The Robot Intelligence Kernel

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Abstract

The Robot Intelligence Kernel (RIK) is a portable, reconfigurable suite of perceptual, behavioral, and cognitive capabilities that can be used across many different platforms, environments, and tasks. The RIK coupled with a virtual 3D interface have been shown to dramatically improve human-robot interactions across a variety of navigation and exploration tasks.

The Robot Intelligence Kernel is a portable, reconfigurable suite of perceptual, behavioral, and cognitive capabilities that can be used across many different platforms, environments, and tasks. The RIK integrates algorithms and hardware for perception, world-modeling, adaptive communication, dynamic tasking, and autonomous behaviors in navigation, search, and detection tasks. The integration of software algorithms and hardware takes place over four levels of the RIK.

The foundation layer is the Generic Robot Architecture that provides an object-oriented framework and an application programming interface (API) that allows different platforms, sensors, and actuators to interface with the RIK. The second layer is the Generic Robot Abstractions layer which takes data from the first layer and abstracts the data so that it can be used in algorithms that are designed for generic robot systems. The third layer is comprised of many reactive and deliberative robot behaviors that take, as input, the abstractions from the second layer and output commands for the robot to follow. The fourth and final layer provides the "Cognitive Glue" that orchestrates the asynchronous firings of multiple behaviors towards specific application-based tasks.

The goal of the RIK has been to create an integrated suite of primitive behaviors that will degrade gracefully in the face of uncertainty. Instead of crafting algorithms to be optimal, these behaviors are crafted to be robust, responsive, and adjustable across different search, detection, and exploration tasks. These behaviors are intrinsic, meaning that they can provide a basic level of competency to the robot even when all external input (such as global positioning (GPS) or communication with a human operator) is unavailable.

The RIK is not just a collection of independent, unrelated behaviors, but rather an integrated suite of capabilities orchestrated by the cognitive glue. Hence, the RIK is a collection of interdependent meta-level capabilities providing a) real-time map-building and positioning, b) reactive obstacle avoidance and path planning, c) high-speed waypoint navigation with or without GPS, d) self-status awareness and health monitoring, e) online adaptation to sensor failure, f) real-time visual- and laser-based change detection, g) human presence detection and tracking, and h) adaptive, multimodal communication, and i) problem solving that can be used to accomplish high-level tasking, dynamic autonomy, and dialoging for flexible human-robot teaming.

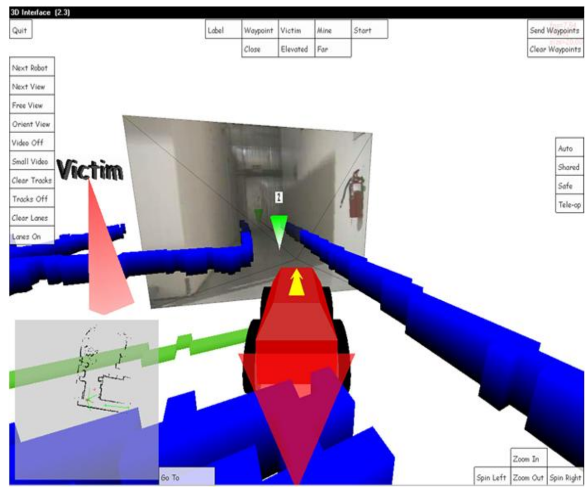

Figure 1: The Virtual 3D Display shows semantic entities added by the robot or the human.

True teamwork requires a shared understanding of the environment and task. To support a dynamic sharing of roles and responsibilities between a human and a robot, the RIK employs a representation that allows both the human and robot to reason spatially about the world and to understand the spatial perspective of the other. Understanding the robot's perspective of the environment allows the human to predict robot behavior. Understanding the human's perspective enables the robot to interpret and infer intentions from tasks given by the human.

