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Command Chain Automation

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In today's design for new space missions often the automation of the mission control center is requested by the customer. As a consequence a mission control center which offers automated space- and ground operations is earning a remarkable benefit as the routine operations costs are decreased by automation.

The TanDEM-X mission is based on the close formation flight of two radar spacecraft (TerraSAR-X and TanDEM-X) currently flying with a minimum separation of only 150m. Ground station contact times for the uplink of the master timelines are taking place in parallel over different ground stations. Two operators at the same time are needed for commanding both spacecraft in order to ensure a safe uplink of the onboard timeline. As the operators are not only performing the command uplink but many other actions prior, during and after the contact, the risk for operator errors increases. Beside this fact, the operators at GSOC are not uniquely assigned to the TanDEM-X mission but supporting multiple missions operated by the German Space Operations Center (GSOC) within different control room areas and with different required needs of support.

The need to lower the operational routine costs in GSOC has increased within the past years. After detailed analyses of existing possibilities, one option was to automate the command chain using the native Test and Operations Procedure Environment (TOPE) interface of DLR SCOS2K based on ESA SCOS2K R3.1. SCOS is the standard monitoring and control system used at GSOC. It was a strong requirement that the automation fits to the existing mission data flow in the command chain. In addition, any software change of the monitoring and control system should be avoided. This was also advantageous due to the tight development schedule. Finally, the presented solution must be integrated to the mission security concept of the TanDEM-X mission, which is also driven by German law. All low earth orbiting missions of GSOC using the SCOS2K system could easily benefit from the developed solution as a generic implementation approach was selected. Since both spacecraft of the TanDEM-X mission (TSX and TDX satellite) are operated within one control room, both of them are subject of command chain automation. Only one operator is needed to fulfill the mission operations for both spacecraft with both missions automated. Furthermore, the operator gains more time for monitoring of spacecraft and ground systems.

This paper will describe the constraints and requirements for the automation of the command chain in GSOC for LEO missions. Furthermore, the integration into the operational monitoring and control system is described in detail as well as possible drawbacks. The paper concludes with the first experiences and lessons learnt during operations with an automated command chain.

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I. Introduction

Seven years ago, in 2007, the TerraSAR-X mission was realized and is operated from the German Space Operations Center (GSOC). With the TerraSAR-X mission, also a new command and telemetry processing system was introduced. Based on the ESA SCOS2K R3.1 application and with certain software adaptions made [1], TerraSAR-X was the first mission at GSOC using an integrated TM/TC system. In 2010, the TanDEM-X satellite was launched which established the TanDEM-X mission. Shortly afterwards both satellites started a close formation flight with an average distance in between of not more than 400 meters. The close formation flight requires one S-Band contact every six hours in order to control the satellites health and close formation status [2]. The mission planning system generates the mission timeline (MTL) for both satellites in an automatic manner, leading to roughly 1000 telecommands to be uplinked to both satellites twice a day. This is made with the GSOC ground station in Weilheim for TanDEM-X and the Neustrelitz ground station for TerraSAR-X. The uplink of the MTL is performed simultaneously by two operators within the same control room. However, the operators are not explicitly assigned to the TanDEM-X mission and support also other GSOC missions. The required operator support increase in general with mission elapsed time because of the degradation of the satellites. In addition, newly acquired projects require a reduction of operator shifts in order to significantly decrease the overall mission costs. As a consequence the mission operations department of GSOC started an internal assessment to identify possibilities to decrease the overall mission costs. Besides standardization of mission operations software, multimission software design approaches, and mission operations synergies the automation of the command chain offered the potential of a substantial cost reduction due to reduced operator shifts on console. Therefore the automation of the command chain for the TanDEM-X mission was subject of more detailed analyses, internal proof of concept studies and a first implementation.

II. Basic Automation System Constraints & Requirements

The command chain automation shall offer the possibility to upload a mission timeline in an automatic manner without any manual interaction. The DLR-SCOS2K system used in GSOC for both missions already offers an implemented TOPE interface and therefore a possibility for automated commanding. In the past GSOC did not utilize this interface for commanding activities during the operational phase. Furthermore, the system design and - much more important - the data flow inside the monitoring and control system (MCS) shall remain identical, compared to a MCS without an automatic command chain. The operators on console shall always have the possibility to fully control not only the standard MCS system and to perform manual commanding, as they normally do, but also the automatic uplink system in a safe and easy way. This implies that the automation system provides at least a certain set of telemetry parameters, which allows the operators to clearly identify the current status of the automation system itself. Based on this information the operator shall be able to stop the automation system in the case of a malfunction. The requirement that the DLR-SCOS2K application must remain unchanged was a strong constraint. The same counts for the MCS data flow with respect to the command chain. The automation system was supposed to not affect the existing MCS data flow i.e., whether the automation system is used or not shall have no influence on any data flow. In addition, not only TerraSAR-X and TanDEM-X should benefit from an automated command system but also other low earth orbiting missions operated by GSOC. Therefore a generic approach must be applied, allowing the missions to adapt the system to their needs whereas the TM/TC system stays unchanged.

