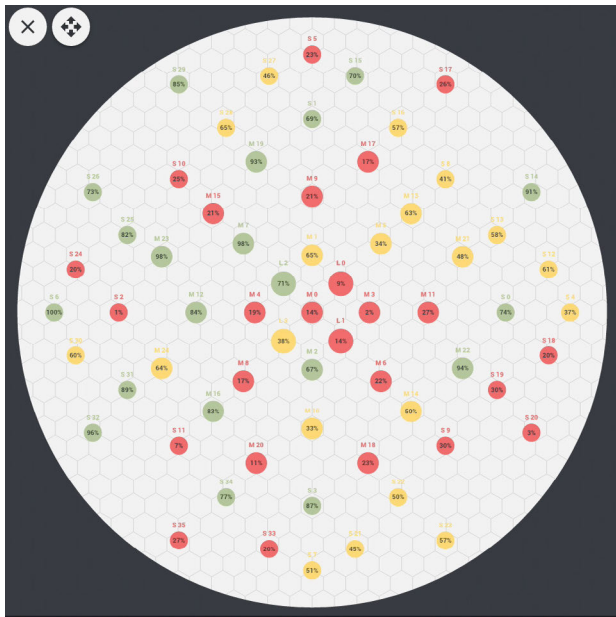
† See <https://www.polymer-project.org/> .

‡ See <https://design.google.com/> .

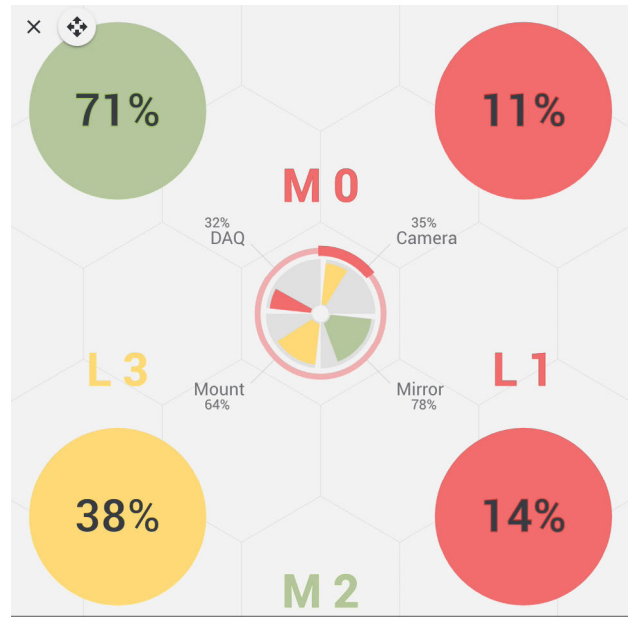
§ See <https://d3js.org/> .

¶ See <https://github.com/dc-js/dc.js> .

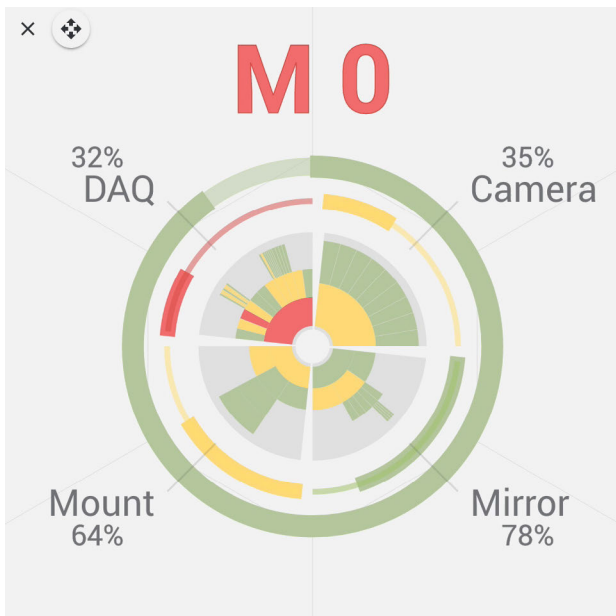
∥ See <http://square.github.io/crossfilter/> .



