Project 1





**FDIR**

*Spacecraft fault protection system*

**Euro Team**

|  |  |
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**CS554 - Design for Software & Systems**

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**Introduction**

In the purpose of applying and studying real case project for the *Design for Softwares and Systems* course, our team is required to understand and design a fault protection system for a spacecraft as described in the article by Steve Easterbrook et al. [Eas98]. The first part of this global project is to understand the problems we have to respond, to specify the needs of our client and to start thinking about a user system interface.

More specifically, we are required to use two different methods for problem understanding, namely **problem frame analysis** and **use-case modeling**. The goal of this study is to get hands-on experience of these two concepts and understand how they can be combined in order to resolve a problem.

When performing use-case modeling and problem frame analysis, we have to analyze the requirements as described in [Eas98], the direct **user needs**. Then, we are expected to identify the **non-functional requirements** of the system as well. Besides that, when identifying non-functional requirements, however, we could improvise and add more quality attributes that we believe are essential to the system in question.

To conclude, we have to consider the **usability issues** for designing the **user interface** of the system, as we learn a couple of weeks ago and provide some screen shots of our interface.

Thanks to our work on the usability, we revised a lot our previous work, starting from the UML design and non-functional requirement. Moreover, our team has been involved in refactoring this project 1 considering the professor & TA feedbacks.

1. **Problem understanding**
   1. Business case & system context

Nowadays embedded development and mission-critical software present a serious and unmet need for early feedback on the viability of a system. Indeed the impact of early feedback on cost and safety has been demonstrated empirically. In a pragmatic and lightweight application of formal methods, we can offer a cost-effective way of improving the quality of software specifications. In this purpose the use of these methods led people to the creation of a new system: the **F**ault **D**etection, **I**solation and **R**ecovery system (**FDIR**).

This system is specially designed for a spacecraft and provides specific functions needed and requested by the client which make this product unique. Customer presents two main needs about this system: the guarantee of the completion of any time critical activities, and the control of the spacecraft with safety, observability and commandability. Indeed each spacecraft device has a predefined set of operating parameters that have a normal operating range. Values beyond this range are called “*out-of-tolerance”*. Besides that, an out of-tolerance condition may come from any possible causes. That is why information from multiple sources must be combined in order to locate the fault.

The FDIR system is unique and specially designed to generate appropriate responses when out-of-tolerance conditions are detected in hardware and software components. It means that it will be able to recover the data, locate the fault with precision and to fix them as well by a restart of a system for example. Moreover this system is designed to answer all actions launched by the crew or the flight controller on Earth. Both actors are able to interact together and launch different actions at the same time.

In this purpose, the requirements of the system are the followings:

1. **Guarantee the completion of any time critical activities of the spaceship**. Even if a device has a problem, the system must be able to analyze, locate the fault, and restart the action again, even if it has to fix by anyway the problem before (recover the data, or restart the device for example).
2. **The system provides a manual control for the user**. The crew or the flight controller must be able at any time to restart, shutdown, or switch to a spare system.
3. **To control the spacecraft and the FDIR system, the crew has to know information about each device**. That is why the system will display information continuously to the both actors.
4. **The system will be able to collect data to data storage**. All data during the journey will be store in a safe place on the spacecraft. After that, the crew must be able during the complete mission to **retrieve old information about a device**, to compare with actual data for example.
5. **System must display the failure localization**. In this goal, system has specific tools to detect and locate failure in a part of the ship, and display information with precision to the crew
6. FDIR Storage System contains the collected values or data from devices as said before. FDIR checks the inputs from the storage system, and analyses these inputs to determine if irresolvable conditions has been reached. **Information about irresolvable conditions is written into a report sent as a notification to the crew.**
7. **System presents an automatic recovery to failure.** If a system is failing, FDIR is required to act on its own to discover the crash,
8. **Keep the control of the spacecraft with safety, observability & commandability.**
   1. Problem frames
      1. Domains identification
      2. Context Diagram
      3. Problem frames
9. **Functional requirements (use-case model)**
   1. Use-case diagram
      1. Actors description

The FDIR system is designed to control systems of the spacecraft. But this system can act alone, would be useless if there were no human control to decide which actions the system must launch. Therefore, this system is designed for the crew of the spacecraft during their mission. Moreover the spacecraft and the crew are helped by the flight controller on Earth. They could do same actions as the crew. For example, during the time the crew sleep, the crew could command the system and do some tests, get information about any devices,…

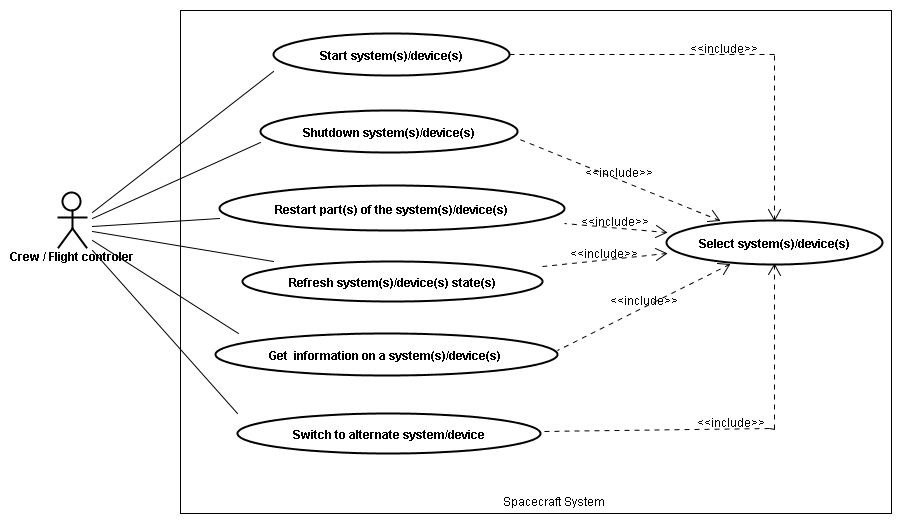
* + 1. Use-case diagram

Figure 1: Use case diagram

* + 1. Use-case specifications

|  |  |
| --- | --- |
| Name | Start system(s)/device(s) |
| Actors | Crew / Flight control |
| Description | User can start device(s) or system(s) of the spacecraft system whenever he wants or because it was shutdown |
| Precondition | - System(s) are off  - One or several device(s) or system(s) have been selected |
| Events flow | 1. Click on the “start” button  2. Wait for the system to start |
| Post-condition | System(s) has been started |
| Exception | - System states could be already turned on while it is still displayed as “off” on the FDIR system |