III. Proof of Concept

In the TanDEM-X mission the flight procedures are developed and utilized with MOIS, which offers a direct interface for automatic commanding together with a DLR-SCOS2K command system. But as neither TerraSAR-X nor TanDEM-X consider MOIS as an application which is used in the operational environment the proof of concept study was done using the native DLR-SCOS2K interface TOPE. Also the fact that the satellite manufacturer AIRBUS Defence & Space performed most of the extensive system tests using the TOPE interface in conjunction with flight procedures utilized in MOIS counts for the native interface approach too. Therefore, a proof of concept study was performed using TCL based scripts, executed within the TOPE environment. A test campaign was performed using a spacecraft simulator, a single DLR-SCOS2K server instance and already available TOPE functions. It could be demonstrated, that the test system was able to run autonomously for several days. The results of the test study reveal a stable and usable interface at first glance.

IV. Detailed Design Description and Implementation Approach

Based on the study results, it was decided to use the TCL language as the implementation basis of the automation system i.e., using the TOPE interface and its dedicated functions available and already tested for use with the DLR-SCOS2K. The utilization of a scripted language offers the possibility of a simple implementation. The automation system is based on several small TCL scripts, each holding a block of specific functions for certain basic functionalities that can be adapted to the specific mission needs. These functions are encapsulated by a TCL framework which performs the most important task: Detection of spacecraft telemetry in the monitoring and control system, which indicates that a real-time contact is taking place. Flight operations of low earth orbiting missions are strongly contact driven, which is dictating the design of the system. Other system drivers are the specific operator tasks, which can be divided into three main groups, and are subject of automation as well:

Table 1: Operator Task Groups

Type	Task	Remark
PrePassOperations	System Check	
	Preparation of command activities i.e., loading of command sequences to the DLR-SCOS2K system	Prepared by MPS or FDS
	Final System Setup	AD-Mode synchronization
PassOperations	Uplink of MTL	
	Telemetry Checks	
	Request specific TM data dumps	
PostPassOperations	Final Uplink Check	
	Product generation based on real time available from previous contact	

The development and set up of an automation system should take these specific operator tasks into account as well. This means, that not only the MTL is uplinked in an automatic manner, but also certain ground segment related tasks prior and after a real-time contact are subject to automation. Here, the choice to use a script based implementation offered its full advantage as most of these tasks could be easily and independently scripted and tested. Besides the activities performed prior and after a real-time contact other ground related tasks could be performed automatically as well. Such task could be the generation of data products covering 24 hours of data or clean-up and archive procedures. Therefore, a cyclic activity task was installed, which will perform any available scripted task. It is important that these kinds of activities are suspended during the detection of a real-time contact and resumed afterwards. With ongoing implementation it was noticed that not all tasks are constantly requested. Cyclic activities are categorized according to the needed frequency, e.g. hourly, daily or weekly. This counts also for pre- and post pass activities.

