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Automated and Intelligent Satellite Mission Operations Experiences with the N2 Satellite Ground Segment and Future Directions

[1]M. Sanusi, [2]M. Ibrahim Ndana, [3]A. Jamilu, [4]S. Ramadan Ibrahim, [5]U. Okonkwo Ngozi, [6]Z. Mohammed Musa, [7]M. Kawuyo Fatima, [8]S. Onozare Aisha and [9]O. Patrick.

[1,2,3,4,6,7,8,9]Centre for Satellite Technology Development- NASRDA Abuja.

[5]Department of Computer Science, University of Abuja.

Email: msanusi2009@yahoo.co.uk

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ABSTRACT:

In 2011, National Space Research and Development Agency (NASRDA) successfully launched the NigeriaSat-2 (N2) and NigeriaSat-X (NX) satellites with the major objective of establishing a principal and leading earth observation satellite capability in Nigeria and Africa. As part of the NASRDA Satellite Earth observation programme, NASRDA also established a state of the art ground segment facility for operating the spacecraft and data handling with higher degree of automation. The establishment of N2 Ground segment components employ several automations in mission operations and satellite control. This strategy has improved the level of safety in operations and the mission management. Managing satellite mission is an expensive activity and hence the need to employ automated operations to lessen the intensity of the expenditure and provide protected operations. In contemporary missions and operations operational tasks are automated for effective mission cost and unharmed control operations. In this paper N2 and contemporary satellite operation automation principles are reviewed and new techniques to improve the level of automated operations are proposed. These techniques include an imaging schedule algorithm that will automate data format on the spacecraft and is based on available spacecraft resources and application meant for the requested image. An automated on-board computer recovery procedure to enhance operations is also proposed. Other significant operational tasks for an improved performance are also projected.

Keyword: Automation, Ground segment, Satellite operations, Nigeriasat-2

1. Introduction

Achieving a satellite in orbit could not meet a mission objective without successful designed mission operation centre for the life time of the vehicle in orbit.. In space mission operations centre design, tasking challenges are involved in driving the required hardware and software modules that are conforming with the designed payload and platform. Basic operations involve payload mission control, attitude control and stabilisation, frequent and scheduled spacecraft updates and daily monitoring of spacecraft health and functionality. Space mission operation remains an on-going activity to the end of mission lifetime and passivisation of the space vehicle. Due to the electronic processing complexities and behaviour, sensors and equipment responses, automated operations are employed onboard the spacecraft and earth station. These operations implement a working decision making algorithms to response or actuate a specific activity. In general all systems are operated with a built in algorithm that monitor the system behaviour and response in essence counteracting to any abnormal performance for proper operations and safety of the system. At the earth station, operators receive any abnormal condition through text messages so that operational activities that must require human personnel are attended to for effective and continuous mission operations.

There are four standard operational plans required for a spacecraft mission. *Launch* and *Early Orbit Operation (LEOP), Commissioning Operations*, *Mission Operations* and the *End of Life* operational activities. *LEOP* is the initial phase of operation which includes launch operations, signal acquisition, initial attitude acquisition to place the spacecraft into safe mode. *LEOP* operations usually last within a week. *Commissioning Operations* activities include functional platform testing, payload testing and performance measurements, and validation of customer requirements. This operational phase can last up to thirteen weeks and can be less when a pair of control stations are used. *Mission Operations* activity include routine operations, periodic payload characterisation and orbit maintenance. *Mission operations* are continuous activity up to the end of the designed life. *End of Life* activity involve passivation of spacecraft and expelling unused fuel to reduce debris risk. This activity usually last for a week.

Satellite ground segment(GS) can either be for communication or earth observation (Remote sensing) satellite. Satellite Earth Stations (ES) are designed and built to achieve a specific mission objective. However modern ES stations function and operate for a number of satellite missions. This technology will require several number of software and hardware configurations that allow implementation of automated operations at particular instances. This include automated response to abnormalities, hosting particular spacecraft for data acquisition or mission operation activity appropriate configurations for equipment. Software programs are automatically set and configured to prepare for a particular spacecraft operation such as tracking/imaging when spacecraft is visible to the station. This process is usually applied by sending pre-configured commands to the spacecraft to allow its resources to be utilised at a specified time. Satellite missions are basically classified based on mission objectives and the type of hosting orbit in space. This paper is organised into seven sections, apart from section 1 which is introduction, the remaining sections include section 2 N2 Ground segment automation structure section 3 Automated mission operation principles, section 4 Proposed techniques and units for automated operation section 5 and section 6 are conclusion and references respectively.

