DTUsat Autonomous Monitoring and Control Preliminary Study

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1 Introduction

This report describes a preliminary study of autonomous monitoring and control of a small satellite.

Autonomous monitoring and control is the software that monitors and controls the satellite while it is not in contact with the ground station. It is needed to ensure proper responses to unexpected events and situations.

The report is part of a project to build a student satellite. The project – the DTUsat – involves more than 50 students at the Technical University of Denmark and its goal is to let students design and construct a small satellite. The focus of this study is the DTUsat.

As the subtitle states, this is a preliminary study. The actual satellite is not completed yet and the software controlling it has not been implemented yet. Therefore, this report discusses the issues relating to monitoring and control on an abstract level; some general rules and guidelines are given. However, when implementing a system based on the findings of this study, everything should be carefully refined.

The report will start by discussing the problem treated and the approach used. The report then focuses on software and gives some guidelines for designing autonomous monitoring and control for the software modules. After this, the report focuses on hardware with an analysis of each of the hardware subsystems in the satellite. With this analysis, some scenarios are defined, each describing a situation in which autonomous control is needed. These scenarios illustrate the general rules for monitoring and controlling the satellite. Finally, a number of "modes" for the satellite's operation are defined. These modes are overall descriptions of a number of parameters and specify how the autonomous control system should act if a situation with these parameters occur.

2 Problem and Approach

The problem considered in this report is that of specifying rules to govern the satellite's autonomous behavior when it is not in contact with the ground or when an unexpected situation occurs. Such a situation could be, for example, that one hardware component suddenly draws a very large current (suggesting a short circuit) or that a software module stops responding. In these cases the autonomous part of the satellite must decide what to do based on the specified rules.

The purpose of autonomous monitoring and control of the satellite is two fold:

1. to ensure that the satellite is never lost, and,
2. to ensure satellite functionality.

This means, that the satellite should transmit as much data as possible to earth; however, survival comes first.

In order to specify the rules, the hardware subsystems and software modules are analyzed. As most of the software modules have not yet been programmed, a direct analysis of them is impossible. Instead, some common properties are identified and some guidelines for the design of software modules are given. For the hardware subsystems, the analysis specifies the subsystems normal operating parameters such as temperature and power consumption. Furthermore, the analysis tries to define how the subsystem reacts when these parameters are outside the norm and what can be done to resolve the situation. This system analysis creates a framework of data on which some the rules of autonomous monitoring can be stated.

To discuss the rules and their usage, we have created a number of scenarios. A scenario defines a situation in which the satellite is not operating optimally and then it is discussed which of and how the rules are applied to ensure that the satellite is not lost and returns as much usable data as possible. From the scenarios, a number of more general rules are uncovered through discussion. These rules form part of the results of the study.

Furthermore, an implementation plan for the autonomous monitoring and control of the satellite is suggested. This plan describes levels of implementation and what they provide. Also, a number of operating modes for the satellite are specified. These modes are defined based on environmental parameters and the general rules, and describes the 'behavior' of the satellite.

This report focuses primarily on hardware. This is because the hardware cannot be changed once the satellite is in orbit whereas new software can be uploaded to the satellite. Furthermore, designing autonomous monitoring and control for systems that are not yet created – or even specified – is a daunting task.

3 Software Modules

The software modules are the parts of the satellite software that handle specific tasks. This task could be controlling a hardware subsystem or providing some service to other modules; examples of these are the camera module and the platform manager module respectively.

To design autonomous monitoring and control for the software modules, it is necessary to analyze their functions and their importance to overall system performance. The software modules must be analyzed in terms of satellite survival and satellite functionality.

As the software modules (for the most part) have not yet been created, a direct analysis of the individual software modules is not feasible. Instead, this section seeks to describe how the software modules function from a monitoring and control perspective. This section also suggests an extension to the platform manager[1]; this extension is designed to provide for more extensive monitoring of the software modules. Furthermore, some guidelines for designing software modules with autonomous monitoring in mind are given; these guidelines use the extension to the platform manager mentioned above. Finally, a new software module is suggested. This module is designed to check memory integrity.