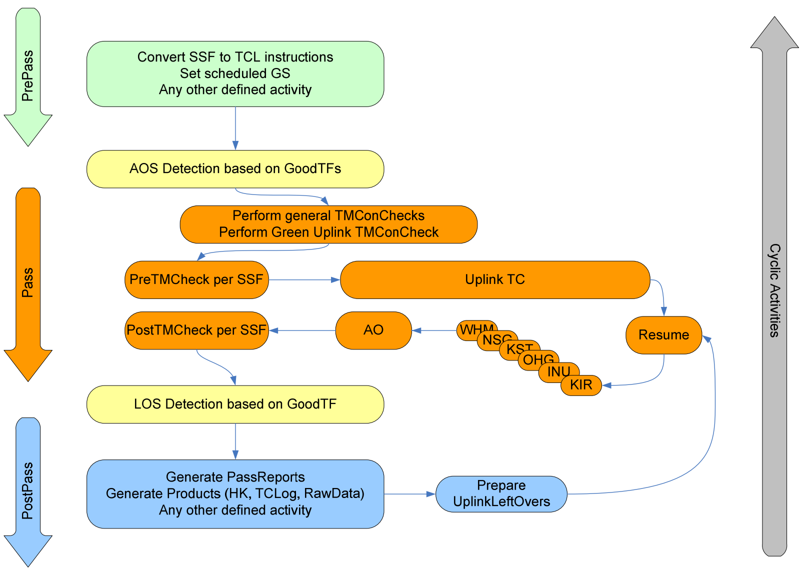

Figure 1: Automatic commanding workflow

For a real-time contact driven system the most important function – besides the automated uplink – is to autonomously detect the upcoming contact, as this is the base to trigger all following actions. In detail, the automation system will perform the following steps based on a fixed schema:

a) Detect start of a contact
b) Check satellite status and uplink capability
c) Uplink telecommands
d) Detect end of a contact

A. Detect Contact Start

One possibility is to check the parameter sample time of a telemetry parameter defined in the mission database, but this approach is not really generic. A generic approach could be achieved if not a specific telemetry parameter is observed but a telemetry packet instead. For a mission, based on the ESA Packet Utilization Standard [3] (PUS), any satellite telemetry packet is transferred to ground using telemetry transfer frames. The DLR-SCOS2K offers the possibility to define an internal telemetry packet, which contains the header of the telemetry transfer frame itself. This kind of information is of generic nature as each PUS mission will use it by default. Fortunately GSOC's DLR-SCOS2K and TOPE is offering the possibility to retrieve status updates for any telemetry packet defined in the MIB. TOPE provides these status updates of a telemetry packet once it was processed by DLR-. In the case that a contact starts the update of this packet will be used as a trigger. Recognizing the start of a real-time contact it depends on the ground station characteristics if the first telemetry samples are already usable or not. It might be necessary to define ground station related offset times which are used to wait for stable telemetry entering the monitoring and control system. Once the defined contact detection offset times are elapsed, the automation system will start to perform the action as described below.

B. Check Satellite Status and Green Uplink

The DLR-SCOS2K system used in GSOC is able to perform telemetry configuration checks (TMConCheck). The TMConCheck consists of a pre-defined set of telemetry parameters and their values, which are checked against pre-defined limits. These checks are defined in configuration files, stating each parameter and its boundaries to check. In general, the defined ranges of the parameter value checks are of a static nature. There are exceptions however. In the TanDEM-X mission, the defined TMConChecks also contain dynamic parameter values i.e., it is expected that the value of such a parameter is higher/lower than currently defined. Normally the operator will update these kinds of parameter values during the contact if necessary. However, for the automation system a dynamic update process was established, which allows recognizing if the parameter is subject to dynamic range extension or not. If defined, the parameter value check will be performed taking the dynamic range extension into account and updating the defined boundaries, if needed. The last TMConCheck will be the one checking the parameters defining the conditions for successfully established uplink capability. If successfully passed, the automation system will start with the automatic uplink of the telecommands. If any of the defined TMConChecks fails the contact will not be used for any automated command uplink.

C. Automatic Uplink of Telecommands

Once the automation system is declared ready for uplink i.e., all defined TMConChecks have been successfully performed, the automatic uplink of telecommands using TOPE is started. In general, the TanDEM-X mission is using saved command stack files (SSF) of the DLR-SCOS2K system. The SSFs represents the result of the parameterized input, delivered as flight procedures in a XML format. The parameterization itself is performed outside of the DLR-SCOS2K system based on input given by various sources, such as mission planning, flight dynamics or even the subsystem engineers themselves. These SSFs are loaded prior to the contact into the DLR-SCOS2K system by the operator. Depending on the payload operations scenario, the SSFs containing the MTL have on average 1000 telecommands. In general, not all of them are sent to the spacecraft, but to organize the MTL itself like comment and breakpoint telecommands.

Before the automatic uplink can take place, the commands and their parameters must be converted to a TOPE compatible format based on TCL. As a contact for low earth orbiting missions lasts a maximum of ten minutes every second of the contact is valuable and therefore the format conversion is performed prior to the contact. This enables the operator to react to any unlikely malfunction of the automation system in the conversion process. Once the conversion process is successfully passed, a TCL script is generated, containing all necessary information. Depending on the system settings, the ratio of telecomand input to the number of tcl instruction lines is 10 to 15 i.e., for 1000 telecommands 10000 lines of TCL instructions are generated.