2. Automated mission operation principles

The practice of automated satellite operations reduces operational costs and risks. On the spacecraft, safety operations are effected for instance due to spacecraft power limits and data storage. On the earth stations files are uploaded whenever the satellite is in view. The business of spacecraft mission operations and management involve people working together to achieve the desired mission operations and control. The task of supporting a big number of people along with the communication network that ties them together is expensive. For this reason, space mission managers are constantly looking to drive new ways to streamline operations and reduce costs or risk. One approach to do this is to employ more functions on-board the spacecraft reducing the need for a big number of operation team members. Here, we define automated operation as the ability of a spacecraft to perform some or most of its functions without the intervention of operators. Employing autonomous operations is a way to cut costs by reducing the number of operators and control centres. For certain mission such as interplanary or some expensive mission, some degree of autonomy is essential. Interplanary missions for example must operate with long time delays because of extremely long distance. the on-board software needs to deal with any contingency without waiting for advice from operators of the earth station [3]. Human error is another strong argument for improved spacecraft autonomous operation. Human errors can be a source of mission failure. The Russian phobos mission and the NASA mars climate orbiter are two prominent examples of human error leading to a mission's termination. In these missions, operators command an erroneous command to fire the orbital insertion rocket engine [3]. In payload mission control, automation is a significant aspect. When data is captured on-board a large amount of data is realized especially for high resolution payload within 1 to 10m Ground Sample Distance. The capacity of spacecraft captured data will determine the ground facility equipment’s size and the amount of time that will be required to download the data . Section 4.7 describe an auto-compression procedure. Compressed data will significantly reduce download time for large amount of data requiring lengthy time. It also allows maximum utilisation of spacecraft resources.

2.1 Automated Mission Planning and Monitoring Systems

In practice all space missions being it a scientific mission, remote sensing, astronauts in space or communication need to be controlled and monitored. To avoid erroneous commands and run a protected mission activities are automatically being controlled and monitored. Spacecraft health is monitored so that actions can be taken where modules are operating in abnormal conditions. Each of the module is being configured to supply temperature and operating power values and these values are stored and automatically scheduled to be sent to the earth station within an interval of a specified time. These values are sent to the earth station every time there are changes and the stored values are downloaded daily.

In remote sensing missions, position of spacecraft is predicted and imaging operations are scheduled specifying a future period of image capture and target position. This operation is done with the intervention of users triggering and specifying the intended operations. However, a number of operations are automatically done including allowing and executing of only safe scheduled and requested operations to be executed. Modern MPS, are operated online and schedules are transmitted to the spacecraft when it is in contact with the earth station that hosts the schedules. This flexibility allows users to perform mission operations irrespective of where they reside. Also spacecraft could be scheduled to allow the data capturing at any pre-configured and compatible earth station. One outstanding research area is the complex task of using multiple earth stations for managing constellation of spacecraft missions. This area of research is significant in disaster managing missions, security applications, environmental monitoring or situation where data for a specific research and monitoring study is required.

2.2 Antenna System Auto Tracking Principle

Auto tracking is a technique allowing the antenna to use pre-defined and configured satellite positional conditions and determine its operational angles within the satellite pan for data reception. Tracking a satellite necessitates the need for the receiving antenna system to follow the transmitting source as accurately as possible to ensure maximum power transfer and hence good signal quality or a high signal to ratio. Until a recent time tracking a satellite could be easily achieved using sophisticated computer software to drive the antenna, the limitation of this method becomes obvious when large diameter antenna is associated with narrow beam width at microwave frequencies. The N2 7.3m Tracking Antenna system employs an additional third axis track over the elevation and azimuth axis for achieving better automatic tracking capability.

An established method of accurately following a transmitting space source in its trajectory is by using the transmitted signal itself to develop an error voltage proportional to the angular deviation of the antenna boresight from the transmitting source and correcting that error by driving the antenna in the direction that zero’s that error. This dynamic “closed loop” configuration needs additional RF design either in the feed-front end itself or behind it to produce a secondary antenna pattern that is termed the “difference” or “error channel”. The primary antenna being termed the sum channel.