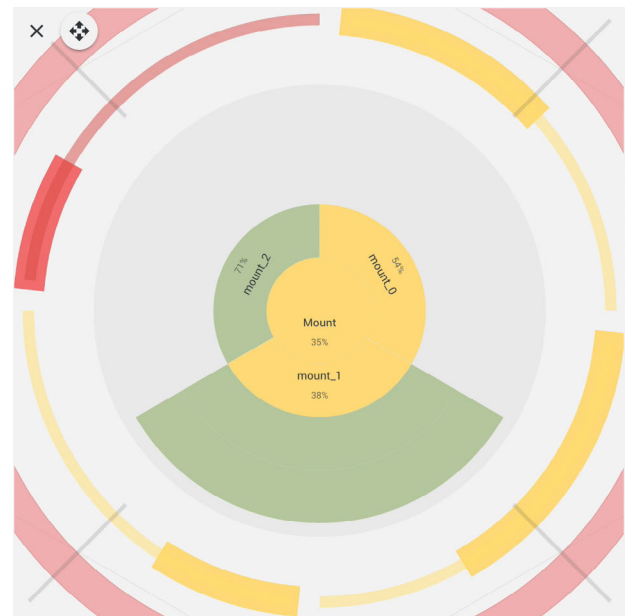
(a)



(b)



(c)



(d)

Figure 1. Pseudo-geographic display of a CTA array, showing different semantic zoom levels, as described in the text. The zoom factors are 1 in (a), 7 in (b), and  $\sim 14$  in (c) and (d).

124 **Zoom factor  $\sim 14$ :** Given this zoom level, another transition occurs. Figure 1(c) shows a second level of  
125 components, which is exposed for each of the four sub-systems. As before, the context from the previous zoom  
126 level is preserved; the health metric of each of the sub-systems is now represented by a thin outer arc. The inner  
127 wedges now each have different layouts of components. These are arranged in *sunburst diagrams*,<sup>11</sup> which are a  
128 hierarchical variation on a pie chart. The change from the view shown in Fig. 1(c) to that shown in Fig. 1(d)  
129 occurs as the user clicks on the wedge of the mount. The sunburst diagram of the latter then opens up to a  
130 full  $360^\circ$ , and the wedges of the DAQ, camera and mirror disappear. The generic names (`mount_0`, `mount_1`,  
131 etc.) are temporary place-holders for different elements of the mount sub-system, such as drivers and PLC  
132 (programmable logic controller) status indicators.<sup>12</sup>

133 Figure 2 presents another telescope-centric view. In this case, two synchronized panels are provided side by  
134 side. The panel on the left shows the positions on the sky, at which telescopes point. The polar plot has two  
135 coordinates. The angular coordinate, denoted by  $\varphi$ , represents the azimuth on the sky; it spans the range from  $0^\circ$   
136 (at the top-most position of the circle) to  $180^\circ$  (for the right-hand side), and  $0^\circ$  to  $-180^\circ$  (for the left-hand side).  
137 The radial coordinate, denoted by  $\delta$ , indicates the zenith, with values between  $0^\circ$  (at the centre) and  $90^\circ$  (on  
138 the edge of the figure). Telescopes are represented by full circles. Each one has an intended target position,  
139 indicated by rings, where faint dashed lines connect telescopes and targets. The display is updated in real-time,  
140 showing the movement of telescopes from their initial pointing, towards their respective target positions.

