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Paper Session II-C - Astro: A Computer-Aided Scheduling Tool for Operational Satellite Control

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ASTRO: A Computer-Aided Scheduling Tool for Operational Satellite Control

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ABSTRACT

Range scheduling for satellite control presents a classical problem of a data intensive task with a very small allowance for human error. On any given day, interrelated information depicting 600-1000 entries of satellite visibilities and scheduled range support must be interpreted and used to make decisions that can be critical to the survival of valuable orbital assets. Given an environment which must account for unexpected equipment outages and satellite anomalies, the scheduling task can exceed acceptable workload levels. Thus, range scheduling for satellite control can benefit greatly from computer assistance and a human factors approach to the task. This paper describes the development, user evaluation, and operational activation of a semi-automated network range scheduling system incorporating a synergistic human-computer interface consisting of a large screen color display, voice input/output, a "sonic pen" pointing device, a touch-screen color CRT, and a standard keyboard. The development and operational use of ASTRO represent the first major improvement in almost 30 years to the range scheduling task.

1. INTRODUCTION

To maintain today's large number of satellites in their various orbits, it is necessary to schedule regular contacts with them using a global network of satellite tracking, telemetry, and control facilities. During the early days of the military space program, the complexity of the satellite control scheduling task was low enough that a daily schedule of satellite contacts could be easily represented with a paper chart. Data representing satellite/ground station visibility, resource allocation, and conflict resolution could be assimilated by scheduling personnel in an acceptable manner using this method.

However, continued growth in number, size, and complexity of both ground and space assets, combined with the increased dependence on these resources for national defense, has made it necessary to search for a more effective methodology for scheduling operational satellite support. The Air Force Satellite Control Network (AFSCN) is a large-scale system which provides the essential command, control, and communications (C^3) support to orbital space vehicles using internetted facilities located across the globe. The task of scheduling these network assets effectively is a challenging problem of supervisory control [1]. On any given day, interrelated information depicting nearly 1000 entries of satellite visibility and scheduled network support must be interpreted and used to make decisions that can be critical to the survival of valuable orbital assets [2]. Given an environment which must account for unexpected equipment outages, satellite anomalies, and changing mission priorities, the scheduling task can exceed acceptable workload levels.

While recent attempts to fully automate this task have been less than satisfactory, it is within the state of the art to implement a partially automated system with human-in-the-loop decision making. This system must effectively convey large amounts of interrelated data to the scheduler and allow the scheduler to manipulate this data and to input selected commands at will. These requirements indicate that an optimized human-computer interface (HCI) is a critical design aspect of such a system [3].

This paper describes the development, user evaluation, and operational activation of a semi-automated range scheduling system incorporating a synergistic HCI consisting of a large screen color display, voice input/output, a "sonic pen" pointing device, a touchscreen color CRT, and a standard keyboard.

2. THE PROBLEM DOMAIN

Before we can examine the HCI design, we must first understand the activities involved in satellite control network range scheduling. While there are many similarities between scheduling support for civilian satellites [4,5] and for military satellites [2,3], we concentrate here on the latter. Military satellites include many low earth orbiters, which, because of their brief "windows" of satellite/ground station visibility, make the scheduling task more difficult than with the predominantly geosynchronous civilian satellites.

Traditionally, scheduling was performed using a paper acquisition chart. The horizontal axis of the chart represents time, and the vertical axis shows the resources for each ground station of the AFSCN, commonly referred to as Remote Tracking Stations (RTS). *(Note: the network of RTSs in the AFSCN is commonly referred to as the "range." Hence the term "range scheduling.")* A single paper chart encompassing a 24-hour period measures 36" vertically by 144" horizontally, with extremely high information density. Three types of schedules are maintained: a seven day forecast, a 24-hour schedule, and a real-time schedule. The basic scheduling activities are listed below, and a flowchart of a typical real-time response to an RTS outage is shown in Figure 1.