These two patterns are by design made coincident and the line running from the tip of the sum channel to the null of the difference channel and extends in the direction the antenna is pointing is termed the antenna bore sight or the Z-axis.

The sum and difference patterns are three dimensional, they are not visible or tangible but can be expressed indirectly when signal power captured by the antenna is converted into voltage that can trace the “contours” of these patterns on paper or displayed by a computer. When the antenna is pointing precisely at the transmitting source all the received power is concentrated on the sum channel while no power is defected by the difference or delta channel.

Any deviation away from the source produces an output from the delta channel which when demodulated is translated to two bipolar DC voltages, one for Azimuth and for Elevation, their sign representing direction i.e. + for up, - for down in Elevation and + for CW (clock wise), - for CCW (counter CW) Azimuth. By feeding those voltages into a servo amplifier the antenna drive mechanism (AC, DC or Hydraulic motors) can be accurately controlled to position the antenna precisely onto the transmitting source. When tracking a satellite in auto track mode the process of generating the tracking errors is dynamic and continuous, the error generating loop is updated many times a second and drives the antenna onto the target but as the antenna “catches up” the target moves ahead again and so on. The actual movement of the antenna is in tiny little steps i.e. 400/sec for example that result in an overall smooth movement. This method of tracking is termed step tacking.

3. N2 Ground segment automation structure overview

Figure 1 is the basic architecture for the operational blocks of the N2 Ground segment. each of the block consists of several designed elements to accomplish the automated satellite mission operations. The TT&C components are designed to allow commanding the spacecraft via S-band 9k6 and receive telemetry data via s-band 38k4 frequencies. the system is also designed to receive payload data with the X/S band feed at 105Mbpsx2 channels. This design flexibility to accommodate other spacecraft such as NX on 20Mbps rate. The mission control (MC) block monitors and control the antenna and spacecraft in an automated processes of executing various tasks and schedule at specified times and instructions. The MC block also manages automatic payload download and transfer of data into the processing parts and archiving. Most of the automated processes are achieved through invoking and executing relevant scripts for every successful and scheduled spacecraft pass. Also Acquisition scheduling processor engine provide effective queuing of every spacecraft pass.

