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This memo describes general requirements for the features of a remote control antenna interface for a typical VGOS antenna. The antenna is typically provided with a control computer that is referred to here as the Antenna Control Unit (ACU). The ACU typically provides functions that include servo control of the antenna, monitor functions, and pointing the antenna in its natural coordinates. The ACU in turn communicates with a separate software system referred to here as the Antenna Pointing System (APS), that implements the monitor and control functions for the end user. These functions would typically include tracking celestial sources and artificial satellites. Thus the ACU provides basic antenna functionality that the APS builds on to provide the higher level functions for the user. The user might be yet another software system or a person, but is typically the NASA Field System (FS). The connection between the APS and ACU is over the Antenna Control Interface (ACI). The ACU is a server to the APS, which is a client. The first section below describes the ACI. The second section elaborates on details related to the azimuth cable wrap of the antenna.

1. Antenna Control Interface (ACI)

The Antenna Control Unit (ACU) should provide a monitor and control interface to an external software system, referred to as the Antenna Pointing System (APS), using a reliable protocol over Ethernet, such as TCP sockets or Modbus. This interface is the Antenna Control Interface (ACI). The ACU should be accessible to the APS using standard available tools, typically in the C language under Linux. The APS is expected to execute in a computer that will be on the same LAN with the ACU. Responses from the ACU should arrive quickly (typically within about 10 milliseconds when no other network traffic is present, but some situations may require tighter constraints) after a command or query is sent to it. There should be a reliable reconnection procedure in case of a time-out or other loss of communication.

It should be possible to command the antenna with an epoch, position, and rate in the natural coordinates of the antenna, and to select the desired cable wrap (see section 2) if applicable, at approximately a 1 Hz rate. These (typically) five commanded values define a target trajectory for the antenna to follow. The commanded position is the target position at the commanded epoch. The target position evolves (to or from the commanded position) at the commanded rate. (Behavior when the user requests a target position beyond a limit is managed by the APS, which typically will command the antenna to "wait" at the nearest limit, but the ACU should protect the antenna in case the APS commands the antenna to move past the limits.) The ACU should accept sufficient precision for the commands to cover at least the full resolution of the encoders and not lose precision in the propagation of the coordinates at that level. Typically a propagation time of 1000 seconds is sufficient. This will normally require higher precision, at least three more digits for 1000 seconds, for the commanded rates than for the commanded positions.

The antenna should track smoothly when the ACU receives consistent trajectory commands regardless of the interval between them. The antenna should slew smoothly when a discontinuity in the target trajectories occurs. The ACU should manage the necessary accelerations and decelerations. If the interface is disconnected and/or reconnected, the antenna should continue to track according to the last command.

The ACU should implement a command to enable/disable a "Dead Man Switch" (DMS) to take action if loss of positive control through the ACI is detected by the ACU. The time-out (interval) for detecting loss of control, might be settable to a value of a few seconds to a few tens of seconds, but typically a fixed value of about 30 seconds is useful. The actions available on time-out should include at least "stop", but "stow" and other options may be useful in addition. A specific command, separate from other antenna commands and queries (so as not to depend on or interfere with other information) should be required to "reset" the DMS time-out timer. The APS would send this command periodically while it is maintaining control.

The ACU should provide all necessary mechanical protection for the antenna including preventing it from overrunning the antenna limits. This may require the ACU to monitor the speed and as well the position of the antenna. If a target position exceeds the antenna limits, the ACU should move the antenna to a position close to the commanded position at the software limits. No manual intervention should be required for the APS to move the antenna out of the software limits. A different target position should be sufficient to accomplish this.

There should be a method to verify that all commands were correctly received by the ACU, such as reading back the received values. It should be possible to read back all values commanded to the ACU. When reading back sequentially organized commanded parameters, the parameters should be returned in the same order as used for their command whenever possible (so-called "parameter parallelism").

The ACU and its operation should be compatible with off-site control. There should be physical "emergency stop" buttons and a "remote lock-out" feature that cannot be overridden by the ACI. Otherwise, the ACI should provide all control and monitor functions that are needed to completely control and monitor the antenna for normal operations for either on- or off-site users. Some maintenance operations such as driving the antenna out of hardware limits may require features beyond the ACI for on-site manual operation to ensure personnel and equipment safety.

The ACU should be designed to operate through small fluctuations and drop-outs in the supplied power. When normal power is restored after a small fluctuation/drop-out or a power failure, it should not be possible for the ACU to unexpectedly drive the antenna away from its current target trajectory (and it should still respect the DMS if enabled). If the implementation of this feature includes a UPS for the controller (typically a UPS would not support the antenna drive motors themselves, but only the ACU), it is desirable for the main power switch for the antenna to fully remove power from the controller, including disconnecting the batteries, when shut off. A less desirable solution is to have a single additional switch to disconnect the batteries.