|  |  |
| --- | --- |
| Name | Shutdown system(s)/device(s) |
| Actors | Crew / Flight control |
| Description | User can shutdown device(s) or a part(s) of the spacecraft system whenever he wants or in case of failure |
| Precondition | - Devices or parts of the system have to be running  - One or several device(s) or system(s) have been selected  - Other systems must not have dependencies to the selected device(s) or system(s) |
| Events flow | 1. Click on the “shutdown” button |
| Post-condition | System(s) has been shutdown |
| Exception | * System states could be already turned off while it is still displayed as “running” on the FDIR system * If other systems have dependencies to the selected devices(s) or system(s) display a warning and information about the dependencies and offer to override. |

|  |  |
| --- | --- |
| Name | Restart part(s) of the system(s)/device(s) |
| Actors | Crew / Flight control |
| Description | User can restart a device or a part of the spacecraft system whenever he wants or in case of failure |
| Precondition | - Device or part of the system has to be running  - Requested system(s)/device(s) have been selected  - Other systems must not have dependencies to the selected device(s) or system(s) |
| Events flow | 1. Click on the “restart” button |
| Post-condition | System is restarting |
| Exception | * System states could be already turned off while it is still displayed as “running” on the FDIR system * If other systems have dependencies to the selected devices(s) or system(s) display a warning and information about the dependencies and offer to override. |

|  |  |
| --- | --- |
| Name | Refresh system(s)/device(s) states |
| Actors | Crew / Flight control |
| Description | User can refresh the states of any device or system to see if this one is still working correctly or not |
| Precondition | - Device or part of the system has to be running  - Requested system(s)/device(s) have been selected |
| Events flow | 1. Click on the “refresh” button |
| Post-condition | System is refreshing |
| Exception | - If the system(s) or device(s) are not responding change status not responding. |

|  |  |
| --- | --- |
| Name | Switch to alternate system/device |
| Actors | Crew / Flight control |
| Description | If the device is not responding or if there is a failure, user may switch to another system/device |
| Precondition | - Select **one and only one** system or device  - Other system(s) or device(s) must not have dependencies to the selected system, or the switch has to be able to be done seamlessly. |
| Events flow | 1. Click on the “switch” button |
| Post-condition | Alternate system takes the control. |
| Exception | * If the alternate system is broken as well, it may generate a fatal error of the system * If other system(s) or device(s) have dependencies to the selected systems and the switch cannot be made seamlessly, display a warning and information about the dependencies, and offer to override. |

|  |  |
| --- | --- |
| Name | Get information on a system(s)/device(s) |
| Actors | Crew / Flight control |
| Description | User may seek information about any device or system on the spacecraft |
| Precondition | - Requested system(s)/device(s) have been selected |
| Events flow | 1. Specify query  2. Click on the *GetInfo* button |
| Post-condition | Information about the selected system appears on the screen. |
| Exception |  |

|  |  |
| --- | --- |
| Name | Select system(s)/device(s) |
| Actors | Crew / Flight control |
| Description | User can select any system or device in order to issue commands |
| Precondition |  |
| Events flow | 1. Select the requested part(s) |
| Post-condition | The chosen part is selected. |
| Exception | The chosen part is still not selected. |

* 1. Sequence diagrams

We build several sequence diagrams in order to explain in detail the use case diagram and specification. Indeed, as the FDIR system is not represented in the use cases, we need to see how it is interacting with the spacecraft, the crew and the ground controller. Three sequence diagrams are explaining how the FDIR is working: *Fault recovery*, *Safe response in case of hazardous*conditions and *Critical failure*.

Moreover, we present three sequences diagrams about the crew and flight controller actions: *Select system & get information*, *Start system, restart system & refresh system state* and *Backup system and shutdown system*.

* + 1. Fault recovery

Fault recovering scenario shows interactions between the FDIR system and the spacecraft when a fault is detected. FDIR is controlling several values. If one is in an out-of-tolerance state, it be automatically returned to the FDIR which will start the fault localization process. Once the fault has been located, FDIR will be able to proceed to several actions like *recovery*, *shutdown* or *retry*.

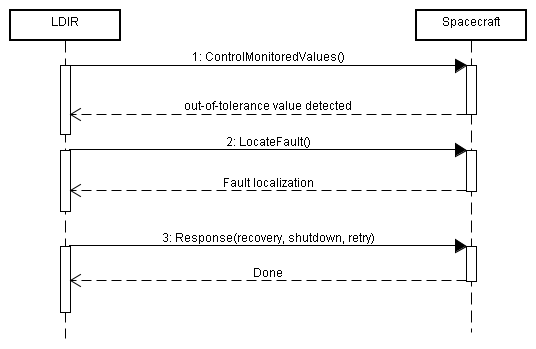


Figure 2: Sequence diagram - Fault recovery

* + 1. Safe response in case of hazardous conditions

This scenario start after that FDIR has detected a hazardous condition of problem in the spacecraft. After having isolated the problem, FDIR is able to proceed to two different actions depending of the kind of spacecraft (unmanned or manned spacecraft).

Within an unmanned spacecraft, FDIR will shut down all the non-critical functions in order to focus on the device/system problem and minimize the damages. It will also move the antenna to point toward earth in order to receive human commands and decisions.

Within a manned spacecraft, process is easier because as humans are inside the spacecraft, they can directly interact with the system without needing is functions shutdown process or antenna redirection. Then LDIR is just giving the hand to the crew.

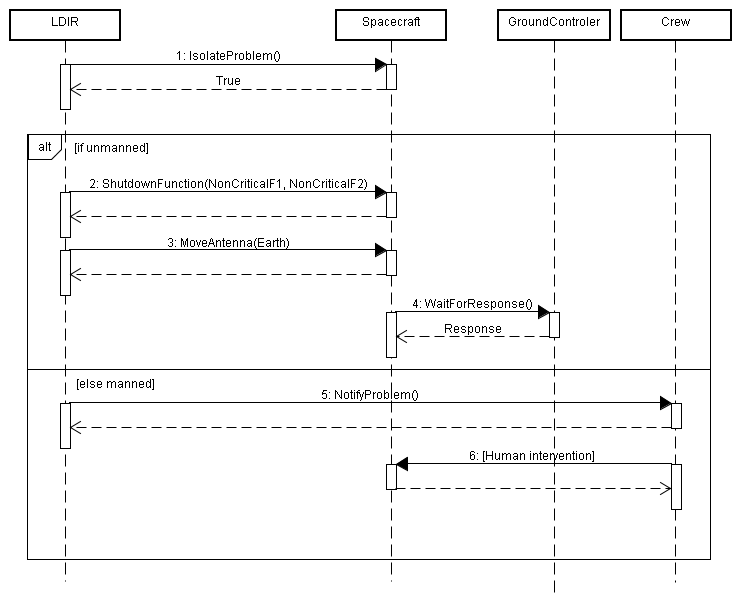
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Figure 3: Sequence diagram - Safe response in case of hazardous conditions

* + 1. Critical failure

Critical failure scenario starts as the *Fault recovery* scenario (cf. 2.2.1) as we consider the detection of an out-of-tolerance value in the spacecraft. But if a failure cannot be recovered, FDIR system is going thru different decisions and actions. After localizing the error, FDIR is giving the hand to the crew and put itself in a manual mode state. Crew can then execute several actions like *backup*, *shutdown* or *retry*.