3.1 Common Properties

This subsection discusses some of the properties that are common to all modules. A very important common property is the execution environment, i.e. (for our purposes) the platform manager; this is described first.

Platform Manager

The platform manager (PLM) is responsible for executing and handling the software modules. The PLM starts each module and queries it at some interval for its alive status. Currently, the PLM expects a "Yes, I'm alive" message from each module; if a module does not respond or answer "No", the PLM does not kick the watchdog and the satellite is rebooted. This default behavior ensures the satellite is working properly in case of an error; it does not, however, consider the importance of a given software module. This can lead to the loss of what data the satellite has gathered due to a minor error that is inconsequential to the short term performance of the satellite. Instead, perhaps the satellite could wait until next ground contact.

Software Modules

Having described the execution environment of the software modules above, the common functionality of the modules are discussed below.

Each software modules consists of one or more threads some of which are vital to the modules functionality and some of which are less important. Furthermore, some threads are interdependent. During design of the software modules, the designers should try to create an overview of the threads, their importance, and their interdepence. This overview can then be used to create more effective autonomous monitoring and control.

[1] The platform manager is the software responsible for executing and handling all other software modules in the system.

In the guidelines for software module design given by the on board software group, a `CMD_ALIVE` command is specified. Every software module must respond to this command from the PLM. The module must either return *YES* or *NO* (or nothing) depending on status.

Another common property of the software modules is, that they must check for incoming messages at reasonable intervals. This is not specified further, but it is done to ensure that the packet router[2] is not overloaded and that the module always receives any messages intended for it.

3.2 Extension to Platform Manager

To make autonomous monitoring and control of the satellite more effective, this section proposes an extension to the platform manager. More specifically, the modules should be able to respond more intelligently to the `CMD_ALIVE` commands from the platform manager.

Instead of responding with a simple *YES* or *NO*, the software modules could respond with an error code. This error code should be within a specified interval (e.g. 1 - 10) and each error code should have a specific severity and meaning assigned to it. Using this system, the software module designers can specify the monitoring and control of their own modules. This is more effective, as they (presumably) know the code and can thus make more 'educated guesses' as to the severity of a given error.

Implementing this extension requires the precise definition of each of the error codes. Furthermore, the platform manager's handling of each error code should be described in great detail. The module designers are then responsible for following the guidelines and for returning appropriate error codes[3].

Besides the precise definition of each error code's severity and meaning, the platform manager's response to each error code should be defined very precisely. Furthermore, the platform manager's response to an error code depends on which module sends the error code. It is in this definition that a more agile and effective autonomous monitoring and control can be achieved; however, great care must be taken to ensure that the definitions do not become overly complex and to check their sanity.

The definition of these relations between modules, error codes, and responses is not done in this study. It requires intimate knowledge of each of the software module's code and functionality and the required time for such extensive analysis is not available.

A different extension to the platform manager is the ability to reload a single module into the same area of memory as it resided in previously. This function could be useful in case of bit flips in memory or a module's loss of function. This way, the satellite would not necessarily have to reboot whenever a module malfunctions. This, in turn, leads to an even more flexible autonomous monitoring system.

[2]The packet router is the satellite's internal post office. It ensures delivery of messages between the software modules.

[3]It is important to avoid an 'inflation' of the error codes, i.e. that each module programmer deems her module more important than others and thus use a more severe error code than what is called for.

3.3 Module Design Guidelines

With the description of the extension to the platform manager above, this subsection goes on to describe some general guidelines for the design of autonomous monitoring and control in the software modules.

When designing autonomous monitoring and control for software modules, it is actually a matter of choosing which error codes to return. This must be done with satellite survival and satellite functionality in mind. With the definition of error codes and how the PLM responds to these, the module designed must carefully consider when to use each error code and how this affects satellite performance.

Many factors affect the choice of error code, some of which are not straightforward. We cannot define any clear guidelines to making this choice. However, in the general case, the least severe error code possible should be returned.

3.4 Memory Checking Module

Another part of autonomous monitoring and control relates to monitoring of the memory. This is important to ensure integrity of software and data in the satellite.