Through sensor fusion and probabilistic reasoning (Konolige 2004), the robot creates a 3D, virtual representation of its surroundings in real time (Ricks, Nielsen, & Goodrich 2004; Nielsen, Goodrich, & Rupper 2006)(see Figure 1). This video game style interface has been shown through human-subject experiments to utilize between 3,000 and 5,000 times less bandwidth than a video display in some navigation tasks (Bruemmer *et al.* 2005). Due to this reduction in bandwidth, the interface can be used to communicate with robots via low-bandwidth, long-distance devices such as cell phone modems or long-range radios. Whereas many teleoperated robots with higher bandwidth needs are limited to line of sight communications with the operator control interface, these same robots when equipped with the low-bandwidth RIK can be tasked from around the world using long distance devices.

The RIK is designed to handle communication in a plug-and-play fashion and can support any serial radio device or combination of devices. The RIK adapts communication protocols in response to changing datalink connectivity and bandwidth, assigning priority to critical communications. This is a significant advantage, enabling operations in more difficult environments and over much greater distances than high-bandwidth solutions.

Robots with the RIK can perform tasks a) avoiding obstacles, b) planning paths through cluttered indoor and outdoor environments, c) searching large areas, d) monitoring their own health, e) finding and following humans, and f) recognizing when anything larger than 10 cm has changed within the environment. Robots with the RIK can even recognize when they are performing badly (i.e. experiencing multiple collisions or an inability to make progress towards a goal) and can ask an operator for help.

The INL control architecture - including hardware, software, and sensors - is designed to support changing levels of operator involvement. To support these dynamic levels of control, the RIK uses a variety of reactive, perception-based behaviors (such as obstacle avoidance, guarded motion, visual and laser tracking, get unstuck, and reactive path planning) that can run separately or in parallel with higher-level, deliberative, map-based behaviors (such as waypoint navigation with automatic speed adjustment, global path planning, and occupancy change detection). These reactive and deliberative behaviors are combined into dynamic autonomy levels that provide emergent behaviors based on the environment and task at hand.

The capabilities provided by the RIK greatly accelerate the speed and confidence with which an operator can accomplish remote tasks. Because RIK-equipped robots handle many navigation and control functions themselves, experiments show a 67% operator workload reduction in joystick usage, 23% reduction in operator error, 27% increase in the operators' feeling of control, and a 56% increase in the ability of operators to respond to secondary or unexpected tasks, allowing much more efficient use of operator time and attention (Bruemmer *et al.* 2004a; 2004b; Bruemmer, Few, & Walton 2006)

The RIK has been applied across a variety of application domains including a) perimeter surveillance and security, b) countermine operations (see Figure 2), c) urban search and rescue, d) military reconnaissance, e) remote characterization of high-radiation environments, and f) mobile manipulation applications within a space exploration context.

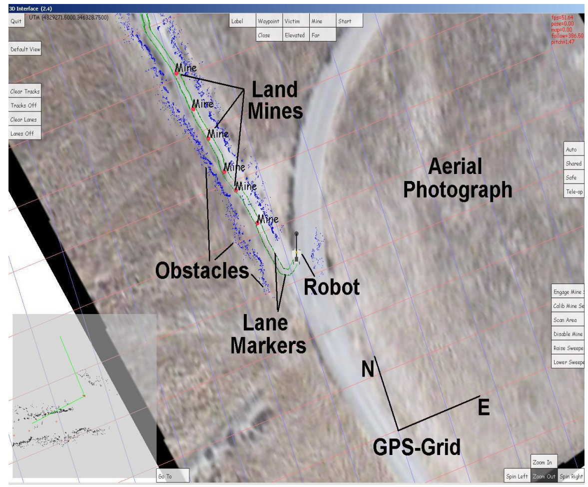

Figure 2: The Virtual 3D Interface fuses real-time aerial imaging from an autonomous unmanned air vehicle with the terrain map and mine locations from the unmanned ground vehicle.

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