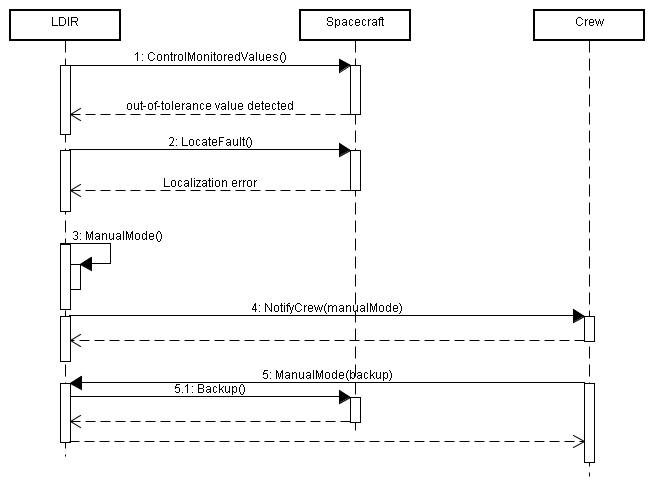
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Figure 4: Sequence diagram - Critical failure

* + 1. Select system & get information

This sequence diagram is introducing the first actions the crew or space controllers are doing. First of all, they have to select the system they want to access to do several actions. Once selected, they can check its information state. All the systems are displayed in a first screen called *System List screen*. We represent this screen by the *SystemListUI* object. When the crew push the button *display information* (*getSystemInformation* attribute), the second screen is receiving the action and shows the system information. This one is called *Information system screen*, and represented by *SystemInformationUI*.

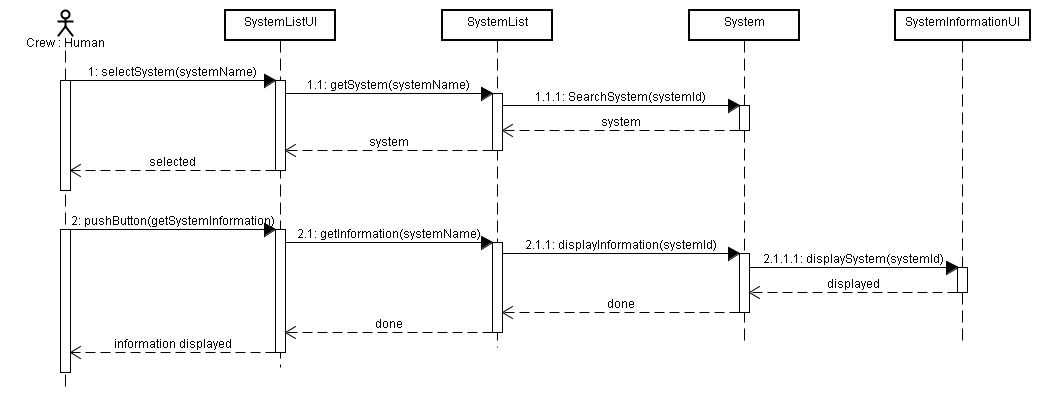
This and the two next sequences diagrams are containing the System object. This one is representing a system in general, but it could be one of the system’s devices.

Figure 5: Sequence diagram - select system & get information

* + 1. Start system, restart system & refresh system state

The goal of the following sequence diagram is to explain the behavior of action buttons while system is selected and the relevance of the *refresh system* button.

Indeed, the refresh button is really useful as a system is sometime doing something whereas its state is not updating. For example, a system can be showed at turned off while it was just restarting. User is attending to do some actions like *start* the system whereas it is already running. This is this case of system behavior we try to explain thanks to this diagram. Moreover, it is also helping you to understand how the *start* and *restart* actions are working.

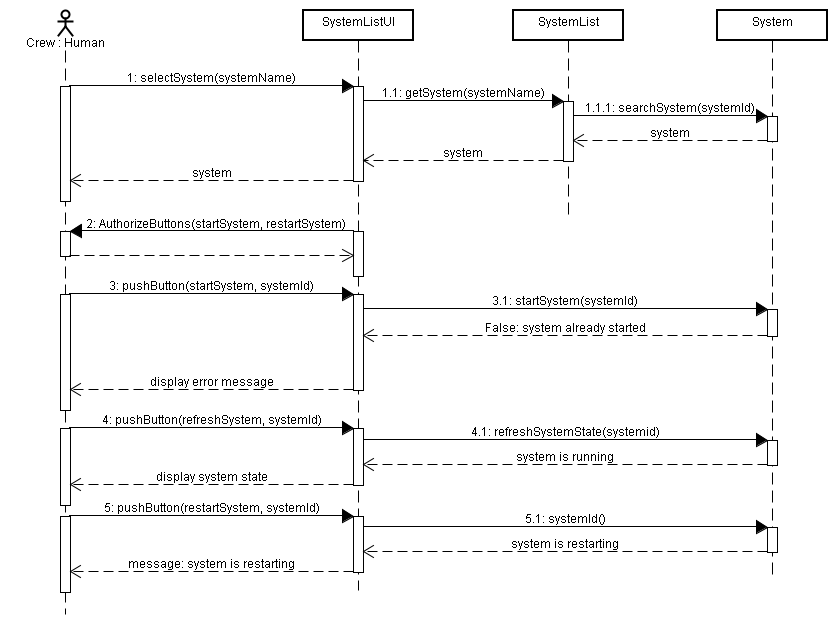


Figure 6: Sequence diagram - Start system, restart system & refresh system state

* + 1. Backup system and shutdown system

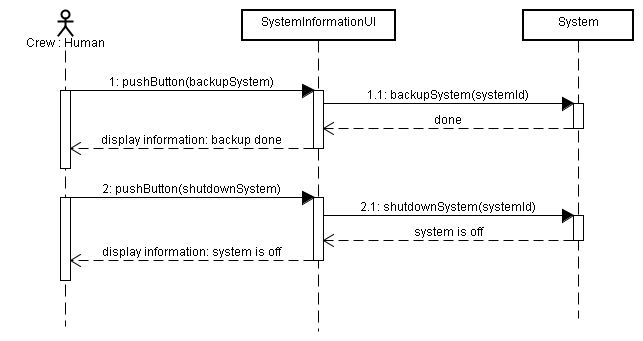
To conclude, let us display the backup and shutdown system scenarios. We already consider that a system is selected and located before being able to do these actions. As user does not have anything else to do besides pushing the buttons, actions are really simple in this diagram.