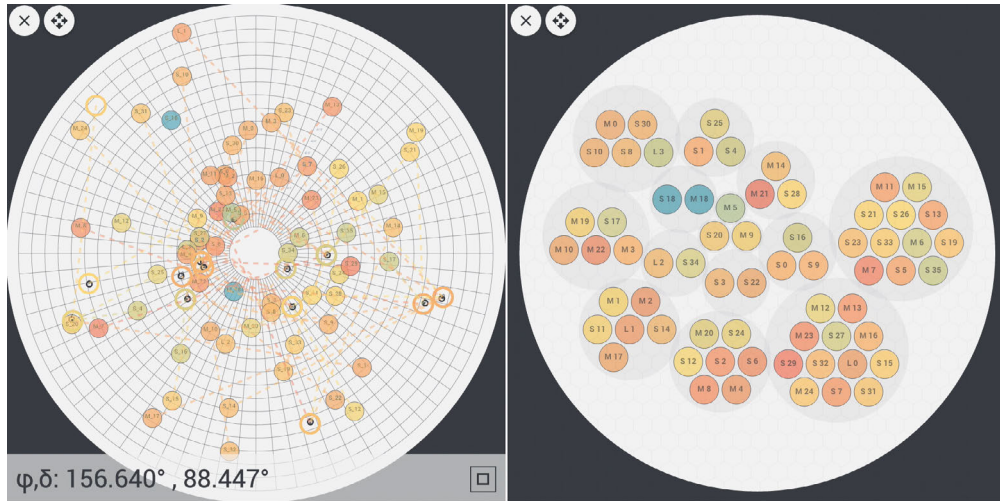
141 The panel on the right shows a logical grouping of telescopes, as opposed to the pseudo-geographic display  
142 of Fig. 1. In this case, telescope positions indicate association to a sub-array, which here stands for a group of  
143 telescopes which all point at the same target on the sky. This type of visualization, called an *enclosure diagram*,  
144 is a hierarchical nested layout of elements. In this case, grey-shaded circles represent sub-arrays, with coloured  
145 circles standing for telescopes.

146 Both the panel on the left and that on the right incorporate semantic zooming, as indicated by comparing  
147 Figs. 2(a), 2(b), and 2(c). For the left panel, the behaviour is a simple scaling of elements. As one zooms in or  
148 out, the size of telescopes and targets changes very slowly with respect to the changing scale of the coordinate  
149 system. For the panel on the right, the semantic zoom includes a threshold transition at zoom factor  $\sim 2$ , as  
150 shown in Fig. 2(b). In this example, each telescope is represented by a circle and an arc; these respectively  
151 indicate the  $\varphi$  and  $\delta$  coordinates of the telescope and its target, using the same visual language as for the panel  
152 on the left. Another threshold transition occurs at zoom factor  $\sim 14$ , as presented in Fig. 2(c). In this instance,  
153 the purpose of the visualization is to provide detailed information regarding the coordinates of the telescope.

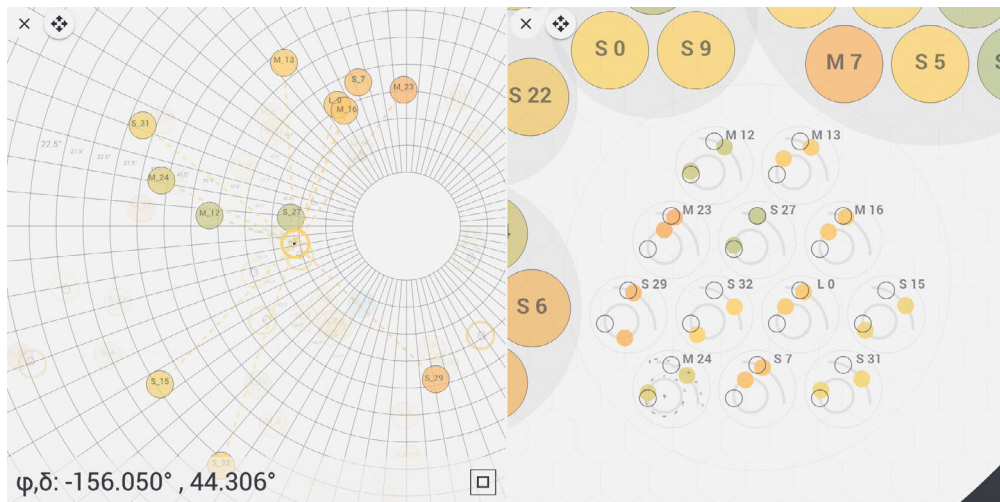
154 The two panels are synchronized using brushing and linking, following the principles of coordinated multiple  
155 views.<sup>13</sup> In Fig. 2(b), a sub-array is selected on the right panel; this causes the associated elements in the panel  
156 on the left to become highlighted. Such behaviour allows to quickly identify in the display on the left, which  
157 telescopes are assigned to which sub-array. In Fig. 2(c), the single selected telescope is similarly the only element  
158 in focus, both on the right panel and on the left. The interplay between the two panels illustrated here also  
159 serves to demonstrate an important feature of panel-synchronization. Namely, that synchronization need not  
160 necessarily work both ways. As in this case, user interactions with the panel on the right affect the panel on the  
161 left by focusing specific elements, but the reverse does not hold.