A software module could be designed to handle memory checking functions. The module should check whether the memory is physically intact. Furthermore, it should check that the pointers of the different modules are within the area of memory assigned to that module. Finally, the module should check that the buffer zones between modules in the memory are not used.

The above analysis of the satellite software suggests some extensions to the satellite. It adds a level of complication to the system and should be reexamined with respects to the *KISS*[4] principle.

[4] Keep It Simple, Stupid.

4 Hardware Subsystems

The satellite consists of several hardware subsystems. Some of these subsystems are vital to the operation of the satellite while others extend the satellite's functionality.

To implement intelligent control of the hardware subsystems, all the subsystems must be categorized in terms of 'vitality' to overall operation; furthermore, the critical physical operating values of each subsystem must be determined. The physical values considered are primarily operating temperatures and power consumption; other physical parameters are considered for the subsystems to which they apply. Finally, the performance of each unit under non optimal conditions is considered.

In the following, each hardware subsystem is analyzed and categorized. The critical values for each of the subsystems are also specified; these values, however, are preliminary only and should be corrected when the final prototype of the satellite is tested under suitable conditions. The values are obtained from the groups responsible for each of the subsystems[5].

4.1 ACDS

The ACDS consists of three components: the magnetometer, the magnetotorquers, and the sunsensors. The critical values for each of these must be determined to enable intelligent control of the unit.

Operating Temperatures

The table below shows the ACDS hardware subsystems temperature ranges under different conditions. All values are in degrees Celsius unless otherwise specified. The first column shows the component's preferred operating temperature range; within this range, the components perform optimally. The second column gives the temperature ranges within which the components can operate with lowered functionality. Finally, the third column gives the components' maximum temperatures assuming the component are not operating. If temperature goes beyond these values, the component will cease functioning (correctly, if at all). The N/A values in the third column are due to the fact that these components are always on.

	Normal temp. range	Low functionality temp. range	Off temp. range
Magnetometer	$+5 - +45$	$-40 - +85$	N/A
Magnetotorquers	$-10 - +65$	$-40 - +85$	N/A
Sunsensors	$-10 - +65$	$-40 - +85$	$-60 - +150$

Table 1: Temperature ranges for the ACDS hardware subsystem.

Lowered functionality has different meanings for each of the components. For the magnetometer and the sun sensor lowered functionality means less accuracy of their measurements. For the magnetotorquers the dipole momentum is changed.

[5]Each group was send a short list of questions to supply the needed values. See Appendix B for a list of the questions.

Power Consumption

Temperature and power are interrelated as consumption of power creates heat (in electrical systems). However, for the ACDS subsystem the power consumption is very small and thus it affects the satellite temperature only little.

For attitude determination the ACDS uses $3-5mA$ for the magnetometer and the sunsensors. When the magnetotorquers are in use they draw between $0mA$ and $45mA$ of power.

4.2 On Board Computer

The On Board Computer (OBC) is vital to the satellite; at the same time, it is a very sensitive hardware subsystem.

The normal operating temperature range of the OBC is $-40C$ to $85C$. If the temperature goes beyond this, the OBC might not survive. In case the functionality of the OBC is limited (due to environmental circumstances), it can result in the loss of time or the loss of the ability to communicate with other subsystems (e.g. the radio).

Furthermore, the OBC cannot be turned off as a protective measure; this is because all the satellite's functions depends on it.

The OBC draws a current of $50mA$ during normal operation and up to $110mA$ during boot or upload. This corresponds to an average power consumption of $165mW$.

4.3 Power Subsystem

To be able to control the satellite autonomously according to power consumption we need some sensors that gives us information about the satellite. The Power subsystem has sensors that can tell us about the current on the solar panels, the battery current, the regulated bus current, the unregulated bus voltage, the regulated bus voltage, the battery voltage and the battery temperature. These sensors will allow us to monitor the power subsystem and to control the satellite according to the specifications of the power subsystem. This means, for instance that we can turn off subsystems before the satellite has a power shortage.