Figure 7: Sequence diagram - Backup system & shutdown system

1. **Non-functional requirements**
   1. Identified quality attributes

|  |  |  |
| --- | --- | --- |
| Attributes | Explanations | Priority |
| Testability | The system and its parts have to be able to be tested through inspections, simulations and analyses before on-board installation.  *Hence, FDIR functionality must be validated through a combination of inspection, simulation, and analysis.* [EAS98] | D:\Bureau\3.png |
| Availability | The system must not lock or stall when processing data. It must work asynchronously and must be available all the time.  *Fault protection operates asynchronously, and may be invoked at any time.* [EAS98] | D:\Bureau\3.png |
| Adaptability | The system has to be configurable in order to adapt to several environment. FDIR has to be adaptable for manned and unmanned spacecraft. It also has to adapt to several hardware component, different from one spacecraft to another.  *For unmanned spacecraft […] additional requirements over those for unmanned craft.* [EAS98] | D:\Bureau\3.png |

* 1. Improvised quality attributes

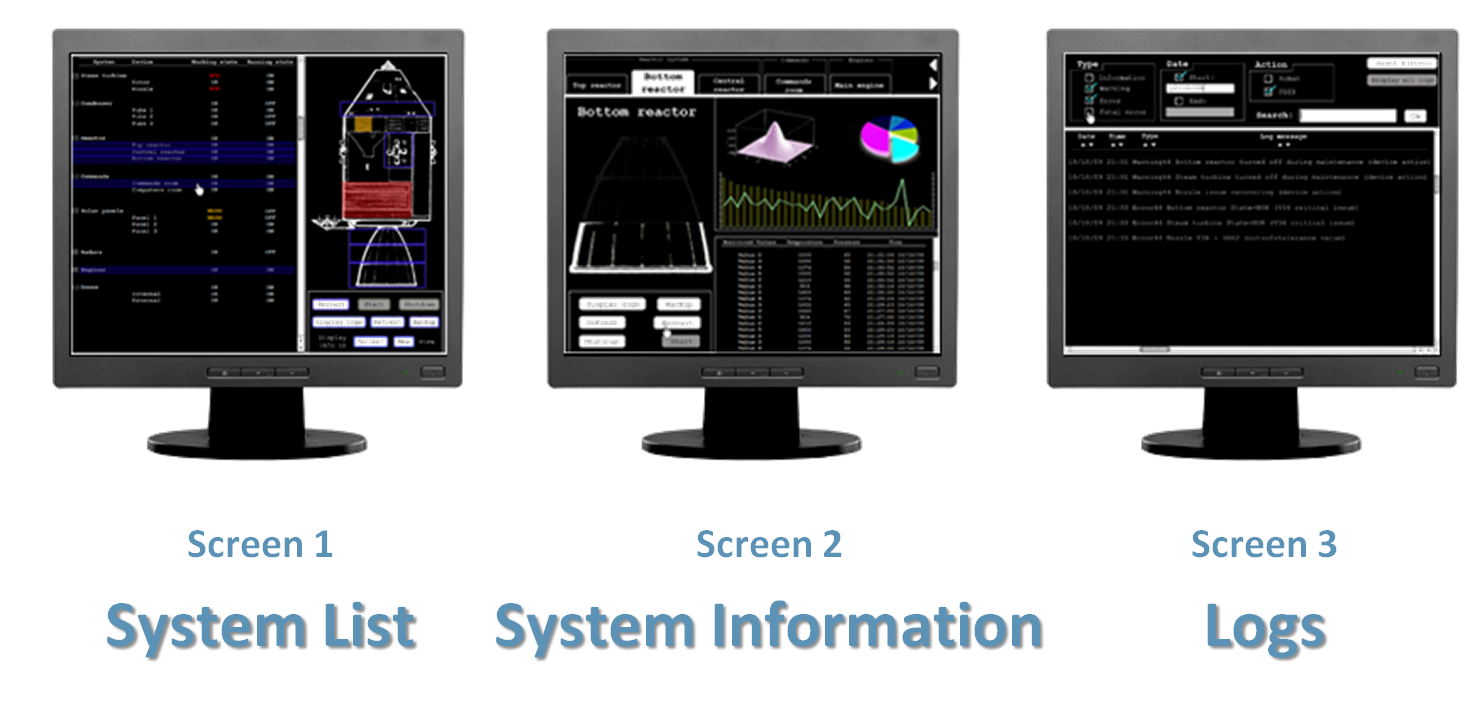
|  |  |  |
| --- | --- | --- |
| Attributes | Explanations | Priority |
| Availability | FDIR is processing a lot of critical information that shouldn’t be lost. Redundant storage system has to be added in order to avoid any waste of data. | D:\Bureau\2.png |
| Reliability | The system must be reliable in all operating conditions. System failure could lead to loss of human life. However, as reliability is inversely related to complexity in software application, this non-functional requirement should be one of the top priorities. | D:\Bureau\3.png |
| Resilience | The system must be able to maintain an acceptable level of service in spite failures in parts of the FDIR system. | D:\Bureau\2.png |
| Performance:  Response Time | The system must respond in timely manner so that problematic systems can be shut down before any damage is done. | D:\Bureau\2.png |
| Performance:  Thoughput | The system has to be able to deliver and receive a lot of requests and messages at the same time, and so we have to avoid overloading the FDIR. | D:\Bureau\2.png |
| Usability:  Recoverability | FDIR has to limit errors of manipulation from users, considering the criticism of operations on a spacecraft. No operation should be irreversible, and confirmation should be asked to user each time he wants to do an action. Flow of information should be filtered to allow user to only focus on interesting parts, diminishing so the probability of mistakes to happen. | D:\Bureau\2.png |
| Usability:  Learnability | FDIR is a professional application that treats a lot of information and needs a good efficiency from the users. However, system must provide easy-to-learn features, by displaying confirmation and error pop-ups, and by providing easy-to-understand views. | D:\Bureau\1.png |
| Usability:  Consistency | The FDIR interface should provide several views with consistent naming conventions and features from one view to another. | D:\Bureau\1.png |

1. **Usability analysis & design**
   1. Preliminary user interface design

Interface for the FDIR system has to be accurate, efficient and exhaustive. As a professional software, FDIR doesn’t need to be particularly easy to learn or user friendly, that is why our design is more focused on interface performance and on displaying the more information possible while keeping it logic and accessible.