Receive new or modified request for satellite support.
Validate acquisition data and satellite/RTS visibility.
    Compare new data with most recent data from scheduling database.
    Slide supports along time axis of chart to accommodate changes.
Assign or modify satellite support(s).
    Visually scan chart for resource availability.
    Enter support(s) on chart.
Prepare schedule.
    Identify time/resource conflicts.
    Scan chart for alternate support possibilities.
    Propose alternative solution to Mission Control Center.
    Reassign supports as approved and notify RTS.
    Enter new support on chart.
Update scheduling database to reflect latest chart.

It is important to note how the scheduling chart is central to these activities. It contains a large amount of information relating to the various satellites, RTS resources, and visibilities for the entire world-wide AFSCN by using twenty-nine distinct variations of symbology and annotation style [2]. This graphical representation enables the scheduler to view the "big picture" at a glance, make the necessary RTS assignments, identify conflicts, and resolve them quickly. This is especially critical during real-time scheduling, which is driven by random events (satellite anomalies, RTS equipment outages, changing mission priorities, etc.). The main drawback of the paper chart is that it is a totally manual process, which has become increasingly unmanageable due to the trends identified in Section 1 above.

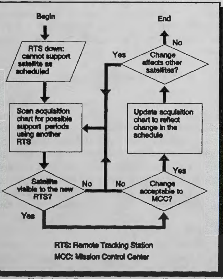

Figure 1. Typical task flow for an unexpected RTS outage [3].

Greater automation of the scheduling task is highly desirable; benefits would include a more acceptable scheduler workload, reduced chance for human error, and greater responsiveness to highly dynamic national security priorities. However, any acceptable design must incorporate into the HCI those positive aspects of the paper acquisition chart outlined above.

3. ASTRO: A NEW APPROACH

The importance of a well designed HCI has been documented extensively in the literature [6-11]. Recently, significant progress has been made [2-5] in investigating optimal HCIs for various satellite control tasks. The GT-MSOCC simulator at Georgia Tech, for example, has addressed many aspects of NASA satellite operations. However, the Air Force had a pressing need to address the problem of range scheduling for satellite control in an operational military environment.

Initial designs to solve this problem proposed an HCI using standard CRTs, which were limited to displaying only a small subset of the information contained in the paper chart. It was thought that the use of panning, scrolling, zooming, and windowing techniques could overcome this limitation and provide an equivalent capability. However, experienced scheduling personnel evaluated this approach as unacceptable; their stated requirement was to view all the information that the paper chart provided with at least 12 hours of data on a single display. It has been shown [3] that human factors design considerations support this position in that the necessity of accessing multiple sequential displays forces excessive reliance on the short-term memory of the schedulers, resulting in increased error rates. In particular, the error rate increases proportionally with the number of screen accesses required, and with the time required to perform those accesses. By taxing short-term memory, the perceived workload and level of stress experienced by schedulers would actually increase compared to using the paper chart, and scheduling productivity would go down. A new design approach for the HCI was required, and the Automated Scheduling Tools for Range Operations (ASTRO) project was started in October 1987.

In order to satisfy the core requirement of providing 12 hours of scheduling data on one display, a high resolution, large screen color display is required. Analysis indicates that an approximate displayable resolution of 3K vertical points and 4K horizontal points is necessary [2]. ⟨*Note that manufacturer specifications typically cite only addressable resolution, which is generally two to four times greater than displayable resolution.*⟩ For comfortable viewing of 7×9 format characters, the screen size should be roughly 25" vertically by 42" horizontally [2]. A 12-hour section of the paper chart was photo-reduced to validate these derived estimates. Further requirements include at least 16 colors, ability to mix graphic symbols with characters, imperceptible flicker, low noise level, standard computer interface, standard power and cooling needs, high MTBF, and low MTTR. While these requirements push state-of-the-art display technology, the best match was found to be a