An important aspect of the power subsystem is that whatever happens we can not turn the system off. We can, however, if the system gets too hot or too cold try different things. We could for instance turn other subsystems on and off to try to regulate the temperature of the satellite. We could also try to rotate the satellite a little bit to get more or fewer sides of the satellite in to sunlight. This would also apply if we start to run low on power. A rotation could increase the power supply from the solar cells if we could rotate the satellite so that more solar cells are reached by sunlight.

Operating Temperatures

The temperature ranges in which the power subsystem can survive is given in 4.3.

	Normal temp. range	Low functionality temp. range	Off temp. range
Electronics	$-40 - +50$	$-40 - +50$	$> +50$
Battery	$+10 - +40$	$-20 - +40$	$> +60$

Table 2: Temperature ranges for the power subsystem

4.4 Radio

The radio is responsible for communication to ground, and is therefore very important. The radio operating temperature is $-40C$ to $+70C$. The radio does not have reduced functionality as such, either it works or does not. However, less power can be directed to the amplifier, resulting in less output power. The radio has a temperature sensor mounted close to the power amplifier.

The part of the radio that radiates most heat, is the amplifier. It uses a lot of power, and if it gets too hot (65-70 degrees C) then the power should be turned down, possibly turned off. This will, of course, depend on the situation; it will not be desirable to turn it off while communicating with earth. The amplifier can use from $0.5mW$ to $0.1mW$[6], so if it gets too hot while communicating with earth, its power consumption should be turned down. This will result in a weaker signal, but it could still be possible to communicate. The temperature should then be monitored to see when the power amplifier should be turned on or up again. Another approach could be to let ground determine all this, and simply turn off the amplifier until told otherwise. Also, the power amplifier uses so much power that, in general, it should be turned off while the satellite is out of the communication window.

The amplifier could also be used to generate heat if the satellite gets too cold. However, it might be more feasible to turn as many sides as possible towards the sun.

Regarding power to the radio; the amplifier draws its power from the unregulated bus. It includes a step-down converter, to ensure the right range of voltages, and thus the protection of the voltage to the amplifier is done in hardware.

4.5 Camera

The camera subsystem is one of the payloads, and its task is to take pictures of the earth.

The camera operation temperature is $-10C$ to $+60C$ and the optimal temperature range is $0C$ to $+10C$. Less than optimal conditions will result in more noise in the picture. The power usage of the camera is $200mW$ - $250mW$ in fully operational mode; in some modes (e.g. standby mode) it is much less. Most likely 3 sensors will be connected to the camera, one to the CCD chip, one to the circuit board, and one to the power supply[7].

The most temperature sensitive part of the camera is the CCD lens. It is the one that requires the lowest temperature, and thus the sensor on this component will be the most important to monitor. The most likely reason for the lens to get very hot, is if it is turned towards the sun. Since it is not taking pictures here, a simple thing to do would be to turn the camera off in this position, to keep it colder. If the lens still gets to hot, it would be

[6] This are the values obtained from the Radio group. These values does not, however, correspond to the values in the power budget. Furthermore, the values seem to low.

[7] the camera converts the voltage from the satellite's power supply.

preferable to turn the satellite, so the camera does not look into the sun; this action should be considered as the camera is not vital to the satellite. Hopefully, when the satellite is stable, it will be positioned with the camera pointing towards earth, and it will only point to the sun briefly, if the satellite is spinning. However, we cannot be sure of this.

4.6 Tether

The tether payload is not yet specified and an analysis of it would thus be void. For the final implementation of autonomous monitoring and control, a thorough analysis of the tether hardware subsystem should be conducted.

4.7 Common Properties

The above analysis of the individual hardware subsystems leads to a set of rules concerning their autonomous monitoring and control. In the following, the subsystems are prioritized and a brief discussion of subsystem interaction is given.

The hardware subsystems are prioritized as follows:

Power The power subsystem is given the highest priority, as without it, the satellite cannot operate at all.

Radio The radio is prioritized next because it is necessary to communicate with the satellite. At the same time, the radio alone is enough to show that the satellite is in orbit (via the radio beacon) and send basic debug data.

On Board Computer The OBC is the third priority. Without it, the satellite cannot perform its functions and is of very limited use.