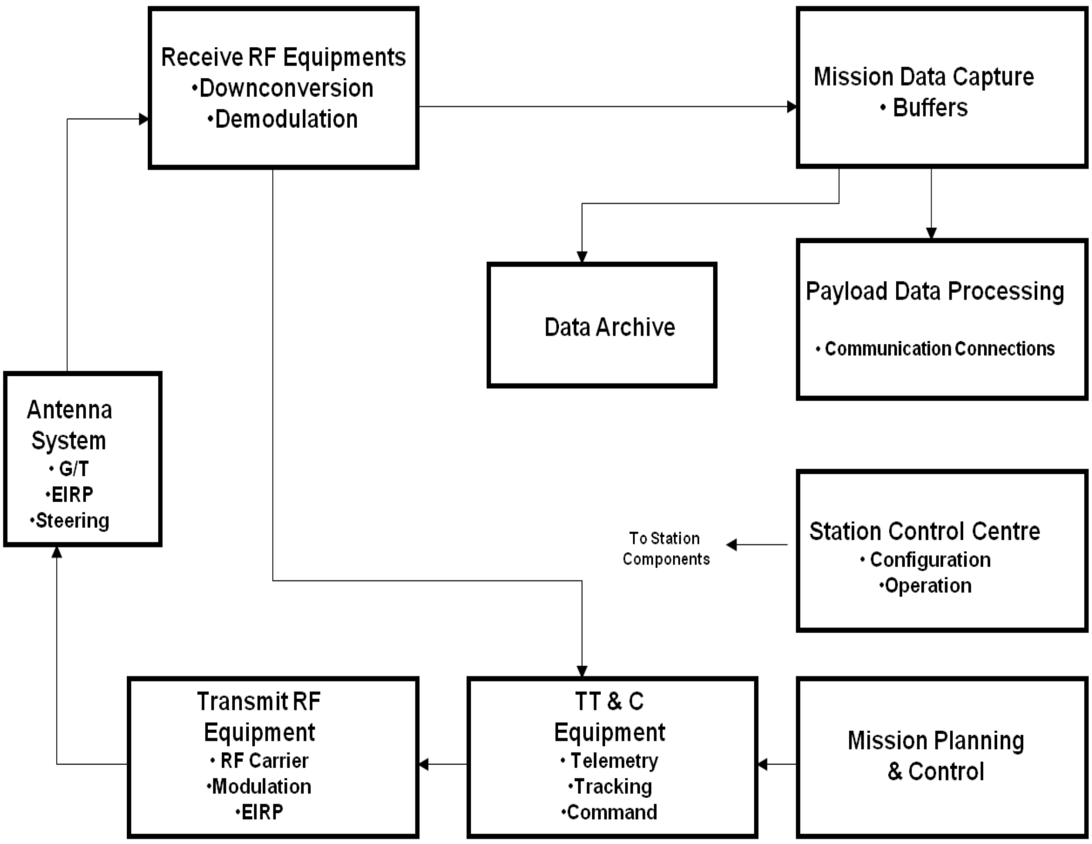

Figure 1 : N2 Ground Segment Operational Equipment Basic Architecture

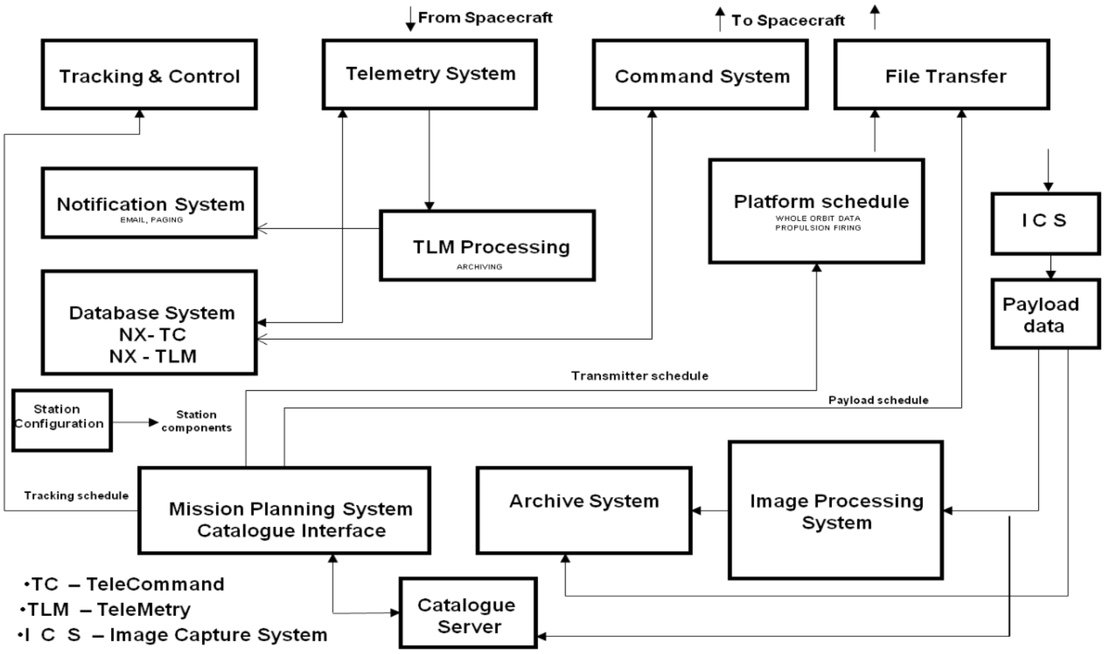

Figure 2 : N2 ground segment software Architecture

The mission control resources operate the platform and monitors the health, safety and performance of the spacecraft. the control software interfaces with the operational antenna and the supporting electronics, routers and switches to provide an automated monitoring and control of the spacecraft and the ground segment systems. This functionality is provided and tested from the initial phase of the mission operation, and is continued to the end life of the mission. The continuity test is usually re-confirmed through RF test continuity, G/T, and operational performance of data and image processing chain. The system has the capability to automatically monitor critical telemetry for safety control during unattended operations. Appropriate staff are notified of any abnormal values via text messages. The design and built modules for the satellite and station operation are reconfigurable a feature which highly automate the operational setting with robust and increase operational flexibility. this feature also provides flexibility and multiple interfacing with other system modules and satellites. Most of these functionalities are effected and facilitated by the use of scripts and file system. to provide future debugging data and technical design reference, the system maintains a log of all commands, telemetry data and upload schedules.

