# Human Interaction with Control Software Supporting Adjustable Autonomy

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**Abstract**

Reductions in operations personnel and the availability of more capable automation technology have resulted in increased automation of space control systems. One of the challenges of deploying autonomous systems is ensuring that people can interact effectively with them. An important strategy for such interaction is providing for different levels of control autonomy, or adjustable autonomy. At TRACLabs/Metrica, we are developing software for human interaction with control software supporting adjustable levels of autonomy. Our domain of application is the control of space systems and robots for NASA's manned space exploration program at the Johnson Space Center.

Traditionally test and flight operations have been manually intensive. Flight controllers monitor astronauts directly controlling the operation of space vehicle systems, robotics, and life support systems. The use of automated software changes the role of humans in command and control. Low level data monitoring and control is replaced by the supervision of autonomous control and by joint human-computer task performance. These new human tasks require new types of information and new ways of presenting this information, as well as new ways of intervening in autonomous operations. Additionally, these changes in operations have increased the likelihood of humans supervising multiple automated systems that are physically dispersed and functionally diverse. It is important to provide an integrated view of system operations and to support access to such information from remote locations. Intelligent information processing is needed to derive and integrate heterogeneous control data in support of these new human tasks. And an architecture is needed that supports remote human interaction with distributed, autonomous control systems.

We use the Three Tier (3T) distributed control architecture [3] to automate system control. The 3T architecture consists of three parallel tiers of control processing:

- Planner: determines tasks required to meet control objectives and monitors task execution
- Sequencer: reactively activates sequences of situated skills to accomplish planned tasks
- Skill Manager: manages skills interfaced to instrumentation to achieve desired world states

We are developing a fourth layer of software - the *interaction layer* - for human interaction with control software supporting adjustable autonomy. The interaction layer collects, processes, and integrates information from each tier of the agent architecture to provide a human supervisor with a view of control activities integrated with the intended effects of control. It also provides the human supervisor with the ability to interact with each tier of the architecture to perform such tasks as mixed-initiative planning, situation assessment, anomaly response, and manual override of automation.

To effectively use automated control software, the human must be able to monitor autonomous activities easily and, with little effort, be able to intervene if the situation calls for it. We have developed user interface designs that support minimal human involvement during routine operations, and that assist humans in actively participating in control during novel or complex operations. We have designed user interfaces that support a human supervisor in (1) understanding automated control actions and their environmental consequences, (2) accessing the archived details of these control activities easily, and (3) intervening in control as needed.

We have made progress in adding the interaction layer to the 3T architecture. The interaction layer features distributed processing with client-server process communication. It includes common data models that characterize both the information that must be exchanged between the control system and the human and the representation of that information best suited for supervisory tasks. We have built reusable user interface software that interfaces with the sequencer and skill manager tiers of 3T. The software developed for the sequencer user interface provides a suite of application-independent display and logging tools. Each tool can be individually enabled and disabled during execution for easy configuration changes. A single user interface provides access to all tools and an overview display summarizes which tools are active. This suite of tools also provides baseline user interface capabilities that can be included in control applications. The current capabilities of the software at the interaction layer are summarized below:

| User Tasks | Interaction Capabilities |
|---|---|
| Monitor Autonomous Operations in Real-time<br>• Situation assessment and anomaly detection<br>• Joint task performance<br>• Supervised autonomous anomaly response<br>• Support for software maintenance and degraded mode operations | 1. Monitor execution of task sequences<br>2. Monitor autonomous control actions with consequences of control using checklist form<br>3. Determine which control alternatives/methods were executed<br>4. Monitor control context (modes, status, configuration)<br>5. Monitor device data<br>6. Detect alerts and alarms<br>7. Monitor activation of skills (skill network) |
| Review Past Autonomous Operations<br>• Understanding of unsupervised autonomous control actions (not real-time situation assessment)<br>• Assessment of system performance, including detection of problems resulting in degraded mode operations or maintenance<br>• Identification of relevant control commands and environment states leading up to anomaly | 1. Review logs of autonomous control actions<br>2. Log data from both the sequencer and skill manager<br>3. Review plots of data logged from both sequencer and skill manager tiers<br>4. Start/stop data and message logging based on control actions |
| Intervene into Autonomous Control<br>• Volunteering new information to control system<br>• Execution of manual control for anomaly response, including diagnostic task sequences and manual control override<br>• Execution of manual activities during joint task performance<br>• Alteration of control software in response to degraded situation or change in requirements | 1. Alter the state of sequencer memory<br>2. Execute manually a task in the sequencer |