FDIR system has to display continuous information about monitored values, systems state, interventions (by both human and computer), errors and warnings. That is why we don’t want to hide any information as possible. We are using 3 main screens, supposed to be displayed on three different screens. We can focus on a specific part by using tree architecture containing a list of every systems, sub systems, and devices. Selecting a part affects the state of every screen, it is updating the allowed actions, it filters information on the log screen, and it is updating the spacecraft scheme in order to provide geo localization. User is also allowed to select the entire spacecraft. Then, any information about it will be displayed.

Another feature not described in the following prototypes is the case of a critical issue happening, FDIR will so have to provide an alert (like a pop-up system) so that the crew will be directly informed.



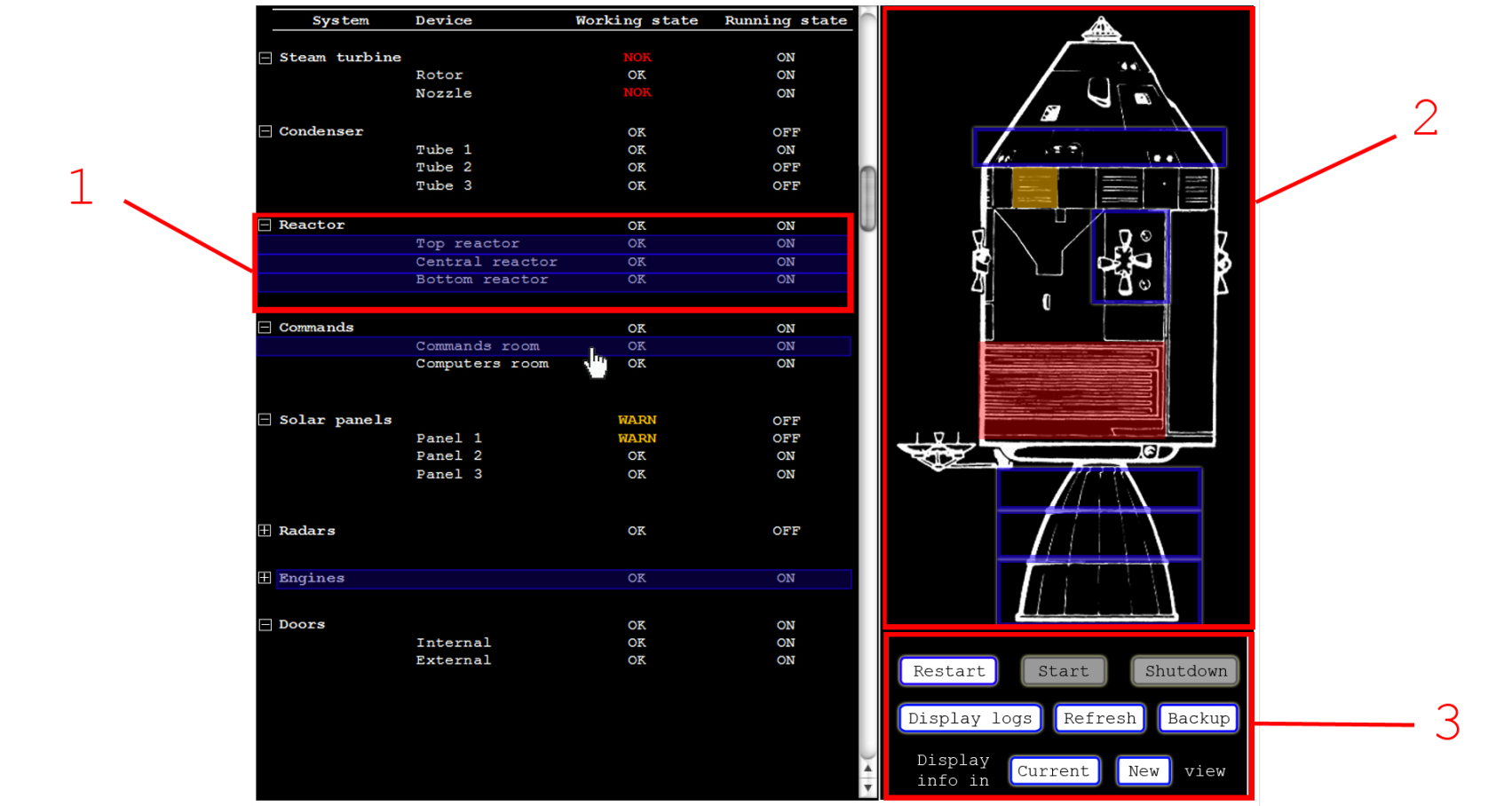
* + 1. Screen 1: System list

Figure 8: Systems list window prototype

**1**In this tree panel we display every system, divided into several devices. Working states and running states will always be displayed in this tree. The user can make a multi-selection between several systems and devices, affecting the other two panels.

**2**This panel gives a geographical localization of the selected parts to the user. This is useful in the case of a need of a fast human intervention on some part of the spacecraft.

**3**This action panel displays every allowed action considering the selected parts. User is so able to start, restart, or shutdown a part or several parts of the system at any time. He can also ask for a manual and direct refresh of the states, he can operate a change on the current used backups (a pop-up window will so appears to permit him to select which backups are currently working on the selected parts), he can make a filter on the log screen by considering only components selected on this view, and he can display monitored values corresponding to these components on the appropriate screen (on the current tab or opening a new one).