Besides the telecomands itself most of the instruction lines are generated in order to ensure and verify the correct uplink. For PUS designed spacecraft the telecommand acknowledgments offer a possibility to confirm the successful execution onboard in an elegant way. Assuming that the spacecraft supports this PUS service in an adequate way, for each real-time telecommand DLR-SCOS2K will receive acknowledgments (as telemetry) for onboard acceptance and execution. However, this counts not for timetagged telecommands. The reason is that a timetagged telecommand is uplinked to the spacecraft using a real time carrier command. This carrier command is not accessible at the TOPE interface. Therefore no telecommand acknowledgments will be received by ground until the telecommand is executed on board. For low earth orbiting spacecraft this is most of the time outside of any ground station contact.

Another point to consider is the procedure based approach: In general, any delivered command input is based on flight procedures defined in MOIS. For safe satellite operations it was required to ensure a procedure based upload i.e., any partial upload of procedures shall be prevented. Therefore, the automation system must have the knowledge about the maximum contact duration. Several derived parameters were introduced in DLR-SCOS2K in order to calculate the elevation of the satellite with respect to the S-Band ground station network used. Based upon real-time telemetry from the on-board GPS receiver, the maximum time left for commanding is derived, taking the ground station with the highest calculated elevation into account. As long as the mission is using a S-Band network where the allocated ground stations have no overlapping visibilities, this approach works reliable, however for the TanDEM-X mission this is not always the case. Therefore, a secondary interface is needed, which carries the scheduled ground station information and pre-selects the next upcoming ground station which will be used for the contact.

If a procedure based upload is requested, it is necessary to know the total number of commands per procedure. As already pointed out, the MTL consists of roughly 1000 telecommands per session, using a certain number of parameterized procedures. The procedure based approach is only useable if each procedure start and end is marked explicitly, thus enabling the automation process to recognize the procedure blocks itself. Assuming that the procedure blocks are marked, the automation system is able to decide, if a procedure block could be safely uplinked. The decision is based on the calculated effective remaining commanding time and the presumed telecommands per seconds. In the case that no safe uplink is ensured, the automation system will stop the uplink and prepare the remaining telecommands for the next possible contact.

D. Detect Contact End

After finishing all command activities, the automation process will detect the contact end using the same mechanism as for the contact start detection. But in this case, missing telemetry transfer frames within a predefined time span are taken as a trigger for the end of a contact. In general, the telemetry might be influenced by bad signal strength at the end of a contact. Special countermeasures must be taken to prevent the system from detecting a new start of a contact instead of the end of it. Once the contact is finished and no more satellite telemetry updates are detected, the PostPass activities will be executed. In the TanDEM-X mission the PostPast Activities consists of report generation, specific data extraction from the MCS like telecommand log files, OnBoard Queue Display data and telemetry data extraction.

V. Operational Introduction and First Experiences

The automation system was integrated into the operational TanDEM-X environment using an approach which should ensure that the routine operations are only influenced by a minimum. Before any operational introduction could take place, the mission databases (MIB) for both satellite missions were adapted. In general, the user defined constant interface of DLR-SCOS2K was activated, appropriate telemetry packets in the MIB were defined and special settings in the central configuration file of the DLR-SCOS2K system have been changed. Once these pre-requisites were fulfilled, the implementation and first tests could be performed using the TanDEM-X satellite simulator reference system at GSOC.

However, moving the automation system to the operational TanDEM-X environment for additional tests revealed several times a different behavior compared to the one observed at the simulator reference system. Especially timing issues during the evaluation of the command feedback were found to have a major influence on the automation system workflow. In particular, the command acknowledgments reported via the TOPE interface turned out to be a challenge: Once missed or not received in appropriate time the automation system is designed to stop the uplink, assuming that the affected commands were not successfully received or executed onboard. A specific test mode was implemented in order to test that a complete MTL uplink could be successfully supported even in the operational environment. The test mode exchanges all commands of a given MTL with spacecraft pings. In addition, all timetags of the commands were removed i.e., the commands are sent as real-time commands. With this approach also the partial upload of command requests could be tested. This is necessary in case that more commands had to be uplinked than the calculated contact time would allow. During the tests of this feature it was realized, that a possibility to configure the automation system depending on the pre-selected ground station would be highly recommended. The driver is the different ground station characteristics as well as the possibility to control the automatic uplink for specific ground stations at all. Furthermore it was observed, that not all command acknowledgment updates were properly reported by the TOPE interface, especially not for timetagged commands. As a consequence the conversion process was adapted accordingly. With this change the uplink of timetagged commands could be ensured without having direct access to the real-time carrier command itself.