162 Figure 3 shows three views of a panel featuring monitoring plots. In this example, the data are extracted  
163 from the database of a weather monitoring station. They include measurements of the temperature inside and  
164 outside of the weather station, of the speed of the wind near the station, and of the humidity inside of it.

165 The monitoring plots are placed inside a container, designated as a *Dashboard*. Plots may be resized and  
166 dragged within the Dashboard, or placed in separate Dashboards. The plots are generated using `dc.js`. They  
167 are correlated (a feature of `Crossfilter`), as shown in, e.g., Fig. 3(b). In this case, the user has selected a range  
168 of values of the wind speed parameter (marked by the blue brush). The other plots reflect the selection, by  
169 showing only those measurements which have corresponding wind speeds within the chosen range. A side-menu  
170 may be overlaid on top of the plots, as shown in Fig. 3(c). Several control options exist. To name a few, the  
171 user may add new plots; the user may select new dates for querying the database; and the user may switch to a  
172 *live-mode*, where real-time data are updated every few seconds.



(a)

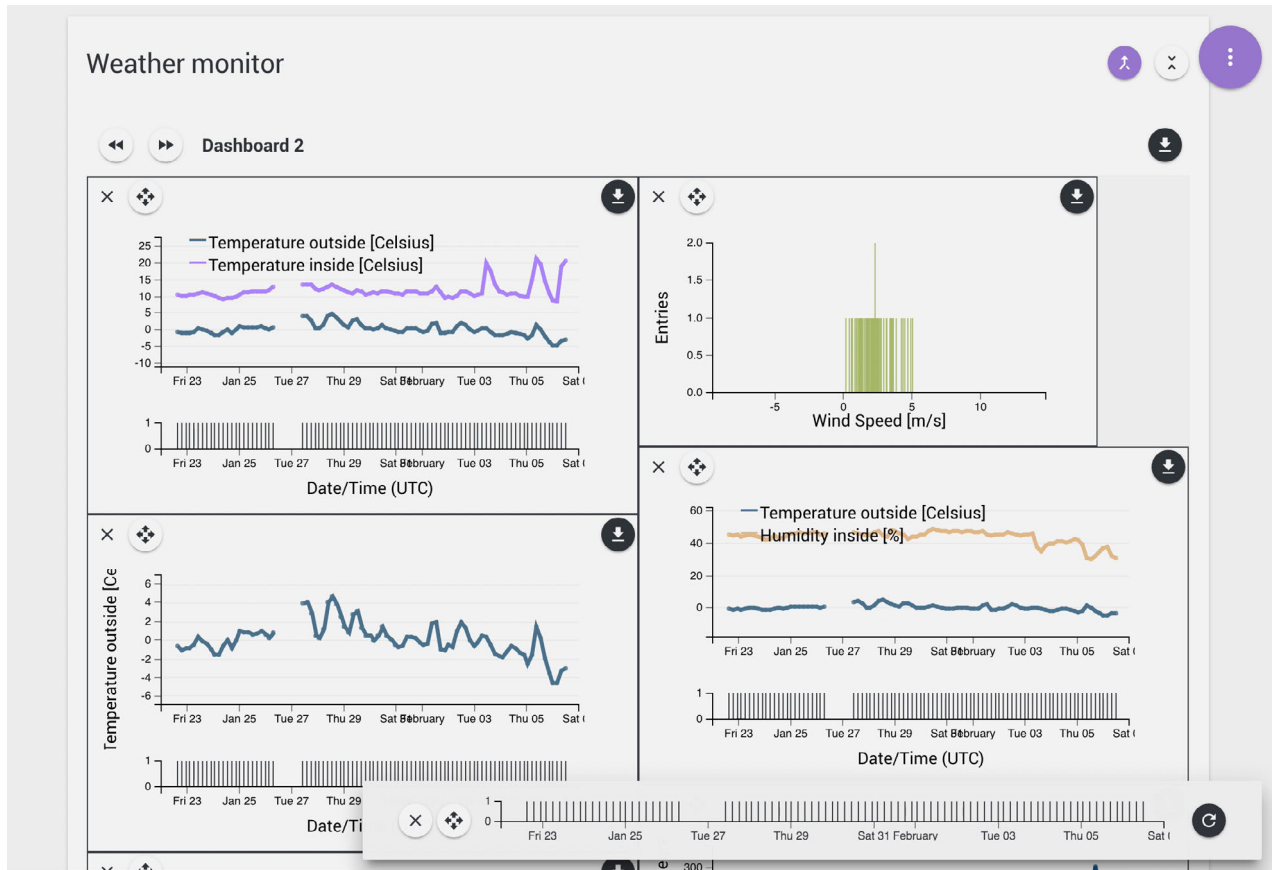


(b)



(c)

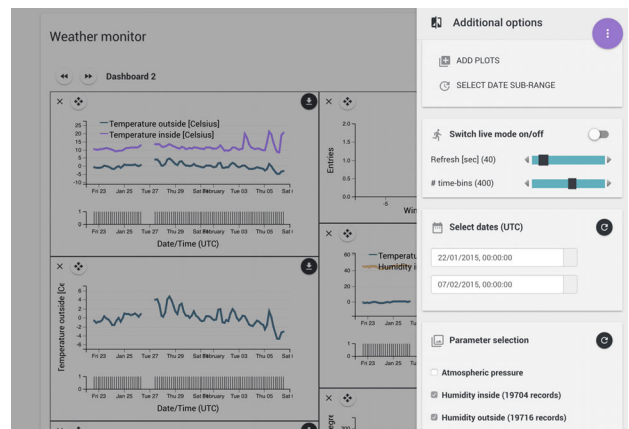
Figure 2. Synchronized panels, showing the positions on the sky at which telescopes point (left), and the grouping of telescopes into sub-arrays (right), as described in the text. The zoom factors for the panel on the right are 1 in (a), 2 in (b), and  $\sim 14$  in (c).



(a)



(b)



(c)

Figure 3. Example of a monitoring panel, featuring data extracted from the database of a weather monitoring station. (a) : A selection of data monitoring plots, including measurements of the temperature inside and outside of the weather station, of the speed of the wind near the station, and of the humidity inside of it. (b) : Illustration of the synchronization of plots. A selected range of values of the wind speed parameter (marked in blue), affects the other plots, by excluding data outside of the chosen scope. (c) : A side-menu with various control options may be overlaid on top of the plots, upon clicking the purple button on the top right corner. The option also exists (not shown), of pinning the menu alongside the plots instead.