* + 1. Screen 2: System Information

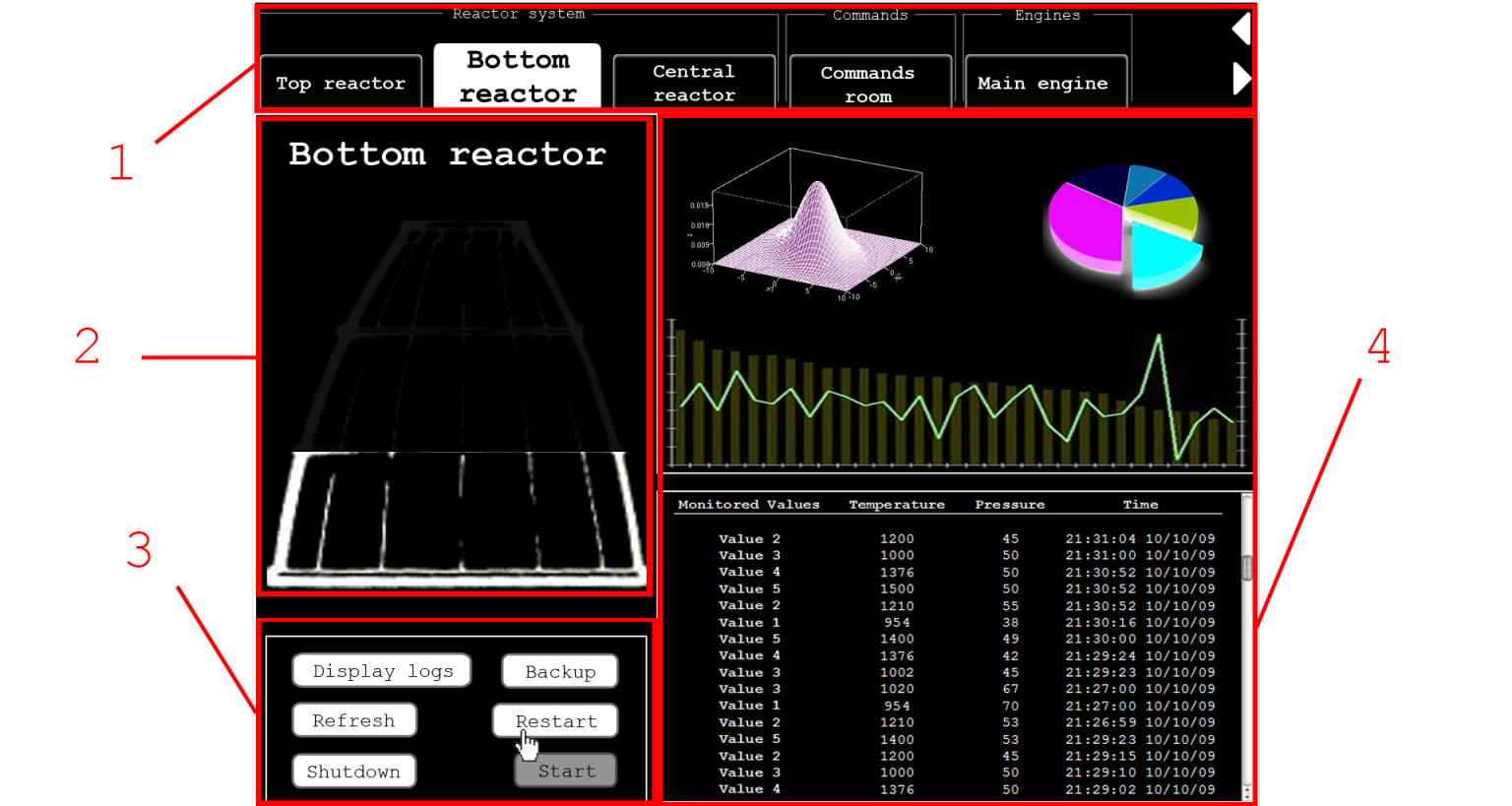


Figure 9: System Information window prototype

**1**This tab system allows the user to manage this view by making groups of monitored systems/devices. We add new tab or new systems/devices to the current tab thanks to the system-displaying window, and we can remove tabs or groups of tabs on this window (not represented on the prototype).

**2**This view offers a more accurate geographical view on the selected part, while the general view is always kept on the other window.

**3**This action panel is basically the same that what was presented in the previously screen. The difference is that here we are considering a single part of the global system, no multi-selection are allowed.

**4**Every monitored value is displayed here. We can sort them by period, increasing values etc… FDIR is also automatically generating stats, charts, and miscellaneous information, based on the monitored values.