It should be possible to set the time that the ACU uses for calculating the command positions and report the actual positions of the antenna to within a few tens of milliseconds of UTC and adjust

to leap seconds over a few tens of seconds or faster. Higher accuracy may be required in some situations. Typically, NTP (or SNTP) can provide sufficient accuracy. Except for initial time setting, any adjustments in the ACU time should be made by slewing the time, rather than stepping. At least for NTP (and SNTP) there should be a way to designate at least two sources of time so that if one server fails, a back-up will be utilized.

It is useful if the ACU is supplied with a stand-alone program that demonstrates the important control and monitor features of the ACI and can be used for testing and maintenance operations.

It is desirable for the antenna to have hardware inputs to command the antenna to stow (overriding the DMS if enabled), overriding any current trajectory. This feature should not be available unless the antenna is in "remote", with the drives energized, the antenna is safe to move, and the antenna is prepared for motion, i.e., it should not cause the antenna to move if it has not already been enabled to do so. This feature might be used with an anemometer to implement an "auto-stow" of the antenna under windy conditions without relying on APS control.

It is important that the ACU have the option to disable azimuth movement when stowing the antenna. This should cover any method of stowing including "auto-stow", command, and by the DMS if that is available. One option can be used for all cases.

The ACU should be able to respond to the following commands:
- Antenna command trajectory: epoch (time typically with millisecond precision), position (degrees), rate (degrees/second), and desired sector (see section 2). The commanded epoch is the time for the commanded position. This command is typically issued at approximately a 1 Hz rate, but there may be significant variations in the times between commands. However, while tracking a source, the updated trajectories will all be nearly exactly collinear despite any variations in the update interval.
- Set antenna mode: track, or otherwise as applicable
- Specific function commands that are needed for operations, if applicable, such as:
  - Turn drive power on/off
  - Set/release brakes
  - Array mode for two or more antennas
  - Command stow position
  - Command service position(s)
  - Drive/withdraw stow pin
  - Turn antenna drives on/off
  - Adjust focus
  - Adjust sub-reflector
- DMS configuration: A command to enable/disable. A command separate from other antenna control/query commands should be used to reset the "time-out" timer of the switch. Optionally, a command to set the time-out to an interval from a few seconds to a few tens of seconds, but typically a fixed interval of about 30 seconds is acceptable.
- Any other commands needed to operate the antenna so that it can be controlled entirely over the interface. However, commands overriding "emergency stop" and "remote lock-out" (and possibly movement out of the hard limits) are not permitted.

The ACU should be able to respond to approximately 1 Hz queries for the following parameters:

- Antenna position status: epoch of the returned parameters (milliseconds), actual antenna position (degrees), calculated command position (degrees), sector switch if applicable, (see section 2), and tracking mode: fine or coarse tracking. Returned positions should be referred to the epoch time in the response (in order for example to be able to calculate actual minus command angles accurately) and should have at least as much precision as the encoders. The time resolution is typically limited to the period of the ACU's control loop.
- Antenna mode: track, stow, or otherwise as applicable
- Status of all specific functions that can be commanded
- General antenna status if appropriate
- Status of specific conditions: motors powered, sensor readings, errors, status of "emergency stop" switches (by switch if available), "remote/local" switch, and other conditions such as "stowing". Typically these are reported in small groupings of related information or in binary words of "status bits" as appropriate.
- Any other monitor functions that are needed so that everything necessary for operation can be monitored over the interface

2. Azimuth Cable Wrap

In order to track sources and to slew between sources efficiently with an AZ-EL antenna, the antenna's range of motion in azimuth should include a region where range of available azimuth motion overlaps itself. This range of motion is referred to as the "cable wrap". Positions in the overlapped region can be reached in either of two ways. The size of the overlapped region should typically be at least 180°. More is acceptable, but it should be less than 360°. The overlapped portion of the wrap that lies at the clockwise end (viewed from above) of the range of azimuth motion is referred to as the clockwise (or "CW") wrap. The other end of the wrap in the overlapped region is called the counterclockwise (or "CCW") wrap. The portion of the wrap that is not overlapped and can be reached in only one way is referred to as the "neutral" wrap.

Typically, the center of the range of azimuth motion should be +90° (East). However, specific sites may have other requirements.

The ACU should provide an unambiguous way to identify all azimuth positions of the antenna. Preferably, this would be with a continuous range of command (and reported) positions. For example, a range of -180° to +360° could be used if those are the limits of the antenna's motion.

A less desirable alternative would be to use a range of values from 0° to just less than 360° and have a way to specify which overlapped region is in use when the position is in the overlapped region. However this approach requires more care both by the ACU and APS to handle the discontinuity at 0° to 360° transition and edge effects at the ends of the overlapped region. In this case, a "sector switch" could be used to indicate which overlapped wrap region the antenna is in: CCW and CW. The azimuth at which the sector switch changes state is not critical except that it must not be near the edges of the overlapped region; a reasonable location is typically the approximate middle of the neutral region.