173 The main purpose for implementing this visualization, was to create a practical example for a monitoring  
174 panel. In addition, it was also used as a platform to conduct tests of our prototype. These included the following:  
175 testing the performance of the `dc.js` library for generating synchronized plots; testing the performance of an  
176 interface between the `Python` web-server and an external database; splitting data processing tasks between the  
177 `Python` server and the web-browser client. The results of these tests have so far been encouraging; they have  
178 indicated that a web-based framework is suitable for the next stages of development of the operator GUI.

#### 179 4. SUMMARY

180 The planned Cherenkov Telescope Array will be comparably more complex than existing IACT experiments.  
181 This poses new challenges for creating an effective graphical user interface for the operator of the array.

182 The development of the GUI for CTA follows the successful working model of the ALMA experiment. The  
183 design process brings together experienced telescope operators and astroparticle physicists on the one hand,  
184 and experts from the field of Human-Computer Interaction on the other. The relevant stakeholders have so  
185 far conducted two participatory design workshops, in addition to other face-to-face meetings. The outcome of  
186 the work to date is: a refined definition of the scope of the GUI and of the requirements on its performance; a  
187 preliminary list of GUI panels; identification of a set of relevant data visualization techniques.

188 A preliminary prototype of several GUI panels has been implemented. It is based on Web technologies,  
189 incorporating a `Python` web server, `Web Sockets` and graphics generated with the `d3.js` Javascript library.  
190 The prototype illustrates semantic zooming and coordinated multiple views, and serves for performance testing  
191 of the proposed technology.

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