ACDS The ACDS is prioritized next because it is necessary to stabilize the satellite and this, in turn, is necessary to operate any of the payloads.

Camera The camera is prioritized before the tether because of its political value; this follows the overall satellite mission.

Tether The tether is prioritized last as it is the most uncertain subsystem.

Subsystem Interaction

In this section, the hardware subsystems have been analyzed individually. Each subsystem's parameters have been specified and discussed. However, to define some commonly applicable rules, the subsystems' interactions must be clarified.

The effects of subsystem interaction have not yet been tested and documented; therefore, the treatment of this topic is extremely theoretical and subject to change. Before implementing autonomous monitoring and control, these effects should be thoroughly studied to ensure correct operation.

A very obvious and well documented subsystem interaction, is the interaction between the power subsystem and all the other subsystems. To ensure survival of the satellite it is important that each subsystem never uses more power than what has been allocated to it; doing this could cause the loss of another (more important) subsystem.

5 Scenarios

With the analysis of the hardware subsystems in the previous section, this section gives a number of scenarios that illustrates the autonomous monitoring and control of the hardware subsystems. As these are scenarios, we have chosen a number of specific critical values. These values are not final and should be reconsidered pending thermal analysis and testing of the satellite.

5.1 Satellite Too Cold

If the battery reaches a temperature of $-10C$ we should start considering what to do. The value of $-10C$ was chosen because we are adequately far from the lowest normal operation temperature. If we react too early we could be doing work which is unnecessary.

If the satellite is in sunlight we could rotate the satellite so that the battery gets closer to the sun, or so that more sides of the satellite is in sunlight. Of course we need to monitor that no other subsystems are overheated or gets too cold. However, the battery has higher priority than all other subsystems since nothing works if the battery is dead.

If the satellite is in shadow we have other possibilities. If we are reaching critical ($-10C$) temperature on the battery we could try turning on the radio power amplifier since it creates heat. However, this needs to be considered very closely since this operation could drain the battery completely and we would have gained nothing.

We have chosen the battery as an example of a subsystem that gets to cold. The solution options would apply to practically all subsystems on the satellite.

5.2 Satellite Too Hot

If the battery should reach a temperature of +55 degrees C there is a good chance that it is overheating. We have chosen 55 degrees C because it is adequately far from the absolute maximum temperature that the battery can survive.

If the satellite is shadowed we can try to turn off different subsystems to stop them from generating heat.

If the satellite is not shadowed we have more options to choose from, we could still try to turn off different subsystems, but we could also try to rotate the satellite so that the battery gets as far away from the sunlight as possible.

We have chosen the battery as an example of a subsystem that gets too hot. The solution options would apply to practically all subsystems on the satellite.

5.3 General Temperature Solutions

In general we have a couple of solutions to prevent the satellite subsystems from overheating and getting to cold. These options include rotating the satellite so that the systems is moved into or out from the sunlight. Other solutions is turning on/off different subsystems to make them generate heat or to stop them from generating heat.

5.4 Satellite Power Shortage

This scenario will be a more general description of what happens and what to do when the satellite has a power shortage.

If the satellite should run low on power we have different options we could try. The most obvious one is to simply turn some of the subsystems off. Before we just start turning the subsystems off we need to determine which subsystems we can do without. Hence which subsystems is not crucial to the survival off the satellite. We have made a prioritized list off the subsystems that be found in 4.7 This means that if we encounter a power shortage on the satellite we would probably start by turning off the payloads. If that is not enough we would continue up the list until we reach the radio subsystem. It would probably be a bad idea to turn the radio completely off. But to save power on the radio we could turn the Power Amplifier (PA) off, since it is the PA that has the largest power consumption in the radio subsystem. A general idea would be to have the PA turned off or at least turned down whenever we are not using it. That means it should be off whenever we are out of reach by the ground station. If the radio subsystem gets to hot when transmitting to earth and the PA is working at full power, a possibility is to turn it down to lower power consumption and to reduce the heat radiated from it.