For the operator the used MCS data flow of the command chain stays unchanged. This allows the operator still to perform manual commanding in parallel to the automation system, if required for any reasons. The automation system is using the same TMConChecks as the operator does. In case the TMConCheck done by the automation system fails, the operator is still able to update it manually. Once updated, the TMConChecks can be successfully executed by the automation system within the next contact. Furthermore the operator is preparing an upcoming contact as usual i.e., loading the MTL to the command system. In the case an automatic uplink shall be performed the operator is requested to save the commanding input to a specific destination in order to allow the automation system to start the converting process to a TCL file. These TCL files are then subject to automatic commanding if all pre-requisites are fulfilled. The operator is always able to stop the automatic system and start or continue manual commanding. A pre-requisite for this scenario is that the automation process is always reporting a reference counter indicating the command number which is going to be currently uplinked. Ideally this matches the number of the line in the manual stack application which is used by the operator for manual commanding. In case the commanding time is not sufficient for the uplink of the complete MTL the remaining telecommands are prepared for the next contact. They are scheduled to be uplinked prior to any other command requests during the next contact. In these cases, the operator is requested to remove all uplinked commands in the manual stack in order to keep it synchronized to the automation system. This design allows that the operator is able to continue manual commanding if needed.

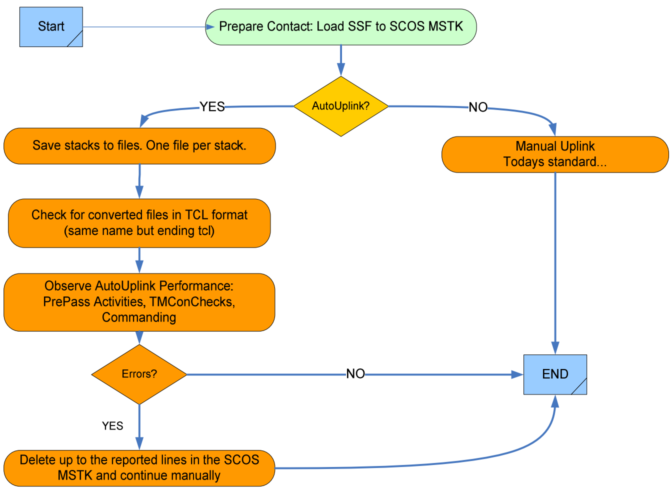

Figure 2: Operator workflow

VI. Drawbacks

It is a matter of fact, that the used TOPE implementation reveals several missing features. For most of them a workaround exists or could be easily applied, except for the handling of timetagged commands. The current implementation uses a negative check strategy: In general, it is assumed, that an acknowledgment of a timetagged command will not expire during the current uplink session i.e., it will be not executed. This allows checking if any of the acknowledgments of the uplinked timetagged commands are reported as expired. If an expired acknowledgment is detected this might indicate an uplink error which will force the automation system to stop continuing the uplink. The established workaround is reliable for GSOC as the MTL is separately checked after each uplink of timetagged commands by means of MTL summary dumps, which are compared against the delivered command input.

Finally the chosen TCL approach based on several small TCL scripts, each performing a specific task, reveals the possibility of more difficult maintenance in general. On the other hand, the selected solution offers the most generic implementation possible as the core of the automation system is the same for all low earth orbiting mission which are subject to automation in GSOC. The other parts of the automation system could be tailored in order to meet the mission requirements.

VII. Conclusion & Outlook

The introduction of an automated command system in the routine operations of the TanDEM-X mission was driven by the need to lower the operational costs. The selected implementation approach offers a generic solution, which could easily be adapted to different mission requirements. Based on the TOPE interface which is available, but in the past not widely used in the GSOC routine mission operations, the automation system is currently significantly changing it.

From an operational point of view, it is important that the automation system fits in the operational command workflow, thus ensuring that parallel manual commanding is still supported and possible. In order to guarantee that all uplinked commands were successfully received and executed onboard, it is necessary to explicitly check the telecommand acknowledgments delivered by the spacecraft. For timetagged commands the handling of these acknowledgments posed a challenge in this context because the real-time carrier command is not accessible from the TOPE interface. The observed command uplink performance is lower compared to manual commanding. The case that more commands shall be uplinked than the contact time would allow is covered by the partial commanding feature i.e., spreading the MTL upload over several contacts.

The first experiences in the routine TanDEM-X mission operations were already gathered, giving a first impression to a future with increased automatic ground operations. The TCL script based approach, using the TOPE interface of DLR-SCOS2K, offers a comfortable way for further automation on a step by step basis.

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