* + 1. Screen 3: Logs

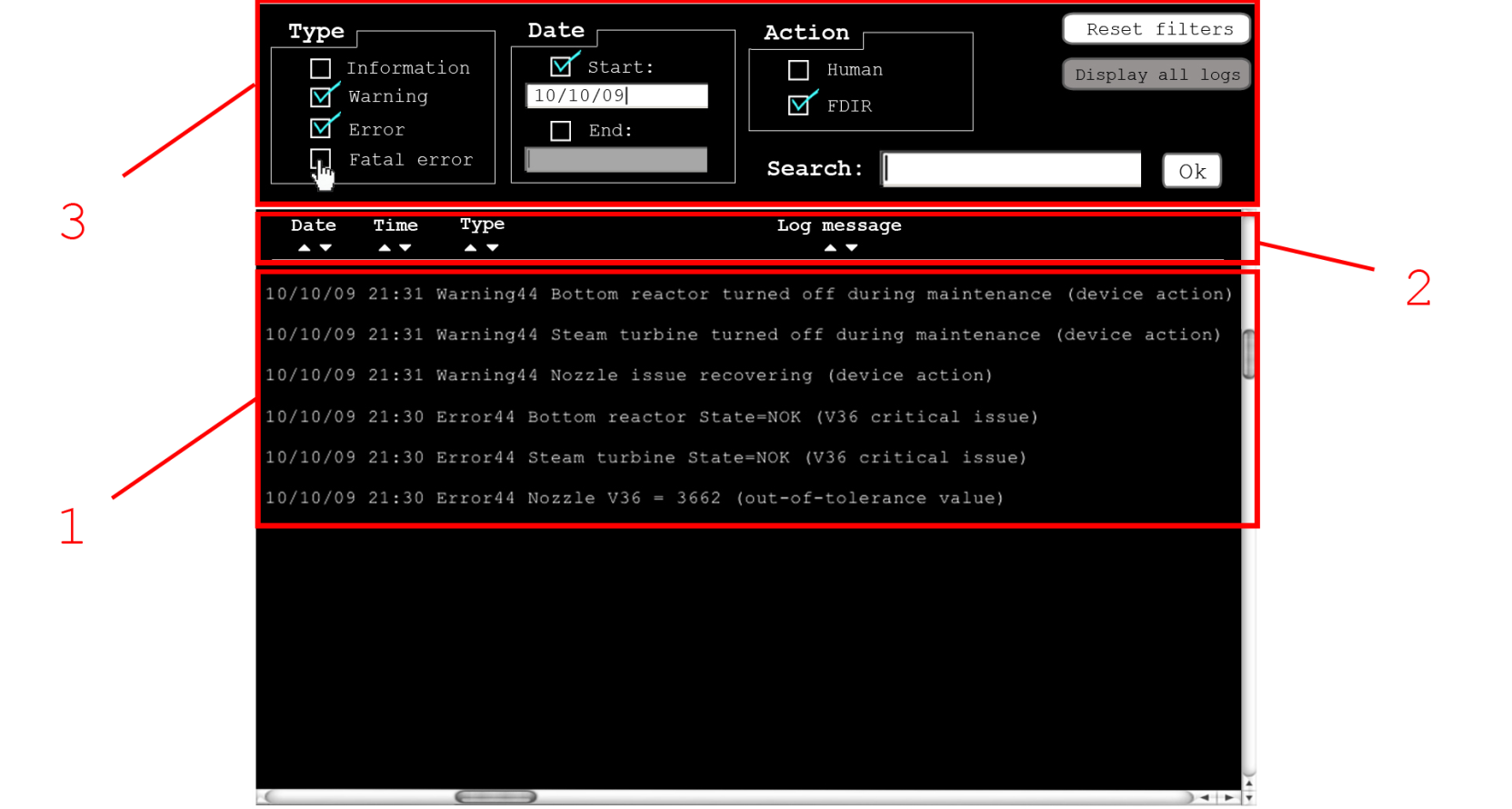


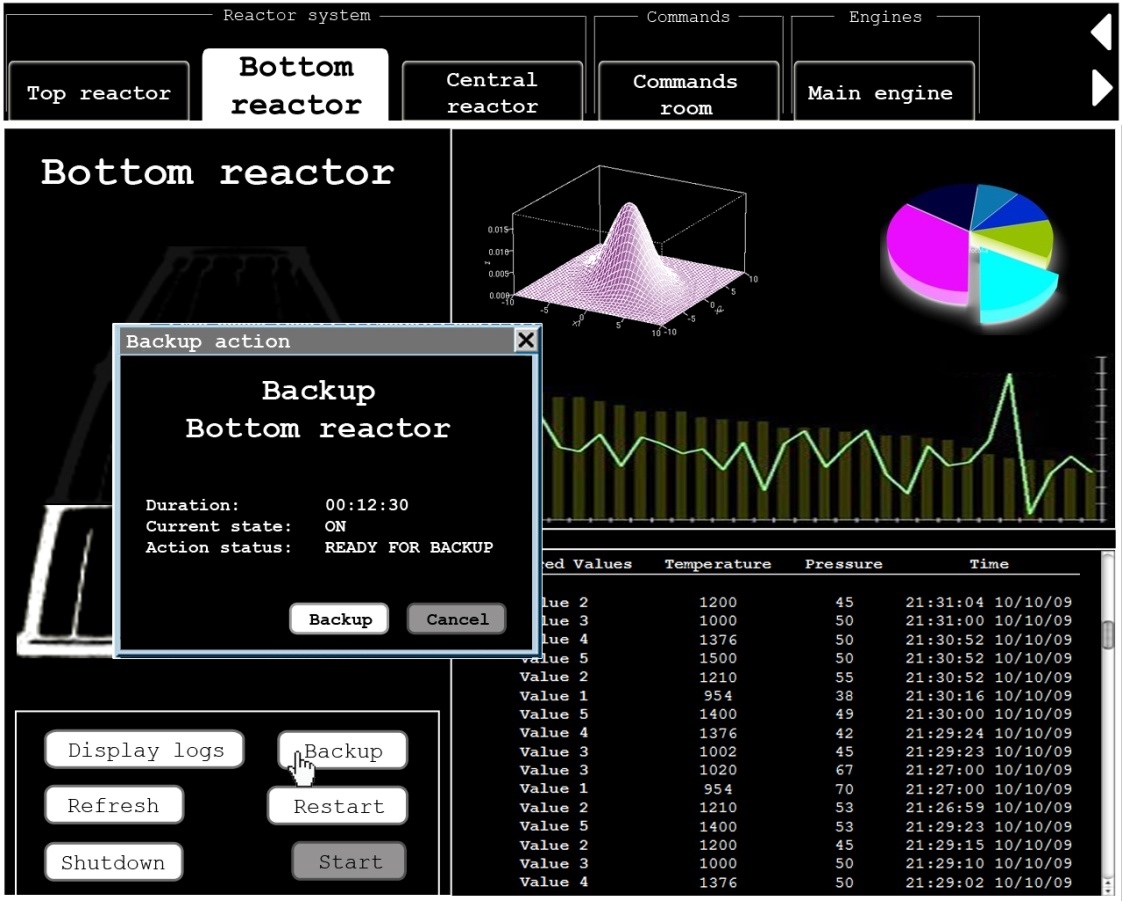
Figure 10: Logs window prototype

**1**In this panel we display every log information produced by FDIR, by specifying date, time, id of message, concerned component, monitored value or action, and type of issue or type of action. If we don’t apply any filter on its, that mean every information is accessible on this tab. We wanted to use a log system for this purpose, because this kind of tool is powerful and adapted to professional applications.

**2**With this interface, user can sort displayed lines by date, time, type of information, and by name of message.

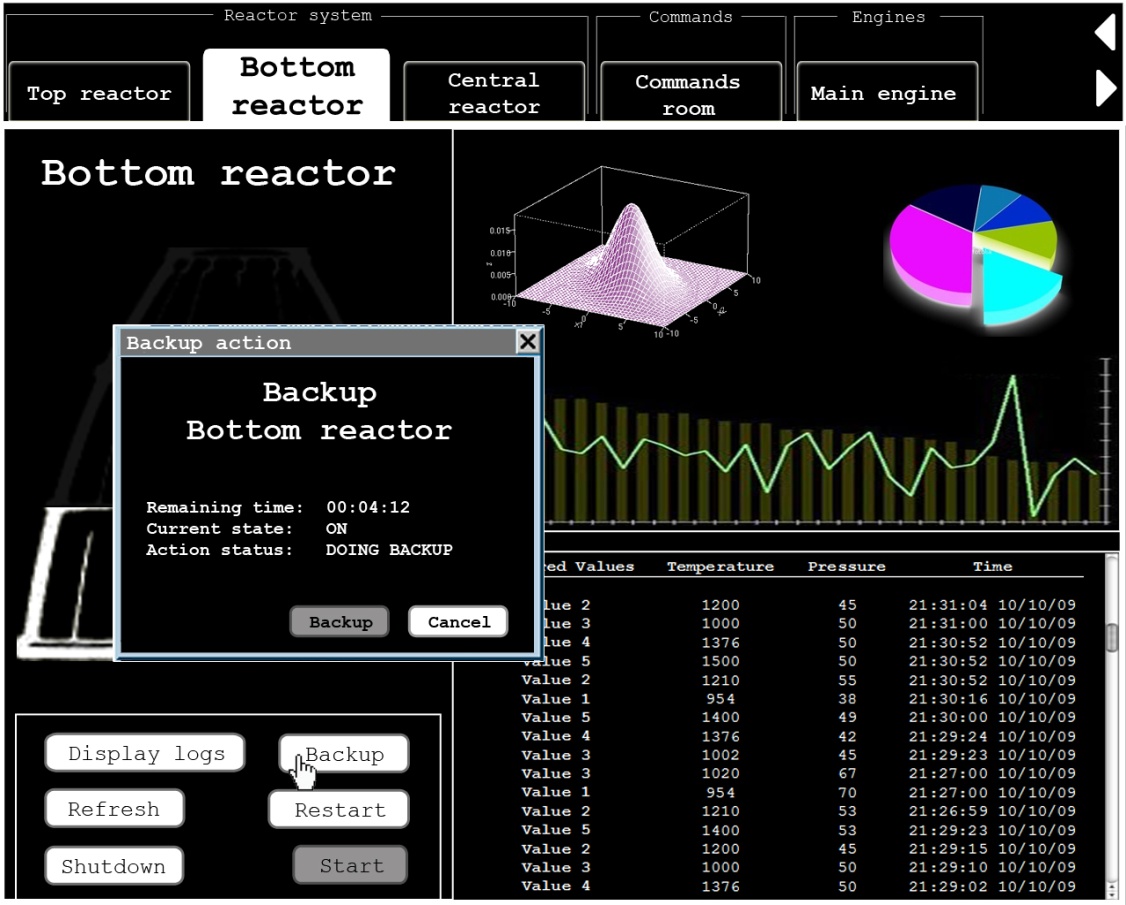
**3**User is able to do filter operations in margin of the systems/devices filter operated on the system displaying window. He can choose between information type to display (information, warning, error, fatal error), and if displayed information is concerned by FDIR automatic intervention or human intervention. He can also make a filter by specifying dates of “start” and “end”. The button ‘Display all logs’ cancel the effect of systems/devices filters, and the button ‘Reset filters’ cancel the effect of other filters. A search allow user to perform a research through the log, for example if he types the string “panel solar”, only lines containing this string will appears on the first panel.