Another possibility if a power shortage should occur, is to rotate the satellite so that more solar panels is reached by sunlight. This of course is only possible if we are in the lighted part of the orbit. Before implementing any of these options one should carefully consider the consequences of rotating the satellite (will any part of the satellite get to hot for instance) or turning off any of the subsystems. We do not have enough information about the different subsystems to completely consider this in detail.

6 General Rules

As the main objective of the autonomous monitoring and control is to keep the satellite alive, it is a very important part of the on board software. The resources of this project are, however, limited, so in this section we will both describe what rules the autonomous monitoring and control should implement to ensure survival. We also state an idea to an implementation plan. A related issue is that this system requires something from the hardware system, and here we will state these requirements and wishes too.

6.1 Rules

We will describe some rules based on the analysis. No actual values for temperatures and similar are included, as they might change. The preliminary values can be seen in the report, refer to the relevant section. The limit values for when the satellite should react, should be a some distance from the malfunction value, to allow the system time to react.

Rules for Overheating

When a subsystem, or a part of a subsystem, gets too hot, the rules are as follows:

1. Try to shut subsystems that have a lower priority than the implied system.
2. If the radio's power amplifier is running, try turning it down without loosing communication ability (assuming it is turned down or off when not communicating).
3. Try turning the satellite to get the hot component away from the sun.
4. Shut down the component.

Whether the shut down or the turning should be first, depends on the importance of the subsystem, and on how difficult it will actually be to turn the satellite.

Rules for Cooling

When a subsystem gets too cold, the rules are the following.

The satellite should be rotate so that most possible sides are turned towards the sun and/or the side closest to the subsystem should be turned towards the sun.

If the satellite is not in the sun, but the battery has plenty of power, the power amplifier of the radio could be turned on so it could generate heat. It is questionable if this has any effect, and it would be advisable to test this.

Rules for Power Shortage

If the battery drops below a certain threshold, the satellite will suffer from power shortages, and the most important subsystems should be kept functioning until the battery has been charged again. In this case, the satellite should start by turning the lowest priority subsystems off. If it is in use, the power amplifier should also be turned down. Then, the satellite should be rotated receive maximum power from the solar cells.

Special Rules

Some systems have a few things that are a little different form the rest.

If the power amplifier on the radio gets too hot, it should be turned down as the first thing, as it uses a lot of power, in that way generating a lot of heat.

If the camera lens is turned towards the sun and getting too hot, the satellite should turn the lens away from the sun, as this is the biggest reason for the lens' overheating. This will of cause not be desirable in situations on low power, as the camera is low priority.

Interaction

If more than one subsystem has passed a critical value, the highest priority subsystem has precedence. Hopefully the actions that should be taken would help both subsystems. We feel it would be too elaborate to specify special actions to maximize the actions taken for combinations of subsystems.

6.2 Requirements and Wishes to Hardware

Based on this analysis, the hardware should provide the possibility to turn off the subsystems individually. Also it should be possible to turn off and adjust the power amplifier on the radio. Furthermore, it would be smart if it is possible for the on board computer to enter a low power consumption mode, by doing endless `NOOP` or similar.

We would also very much like to able to introduce some sort of autonomy in the power subsystem. It should be able to turn off all other subsystems when the battery has a critical low charge. It should also be able to turn on the subsystems again, when the battery has reached a certain non-critical charge, or if a certain period of time has passed. This way, the satellite could be turned almost completely off if necessary to save the battery from permanent damage.

6.3 Implementation Plan

We have developed an idea for implementation steps, based on what we think is most important, or what ideas will carry the greatest risk. We will also describe how long time implementing a step might take, but this is based on our immediate intuition.

Detection

The first thing to do, is to give the platform manager the ability to detect when a problem arises. This implies that the platform manager should know all limit temperatures, battery and power shortage thresholds. This could take some time, dependent on how hard it is to gather data about the subsystems. A good approach would be to use the data gathered in this report, but implement them as constants or similar, so they easily can be exchanged when the exact values for the flight model is known. Also it should be discussed when it is critical based on these values. It should not be very time consuming to implement this, but it does depend on how the platform manager is designed. The detection does not help the satellite very much, but it gives an awareness of the problems, making it much easier to implement the rest of the system, even after the satellite is in orbit.

