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Multilayer cognitive architecture for UAV control

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Abstract

Extensive use of unmanned aerial vehicles (UAVs) in recent years has induced the rapid growth of research areas related to UAV production. Among these, the design of control systems capable of automating a wide range of UAV activities is one of the most actively explored and evolving. Currently, researchers and developers are interested in designing control systems that can be referred to as intelligent, e.g. the systems which are suited to solve such tasks as planning, goal prioritization, coalition formation, etc. and thus guarantee high levels of UAV autonomy. One of the principal problems in intelligent control system design is tying together various methods and models traditionally used in robotics and aimed at solving such tasks as dynamics modeling, control signal generation, location and mapping, path planning, etc. with the methods of behavior modeling and planning which are thoroughly studied in cognitive science. Our work is aimed at solving this problem. We propose layered architecture—STRL (strategic, tactical, reactive, layered)—of the control system that automates the behavior generation using a cognitive approach while taking into account complex dynamics and kinematics of the control object (UAV). We use a special type of knowledge representation—sign world model—that is based on the psychological activity theory to describe individual behavior planning and coalition formation processes. We also propose path planning methodology which serves as the mediator between the high-level cognitive activities and the reactive control signals generation. To generate these signals we use a state-dependent Riccati equation and specific method for solving it. We believe that utilization of the proposed architecture will broaden the spectrum of tasks which can be solved by the UAV's coalition automatically, as well as raise the autonomy level of each individual member of that coalition.

Keywords: Cognitive architecture; Intelligent control system; Sign world model; Path planning; Nonlinear control; State-dependent Riccati equation

1. Introduction

One of the obvious recent trends in science and technology is the rapid growth of the R&D areas related to unmanned aerial vehicle (UAV) design. UAVs are getting cheaper and thus more available both to researchers and the general public due to the following factors: First, sensors which are needed in large quantities to build any UAV are getting smaller, cheaper and more energy efficient while the quality of the output signal remains the same or is improving (sensors become less noisy and more robust). Second, other UAV components, such as rotors and carbon bodies are getting more widespread and available at a moderate price. Third, the computational efficiency of modern in-flight controllers has increased significantly. All of these factors gave an impetus to the creation and proliferation of the unified UAV platforms such as Parrot AR.Drone (ardrone2; Bristeau et al., 2011), mikrokopter

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(mikrokopter), 3DR IRIS (3drobotics), equipped with the sufficient amount of sensors, actuators, peripherals and in-flight controllers, coupled with the core build-in software which automates basic flight maneuvers and modes. This software typically supports easy and seamless integration of the third-party modules via the open data exchange protocols and application programming interfaces (APIs). Thus, a lot of research is now focused on the development of models and methods that can be further implemented as software modules and plugged into existing UAV platforms. The spectrum of the methods under development and investigation is extremely wide: from methods and algorithms for UAV dynamics modeling, identification, and flight controller development to methods of localization, mapping and path planning, to methods of strategic (behavior) planning and UAV coalition formation, etc. An informative recent survey of such methods can be found in Kendoul (2012) for example. Developed methods and algorithms are usually grouped in bundles and implemented as software modules comprising the UAV control system. Thus another direction of research, in which we are more interested, exists in the broad area of UAV design, specifically, studying the methods of interaction between the modules of control systems and the ways of organizing hierarchical relations between them. In other words, we are talking about studying (and developing) the architectures of modern UAV control systems. Control systems which mainly attract researcher's attention nowadays can be considered intelligent control systems (Albus, 2002) (ICS). ICS is a system that is capable of solving non-trivial, intelligent tasks—planning, goal prioritization, coalition formation, etc.—and thus guarantees high levels of UAV autonomy. Under the cognitive approach the ability of the system to solve the abovementioned tasks relies on its ability to model human cognitive behavior and higher psychological functions (and thus only cognitive systems can be characterized as intelligent) (Kurup & Lebiere, 2012). At the same time, researchers of cognitive systems frequently propose such cognitive architectures as can hardly be implemented as software control systems for real-world technical objects due to the lack of interfaces between the proposed methods and modules for solving high-level, intelligent tasks, and the methods for dealing with such lower level tasks as localization, mapping, path planning, control signal generation, etc. Our work aims at filling this gap. On the one hand we are dealing with the non-abstract technical objects involving complicated dynamics and kinematics, such as multirotor UAVs, and creating an architecture for the control system which takes this into account. On the other hand, we are not limiting ourselves to dealing only with low- and mid-level control tasks (UAV stabilizing, performing standalone flight maneuvers, localization and mapping, path planning, etc.), but also trying to automate high-level functions (distribution of roles in the group, coalition formation, goal setting and behavior planning) using cognitive experimental data and psychological methods. As a result, we present the multi-layered cognitive architecture—STRL (from Strategic, Tactical, Reactive, Layered)—of the intelligent control system which automates the control of the coalition of UAVs performing complex tasks in a wide range of scenarios.

2. Related works

Numerous approaches to the creation of the UAV's intelligent control systems exist and the architectures of such systems thus can be classified in many different ways. One of the most advanced ways to do so is to use a hierarchy along with the type of functional specification (implicit or explicit) as a categorization factor. In that case, at one extreme on the spectrum lie ICSs which use simple, flat architectures based on explicit functional decomposition (i.e. the control system is considered to be a bundle of modules without any hierarchy and each module is presumed to solve some functionally specific task). Within this approach the following tasks are typically distinguished: behavior planning, interaction management, contingency management, situation awareness, communication management, navigation (including localization, mapping and path planning) and others. Cognitive functions in that case are dispersed over the whole system, so that each module can implement some of them. One can see (Jameson, Franke, Szczerba, & Stockdale, 2005) as an example of such system (architecture).

On the other extreme there are layered architectures (with possibly infinite number of layers) based on implicit functional decomposition. Each level of the architecture is composed of the elements which abstract specific controllable entities (vehicle subsystems, vehicles, groups of vehicles, etc.) and each element is composed of fixed number of identical modules (groups of modules) having implicit specification. The most obvious example of such an architecture is 4D/RCS developed by the research group of professor Albus (2002). Within 4D/RCS the following 4 implicitly specified modules ("functional processes") compromise each element ("node") of the architecture: behavior generation, world modeling, sensory processing, value judgement. At the higher levels of the 4D/RCS system, behavior generation is meant to be situation planning (i.e. planning in the context of actions, capabilities and high-level goals and constraints) while on the lower levels behavior generation becomes, for example, path planning (planning in the context of spatial constraints) or control signal generation (planning in the space of UAV control inputs). Within such an approach, cognitive functions of the system are concentrated mainly on its highest levels and are specified implicitly.

In between those two extremes lie a vast number of multilayered architectures with explicit module specification. In that case each module is considered to be in charge of solving some specified task(s) and the modules are grouped into layers which encapsulate the level of abstraction: the higher the level, the more abstract representation of input