* + 1. Screen 3: **Backups management pop-up**



When the action “Backup” is selected, a window appears allowing user to select a spare system. This pop-up then appears, informing the user of the expected duration of the operation, and allowing him to cancel the operation if this one is too long or for some other reason.

Figure 11: Backup management pop-up before backup



During the backup operation, this pop-up is still displayed, informing user of the remaining the action’s achievement. User is allowed to cancel the operation for some reason, and then the system recover automatically the original configuration.

Figure 12: Backup management pop-up during backup

* 1. Discussion on usability scenarios

The FDIR system is very important for the success of the mission. It provides information to the crew, can do a lot of specific actions on specific components of the spacecraft. Besides it has to be very reliable and efficient. In this purpose, we will describe some usability scenarios essential for a critical system like FDIR. We will use the general usability scenarios studied a couple of weeks ago, and find some more essential for this type of system.

* + 1. Scenario 24

Besides that the FDIR should provide views that have to be consistent from one view to another, in order to leverage the human knowledge (Scenario 13). User has to understand very quickly and doesn’t have to lose his marks. So with similar interfaces, it will not take much time to user to achieve it.

This is the reason why we tried to harmonize the three views of the three FDIR screens. Every item is implicit and intuitive for user. He does not really need a training to understand the panels, actions or information.

In screen 1 & 2, we can find out that we always have access to the same type of actions, as long as we are handling systems. The difference is that on the first screen we apply the action on every selected systems, while, on the second screen, it is only applied on the current displayed system.

* + 1. Scenario 25

The FDIR system could display views and switch between them to see the spacecraft and systems from another viewpoints. It has to be easy. That’s why, according to this scenario, we decided to create real screen interactions. At any moment, views are accessible. By using a few tabs on the top of screen 2, we display information and other functions in others screen in a very easy way. Moreover, this system of tabs is never disabled, in order to switch very quickly between views anytime.

* + 1. Scenario 15

Moreover the system has to support concurrent activities (Scenario 15). The crew could test one device and do another action, for example restart a second device, during the same time. The crew doesn’t have to wait that one action is over to start another one. Besides this point the ground control could do an action directly from Earth while another function is running. This case must not be a problem for the FDIR.

Respecting this usability scenario, we decided to design three different screens that can be used in the same time in order to do concurrent actions. Indeed, crew can restart a system in the screen 2 while selecting another on screen 1 and displaying logs of this selection on screen 3. Moreover, tab system on screen 2 is also related to this scenario: allowing user to easily switch the view from a system/device to another allows him to do an action in a system (push the *Backup* button) and another action in another system (push the *Shutdown* button) a half of second after just in switching of tab.

* + 1. Scenario 16

In order to be efficient and fast, the system should provide functions to navigate within a single view. That’s why we create the tree with the list of systems and all devices in one screen, to access every system in a fast way. Besides, we provide some filters in the log screen, in order to accelerate the research of the both actors.

* + 1. Scenario 26

Next, FDIR could provide an interface where user can see the entire spacecraft, and at the same time, can navigate in another view through this spacecraft (Scenario 16). User doesn’t have to change several times of menus or screens to see the entire spacecraft system. It will be a huge loss of time for all users.

As for scenario 15, the choice of multiple screens is related to this usability scenario. User can see different information without hiding anything: systems/devices list, spacecraft view, monitoring values, logs, etc. Moreover, we combine the idea of multiple screens with the one of spreading the screens in several parts to strengthen the one and unique system view. Indeed, screen 1 always displays the entire view of the spacecraft, in order to easily see the problems or the selected systems/devices.

* + 1. Scenario 3

First of all, the FDIR system must be able to allow user canceling commands (Scenario 3). Crew could have mistaken one command to another for example, especially during the launch of the spacecraft where pressure is high and movements very hard to control. Let us take another example: if the crew decide to backup a system but received a notice a couple of second after saying that this same system is crashing, he would like to interrupt the backup to restart it. In this case, a cancel button is needed.

We expected these kinds of cases putting a *Cancel* button while action is processing. It is related to the Figure x.

* + 1. Scenario 19

Finally, the system could display the expected duration of any action before the user launches it (Scenario 19). It could be really useful for user in order to estimate the time he need to do several action or to help him to decide for priorities or fastness.

Moreover, FDIR system also display the remaining duration of an action when this one is already started. This can really help crew or ground control estimating the next actions.

**Conclusion**

The first project was very interesting. This project is based about an interesting topic we are not used to study every day: a spacecraft. After the careful reading of the subject we try to identify the needs of the clients, the problems of the actual system or the problems we will encounter during the design part.

In this purpose, we learned how to represent problems using a new type of diagram: the problems frames. These diagrams will be useful for the second project, the design of the FDIR system. Besides we use the UML to represent the functional requirements of the system, by describing them by using use case diagram.

Moreover, we tried to identify non-functional requirements in a specific system like a spacecraft. That’s why we find non-functional needs in the paper of course, but we also think about additional requirements by ourselves. We improvised and put the most important we found.

Finally, we explain some usability scenarios essential for us in this kind of system. We based our scenarios according to the paper we read two weeks ago. After that, we drew some interfaces to represent our idea of this system, including our usability scenarios.

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**Annexes**