Our approach to human intervention in automated control is based on research into mixed-initiative interaction [1]. Mixed initiative interaction requires that both the human and the control software have explicit (and possibly) distinct goals to accomplish specific tasks and that ability to make decisions controlling how these goals will be achieved. Thus it is well-suited for human interaction with automated control systems like 3T. There are two types of tasks where mixed-initiative interaction is needed: during task planning and during joint task performance. During task planning the human and planning software interact to refine a plan iteratively. The human specifies goals and preferences, and the planner generates a plan to achieve these goals [6]. The crew evaluates the resulting plan and makes planning trades at constraint violation and resource contention. The planner uses modifications from the crew to generate another plan. This process continues until an acceptable plan is generated. During joint task performance the human and the automated system interact when task responsibility is handed over. Coordination of manual and automated activities through a joint activity plan reduces context registration problems by providing a shared view of ongoing activities. To accommodate the variability in complex environments, it is necessary to be able to dynamically change task assignment of agents. Finally, as the crew and automated system work together to accomplish a task, it is important to maintain a shared understanding of the ongoing situation. The automated system must be able to monitor the effect of human activities. This may require enhanced sensing to monitor manual operations and situated memory updates. The crew must be able to track ongoing activities of the automated system and to query the automated system about its understanding of the state of the environment. The architecture supports manual control of the automated systems by providing adjustable levels of autonomy. The level of autonomy specifies if the task should be executed autonomously or manually. The approach for implementing adjustable levels of autonomy in 3T is discussed in another paper in this session [4].

We developed 3T control software supporting adjustable levels of autonomy for crew air revitalization during the phase III test of the Lunar/Mars Life Support Test Program. During that test we learned that supporting such supervisory control requires that the autonomous control software be modified to export the required information and to support a variety of communication types. The control software must export information about the control actions it takes and the intended effects of those actions. It must support information requests initiated by both the human and the automated software. It must provide mechanisms for manual initiation of control tasks. Situations during the phase III test where user-initiated manual intervention was needed included (1) uncontrollable events and novel operations, (2) unavailable instrumentation, (3) safety, and (4) user-preferred tactics. Our design of the adjustable autonomy control software for air revitalization has the following characteristics that enable such manual intervention [10]:

- Explicit specification of level of control autonomy (manual or automatic). The level of autonomy could be changed during execution of control software.
- Separate execution of the monitoring software from the software performing control. When in manual mode, the monitoring software continues to execute and provide caution and warning for manual operations.
- Optional manual activation of each hardware controller. For the 3T system, this corresponds to providing for user activation of skills to control life support hardware.
- User-specified control preferences, such as preferred instrumentation.
- Interlocks suspending all control for safety reasons.
- Manual reconfiguration for hardware maintenance. For control of life support systems, it was important to provide manual capability to take sensors out of the control loop temporarily for sensor calibration or repair.
- Parameterized control setpoints and C&W thresholds that can be changed while the control software is executing. These values can be changed by either the planner or the user.

Our work on human interaction with control systems supporting adjustable autonomy leverages over 10 years work at NASA developing intelligent control software for space operations at JSC. The purpose of this software is to reduce the workload of astronauts, flight controllers, and test engineers. We have developed supervisory control applications, including user interface designs, for life support system that revitalize crew air [10] and for robots [2]. Central to this effort is assisting humans in effectively using this intelligent software. To assist control software developers, we have developed design guidance for human interaction with intelligent monitoring and control software [7, 8]. We also have developed user interface designs for supervising autonomous control software [9, 11]. Our recent work has been with control systems that support adjustable levels of autonomy, including mixed initiative interaction between humans and autonomous control systems [5, 6].

### Acknowledgements

This work was performed under NASA contract at JSC and was monitored by Dr. Jane Malin/ER2. I would like to acknowledge the efforts of my colleagues on development of the interaction layer. Carroll Thronesbery/SKE has designed and developed the user interface software for the skill manager tier. Dan Ryan/formerly SKE designed and developed the communication software between the sequencer and the user interface. David Kortenkamp and Peter Bonasso of TRACLabs provided critical expertise about 3T during development of the interaction layer.

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