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SPACECRAFT RADAR TRACKING

Background

The Western Aeronautical Test Range (WATR), located at NASA Dryden Flight Research Center in Edwards, California, provides range engineering, technical expertise, and resources to support aerospace research, science, and low-Earth orbiting missions. High accuracy radar provides tracking and space positioning information on the International Space Station (ISS), as it has previously done with other research vehicles such as the space shuttle.

During previous space shuttle missions, the WATR's Aeronautical Tracking Facility (ATF) provided telemetry (information collected via radio waves), radar, voice communication, and video support of ISS and space shuttle activities to NASA Johnson Space Center in Houston, Texas, using different telemetry tracking, space positioning, and audio communication systems.

The telemetry tracking system provided downlinked status information on the condition of the space shuttle and available video (from the pilot's point of view) to the NASA network via satellite. When required, this tracking system also provided uplinked command data to the space shuttle.

Figure 1: The International Space Station

Figure 2: WATR instrumentation radar

The space positioning system consists of two high-accuracy radars, differential global positioning system ground stations, and Federal Aviation Administration surveillance radar data. This system was used to track every space shuttle orbit, relaying time-space positioning information from launch to landing. The space positioning system also tracked the ISS—from the day prior to each space shuttle launch through the duration of each mission—providing critical information for the docking and undocking of the space shuttle.

Throughout each shuttle mission, voice communication was also enabled by the audio communications system. While a system of communication satellites used by NASA and other United States

government agencies (known as the Tracking and Data Relay Satellite System, or TDRSS) provided the primary voice communication for the space shuttle, the WATR provided back-up support in case of a communications failure during a mission. The WATR also became the primary means of communication support in the event a space shuttle might be diverted locally to Edwards Air Force Base for a landing.

Mission data from these three systems were processed real-time (or near real-time), and were archived by NASA as a means of support for post-mission analyses.

Problem

Great precision is used in tracking and recording sightings of the International Space Station (ISS) and other research vehicles. High accuracy instrumentation radars take measurements of the geometric range, or the distance to the vehicle. These radars track the moving vehicle from horizon to horizon—out to a distance of 4,828 kilometers (3,000 nautical miles), with amazing accuracies to 0.0006 degrees in angle and 9 meters (30 feet) in range. To achieve these levels, the radars must be carefully calibrated to remove atmospheric effects, location errors, and electronic equipment biases.

The following problem will investigate the reason for such great precision. How would inaccurate sightings affect the safety of the crew and the necessary communication and tracking between Earth and the ISS? To answer this question, you will investigate data that was collected from both calibrated and uncalibrated radars.

On the TI-Nspire™ handheld, open the document, *Radar_Tracking.tns*. Page 1.2 shows data collected during one pass of the ISS over the radar site. The radar started tracking the ISS as it came into target a couple of degrees above the horizon. It continued to track it as it passed over the site, and then lost the target a couple of degrees above the opposite horizon. The table shows three different geometric range values of the ISS measured in kilometers (km). The theoretical value represents a value seen from a perfect radar station, with no errors or biases (a scenario which exists only in simulations). The data in the last two columns are geometric range values measured by two different radars (uncalibrated and calibrated).

Read through the questions in the TI-Nspire document and perform calculations within the file. Record your answers either within the file or in the space provided on this handout.

A. Add a **Data & Statistics** page, and create a scatter plot using the theoretical range as the explanatory variable and the uncalibrated range data as the response variable. Determine the least squares regression line, and interpret its slope and *y*-intercept. What kind of accuracy does the linear model predict for the data? Give statistical justification for your answer.

   Conclusions:

I. If the theoretical range data is 1500 km, use the linear model to estimate the range that the uncalibrated radar will predict.

II. If the theoretical range data is 2000 km, estimate the range that the uncalibrated radar will predict.

B. Add a **Data & Statistics** page and create a scatter plot using the theoretical range as the explanatory variable and the calibrated range data as the response variable. Determine the least squares regression line and interpret its slope and *y*-intercept. What kind of accuracy does the linear model predict for the data? Give statistical justification for your answer.

Conclusions:

I. If the theoretical range data is 1500 km, use the linear model to estimate the range value the calibrated radar will predict.

II. If the theoretical range data is 2000 km, estimate the range value the calibrated radar will predict.

C. Compare the uncalibrated and calibrated radars.

I. Based on your findings from both calibrated and uncalibrated radars, which radar is more accurate in tracking range data? Explain your reasoning using statistical justification.

II. What would you expect the model to be for a radar that was 100% accurate? Explain your reasoning.

For vehicles like the ISS, NASA already has very good models that can predict where the vehicle will be from pass to pass. In order to calibrate radars, NASA flight dynamics specialists will compare radar data to the existing model by creating an error plot. After analyzing this plot they will make adjustments to the calibrations. They will continue to compare the data and make adjustments until they have removed all errors and biases other than the small electronic noise that cannot be filtered out. The shape, spread, and offset of the residuals gives insight into exactly what might be causing calibration errors.

D. Add a **Calculator** page and define a new variable that will represent the error of the uncalibrated data by typing: **uncal_error:=uncalibrated_km – theoretical_km** and press **Enter**. Then add a **Data & Statistics** page, and create a plot of the uncalibrated data error versus time. Remember that the radar tracks the vehicle from horizon (0 sec) to horizon (580 sec). The vehicle is furthest from the radar at the horizons, and is closest to the radar when it is directly over the radar.

   I. Describe the error plot. What trends do you see?

   II. Explore the theoretical range data in the table on the next page to see how the distance to the ISS changes during this time. What kind of relationship is shown between the error and the distance from the ISS? Hypothesize reasons that might explain this relationship.