Turn Subsystems On and Off

The next thing to do, is of cause to implement a reaction to the detection. The easiest thing is to turn off subsystems in case of overheating, following the general or specific rules given above. Also turning of subsystems to preserve power should be implemented in this step. This should not be too time consuming to accomplish, provided the systems can be turned off and on, and that the detection is in place. Here we could also add the ability to turn up the amplifier to generate heat if the satellite is cold, if this method turns out to be feasible at all.

Rotate the Satellite

As the second kind of reaction, there is rotating the satellite to either heat or cool specific parts of the satellite, or to get more solar cells in the sun. This is more complicated, as it requires careful calculations. It is also more risky, as we do not want the satellite to spin uncontrollably.

Hibernation

The last step one could implement is the total hibernation. Here the power subsystem shut everything down in case of a serious power shortage, and wait until the battery charge has passed certain threshold,or a certain time has elapsed. This we have put at last, because while it might not be that complicated to do, it might be risky, as we need to sure that we can turn on all subsystems again.

This is implementation steps that describes the monitoring and control of the hardware parts of the satellite. On top of this comes the proposed extensions to the platform manager to monitor the software. While these are nice, they are still lower priority than monitoring the hardware, as without the hardware we will not have much use for software. Possibly the hardware and the software monitoring could be done in two different projects.

7 Modes

We have chosen to formulate different modes of operation for the satellite. These modes should be considered as suggestions to how the satellite should react in different situations. The modes could be implemented so that they can be initiated either by ground crew or by autonomous control by the on board software. In this section we will describe the modes that we think should be implemented. The criteria described in each mode should be perceived as the criteria for autonomous control by the on board software. The modes are described briefly by their subsection.

7.1 Normal Operation

Criteria

The criteria for this mode is:

- Nothing is to hot
- Nothing is to cold
- There is enough power for all systems

Description

Normal operation means that everything is working as intended. This implies that all subsystems has enough power and none off the subsystems is to hot or to cold.

Possible Solutions

Nothing should be done since everything is working as planned.

7.2 Power Safe Mode

Criteria

The criteria for this mode is:

- The battery is running low on power
- The solar cells is not producing enough power

Description

The power safe mode is initiated if for some reason the solar cells is not producing enough power and the battery is running low. This could happen if the systems on board are using too much power or there is not enough power being generated by the solar cells.

Possible Solutions

The options for resolving this is to turn off the subsystems which is not crucial for the survival of the satellite. Another possibility is, if in sunlight, to rotate the satellite so that more solar panels are reached by sunlight.

7.3 Warmup Mode

Criteria

The criteria for this mode is:

- A part of the satellite is getting too cold

Description

Even though the satellite is intended to have approximately the same temperature inside the cube at all times it can not be guaranteed. This means that it is possible that a part of the satellite can get to cold and we need to warm it up before it gets so cold that it dies.

Possible Solutions

If a part of the satellite is getting to cold we have different options of warming them up. One option is to turn on some nearby subsystems and hope they generate enough heat to radiate heat to the cold part. Another option is to rotate the satellite so that the cooled down part is getting closer to sunlight and hope that the surface next to it radiates enough heat to warm it up.

7.4 Cool Down Mode

Criteria

The criteria for this mode is:

- A part of the satellite is getting too hot

Description

The satellite can get to hot on some parts of it, just as it can get to cold. If any part of the satellite gets to hot there is a possibility that the part will die.

Possible Solutions

To resolve this we can turn off subsystems to make them radiate less heat and we can try to rotate the satellite so that the overheated part gets as far away from the sun as possible.

7.5 No Contact Mode

Criteria

The criteria for this mode is:

- The satellite has not been contacted by earth for a long period of time

Description

If the satellite has not been in contact with the ground station for a long period of time a number of things could have happened. The ground crew have been busy with other things. The ground radio have been broken. The on board radio has had a glitch. Any number of things could have happened. The satellite has no way of knowing what happened.

Possible Solutions

The only thing the satellite can do is to reboot the entire system and wait for the next contact by the ground station.