3.1 N2 - Other key operational design elements

The structure of the operational design has facilitated in achieving an automated system and deliver a robust and easy to control system interfaces. The spacecraft control is handled using four main work stations as follows (1) Control station runs Tracking software and controls the ground station operation and other services. It starts other required services in the other control station during spacecraft pass (2) Data station which hosts programs for commanding and control of the spacecraft. The Image capture system (ICS) in Figure 2 has replace some of the functionalities in the data work station. The ICS hosts the Saratoga software services that recover and reassemble the image data download which is then retrieve by the other systems through the network. (3) Telemetry station retrieves real time telemetry and displays it on the workstation monitor. This is achieved via IP protocol or the AX25 link services and is depend on the spacecraft configuration (4) Archive server station provides temporary storage for all data once it is received from the spacecraft. This data can be made available across a network to payload specialists. Facilities are available for storage for long term archiving**.** Trend analyses software analyses housekeeping data received from the spacecraft and places it into a database management system for analyses by support staff. The database management system is typically installed on either the Archive Server or the Control Workstation.

3.1.1 Low Speed Link Server

The *Low Speed Link Server* acts as the ground station's link to the spacecraft when in synchronous mode. It connects to the High Data Link Control (HDLC) card in the station computer which in turn connects to the transmit and receive equipment in the ground station rack. During synchronous operations, all uplink data is passed to the low speed service by ground station software and then on to the spacecraft uplink. This allows many ground station software modules to transmit to the spacecraft at once without conflict. Likewise, all downlink data is received by the low speed service and passed on to the respective software modules for processing.

The transmission of data between the low speed service and other ground station software modules such as Telemetry software DispTLM is carried out via the network using TCP/IP protocols. When a module wishes to receive data from the spacecraft, it must first register itself with the *Low Speed Link Server* and request data from all required callsigns. This makes the ground station highly configurable, robust and autonomous. The ground station software connecting to the *Low Speed Link Server* do not have to be on the same PC or network.

3.1.2 Automation Client

Automation client program called Winidle is set on to run at boot time on the control workstations described in 0. It uses the ground station tracking service to determine which spacecraft is tracked at a particular time. Winidle then automatically executes the script files required for carrying out automated operations for the particular spacecraft being tracked. These script files can be setup to run at Acquisition of signal (AOS), or at Loss of Signal (LOS) or between passes. Generally, the script files run at AOS to set up the ground station for correct spacecraft operation. The script files run at LOS carry out post-pass processing of data downloaded from the spacecraft. Script files run between passes are generally used for automated ground station control and monitoring purposes. Winidle is observable as a taskbar at the top of the screen and includes a number of buttons and status information.

4. Proposed Units for Automation

In satellite operations several number of units are built to facilitate an autonomous and safe operations. Hence these units need to be automated so that more benefits are derived and safety operations are achieved. Recent and new satellite products are more valuable to most application users especially in the areas of security, agriculture, environmental management and disaster mitigation. Hence satellite images may possibly be outdated for use in many data applications and remain useful for other demanding needs. Automating an image Access system from the Ground segment is an essential component in improving the need of getting an instant and recent satellite data. This functionality of image access shall provide an automated processing chain and users access via an online secured interface. The access time after an image is downloaded will depend on the speed and design of the processing software, level of processing required as well as the system hardware composition. Other vital units for safety and automated operations include automation of on-board computer (OBC) reloading and restarting operations. This proposed procedure is described in 0. This system will require an intelligent system configured and hosted on-board the satellite. This will further minimize human intervention errors and improve mission operations.

In building operational components units, re-configurable systems and units enhance the capability of the system through achieving flexible operations on existing and future and future missions. Hence the cost of hosting a satellite with similar format becomes affordable.