7.6 Detumbling Mode

Criteria

The criteria for this mode is:

- The satellite is tumbling around

Description

If for some reason the satellite is tumbling around the ACDS needs all the power it can get.

Possible Solutions

If the satellite is in detumbling mode we would need to turn off the subsystems not needed, hence the camera and maybe tether.

7.7 Hibernation Mode

Criteria

The criteria for this mode is:

- The Battery is so low on power that power safe mode is not enough

Description

Our definition of Hibernation mode is that everything is turned off except the power subsystem which tries to recharge the battery. Hibernation mode should only be used under extreme circumstances. That is when the power level drops below a sudden threshold. Hibernation mode is to be considered the last resort before total power loss. To allow hibernation mode the power subsystem has to be able to autonomously turn on/off the rest of the satellite.

Possible Solutions

Turn everything off and keep them turned off until battery power level is acceptable. When a suitable lever of power is reached after recharge, the power subsystem should restart everything.

If these modes are to be implemented each mode should carefully consider exactly which systems to control and what to do in the different modes. It should also be considered to have the possibility to run in a combination of the modes since low battery power could have something to do with the temperature and so on. The exact implementation scheme for these modes is beyond the scope of this paper.

8 Conclusion

This report presented a preliminary study of autonomous monitoring and control of the DTUsat small satellite.

The study analyzes and considers the software modules and hardware subsystems of the satellite. It results in a number of general rules describing the autonomous control of the satellite. Furthermore, the study suggests an implementation plan for the autonomous monitoring of the satellite. This plan describes several levels of autonomous monitoring and control and their importance.

This is a preliminary study as should be treated as such. On implementing a system based on this study, the rules and values should be examined to ensure correspondance to the physical reality. Furthermore, the viability of each of the suggested improvements should be considered.

In conclusion, this study analyzes both the hardware and software aspects of the satellite and suggests improvements and methods for implementing autonomous monitoring and control of the satellite. Autonomy in the satellite is necessary to ensure that the satellite responds properly to unexpected situations even when not under direct human control.

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A Power Budget

The satellite has different power usage when tumbling around and when stabilized. This is because the magnetotorquers use a lot of power when detumbling the satellite. The power budget for stabilized operation is shown in the table below.

	U(V)	I(mA)	Duty cycle	Average Power(mW)	P when not transmitting(mW)	P when transmitting(mW)
Magnetorquers	3,3	15,3	0,99	50	50	50
Magnetometer 1	3,3	20	0,01	0,66	0,66	0,66
Magnetometer 2	3,3	500	0,00003	0,0495	0,0495	0,0495
Sun sensor	3,3	4	0,02	0,264	0,264	0,264
OBC	3,3	50	1	165	165	165
Boot	3,3	110	0,0006	0,2017	0,2017	0
Upload	3,3	110	0,0069	2,50	0	0
Beacon	3,3	2	1	6,6	6,6	6,6
Reciever	3,3	20	1	66	66	66
Transmitter	3,3	20	0,0833	5,5	0	66
PA	3,7	270	0,0833	83,25	0	1000
Camera	3,3	25	0,0556	4,58	4,58	4,58
Tether	3,3	5	1	16,5	16,5	16,5
Total:				401,1	310,0	1376

Table 3: Power consumption in stabilized operation

When the satellite is detumbling, the change in power consumption is that the magnetotorquers use more power. The values for the magnetotoquers in the power budget for detumbling operation is shown below.

	U(V)	I(mA)	Duty cycle	Average Power(mW)	P when not transmitting(mW)	P when transmitting(mW)
Magnetorquers	3,3	46	0,99	150	150	150

B Subsystem Questionaire

This appendix shows the list of question each of the hardware subsystem groups answered.

1. What is the subsystems normal temperature range?
2. What is the temperature range with lowered functionality?
3. What does lowered functionality entail?
4. At what temperature is the unit damaged beyond operation?
5. If the unit is shut down, will it survive (at that temperature)?
6. If the unit is shut down, does it cool and how fast?
7. How much time is needed to restart the unit?
8. How much current does the unit draw?
9. What measurements are performed on the unit (what sensors are connected to the unit)?