4.1 Proposed Auto-compression configuration algorithm

The following proposed algorithm can be implemented in the payload control and operations system. The algorithm allows the on-board system to automatically compress any captured data obeying a preconfigured commands scheduled from the ES. The algorithm prioritizes the compression depending on the command value specifying a specific application. Several number of applications will not be affected for their data while others may not tolerate any compression due to in-reversible data lost after decompressing. The algorithm proceeds with automatic compression when predefined conditions are satisfied and validated. The conditions are described below:

Ground user configured request (Cnf_rq)

estimated or measured image size (Est_Img)

spacecraft resources availability (Sat_avai)

time availability (time_ava)

The mission or payload control user configured an imaging schedule for compression or for a non-compressed image. The number of scenes to be captured can reveal the size of the image and this value is measured against the available resources at the time of imaging. Spacecraft availability is also considered if the compression is only required for real time download otherwise the compressed data can be stored allowing more adequate space for subsequent imaging activity. The implementation of this algorithm can be integrated with an ES mission planning system and this is included in the spacecraft schedules.

4.2 Proposed Automated procedure for OBC recovery

OBC on the spacecraft hosts several number of operational applications and running software to execute mission tasks and keep all spacecraft modules operational. However, in the process of executing OBC tasks, the system does crashes and need to be reloaded to recover the correct operational functionality. To enhance this functionality and reduce operational tasks to execute immediate mission tasks and safe the risk of losing the task, a procedure is proposed as in figure... The procedure alerts operators when the problem occur and when is successfully recovered back to normal functionality. The implementation of this procedure is assumed to be on the on-board OBC of the target satellite which communicate to ground operators for monitoring and control. Figure 3 describes the proposed system. The Direct Memory Access allow all functionalalities of OBC are recovered when system crashes and put the system to normal. In this case the operators are informed via telemetry when the failure is detectedd and when it is successfully fixed.

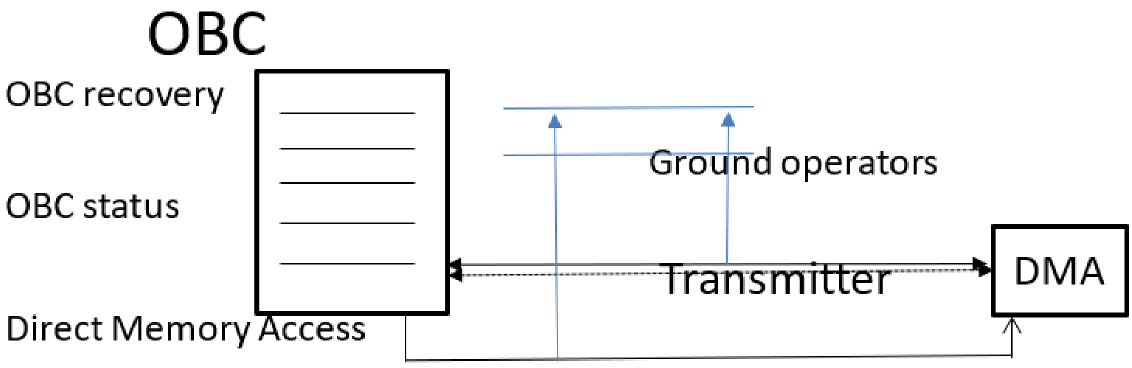

Figure 3 : Automated Control of OBC control functions

4.3 Automating alerts for equipment replacement and service

Providing a system that alerts and send messages to operators for equipment that are nearly to be replaced or serviced will facilitate in keeping continuous system operations. The system should provide an interface where all installed equipment and software are registered with the manufacturers time requirements for replacement or servicing. This has become a challenge in satellite communication and earth observation stations where key communication supporting equipment require long time to be manufactured and delivered. For instance, Low Noise Block(LNB) or Low Noise Amplifier(LNA) becomes un-functional and this is not noticed on time, the situation will break the system operational continuity. Allowing sensitive communication equipment such as LNB/LNA to finally break before replacement can translate to discontinuity in quality of the system and the signal for a period that happens before the final replacement.

5. Conclusion

In this research work, a significant industrial experience on satellite automatic mission operation is discussed. The significant of automated operations and several number of units that require automation are proposed and will constitute significant elements in satellite autonomous operations. The OBC autonomous control procedure will reduce the level of operators intervention and provide quick and safe recovery when failure occurs. The proposed compression configuration algorithm will allow efficient management of spacecraft resources and enhance some level of automations for payload data control.

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