Bio-inspired Slowness for Robotic Systems

Ronald C. Arkin

Mobile Robot Laboratory
School of Interactive Computing
Georgia Institute of Technology
Atlanta, GA USA 30332
arkin@gatech.edu

Abstract: Slowness in robotic systems is a quality that is typically undervalued. It is our contention that as slowness has utility in animal behavior in certain species that it may also provide useful qualities for robotic implementations in appropriate circumstances. In particular we study mammalian behavior as evidenced in the tree sloth and slow Loris as the basis for the behaviors of a robot capable of residing in an arboreal ecological niche, as might be found in certain jungle surveillance applications or agricultural tasks. This concept is explored in the anticipation of the development and deployment of such a robot in the near future.

Keywords: bio-inspired robotics, mobile robotics

1 INTRODUCTION

Common knowledge alludes to the wisdom of being slow, as evidenced in proverbs such as "slow and steady wins the race" (derived from "Aesop's the "Tortoise and the Hare"), "slow but sure", "slow down, you move too fast", and "haste makes waste". Roboticists have traditionally eschewed slowness for speed, focusing on how to make their platforms perform ever faster and faster tasks. But nature has found that in certain cases being slow is better, and as we and many other roboticists subscribe to the bio-inspired and bio-mimetic paradigms this warrants investigation for practical uses in real world settings. Indeed we can see that biological evolution has selected slowness in a number of circumstances, and we now strive to understand how this can be applied to robotic systems.

While slugs, snails, and tortoises are frequently and correctly associated with slow animal behavior, we focus on arboreal mammals for our research, in particular the tree sloth and the Slow Loris, as their arboreal forest environment seems to more closely resemble what is needed for our applications – jungle-like settings or for certain forms of agriculture. Some roboticists have previously considered snail-like locomotion [1] and soft-bodied slug systems [2] but not particularly for the value added that slowness itself can provide, as we do here. Other research has focused on tendril robots [3] and continuum robots [4], which are mechanically slow modes of locomotion, but do not address the associated behaviors for robots that deliberately exploit slowness. There has also been research in slow movements in humans and the use of resistive torques to reduce variability [5]. Finally there have been studies in human factors associated with determining safe slow speeds for robots performing alongside humans [6], which is not a particular concern for our research in the jungle, vineyard, or orchard. In fact, one primary dual-use application that we envision within the context of persistent monitoring is precision farming, where robots are deployed on farms for long periods of time

We consider these SlowBots (slow robots) as long-term denizens of the environment if you will, carrying out routine tasks among the foliage, for agricultural tasks literally nipping things in the bud when necessary for pruning or thinning, removing small slow-moving pests such as aphids, etc. Alternatively they can serve for surveillance in military applications, providing persistent stare and surreptious slow movement, The robots will exist in concert with their environment requiring little or no human intervention, managing their energy effectively yet producing meaningful activity in support of the ecological niche in which they reside. Contrast this to the more common agricultural robotics approach, where heavy machinery moves between planted rows or trees, almost as an invading force. The intent here is to develop a synergy between the plants and the robots that is persistent and symbiotic.

Bio-inspiration for the development of SlowBots is easy to find, with examples including the Tree Sloth and the Slow Loris, as shown in Figures 1 and 2. We here briefly discuss some biological arguments in favor of slowness.

Fig. 1. Two-toed sloth (from [33])

Fig. 2. Slow Loris (from [14])

2 REGARDING THE TREE SLOTH

The sloth is a mammal well known for its slow motion. Indeed one group in Germany [7] argues that evolution has led them to use gravity to their advantage in locomotion and movement patterns [8]. In essence they are said to walk under a tree:

"With their mode of life sloths are filling an ecological niche ... Sloths lead their lives in energy saving mode…. Their usage of energy saving food in connection with an unobtrusive life style turns them into complete 'models of energy saving among the mammals." [9]

It has been observed that despite their suspensory inverted orientation, their morphology and locomotion patterns are not all that different from other animals such as monkeys [8], but use gravity for an advantage. As they have more vertebrae and a longer reach, they require less motion than animals of similar stature, resulting in energy savings.

Physiological and behavioral studies are also available to guide our research [10, 8]. The main patterns of activity are awake-exploring, awake-fixating, awake-alert, and behavioral sleep [10]. It has been observed that by being slow, sloths become essentially "invisible" to certain predators, such as harpy eagles, where slowness has been called "the ultimate weapon in an evolutionary war" [11]. This is an obvious advantage for surveillance tasks. Sloths themselves have relatively poor eyesight with low-levels of visual acuity and discrimination [10].

Oddly, although they spend the vast majority of their time in treetops, they return to the ground to defecate, which makes them more vulnerable to predators [8]. Fortunately this is not an issue for robots.

3 REGARDING THE SLOW LORIS

Unlike the sloth, the Slow Loris is a primate. They are predominantly solitary animals, but express a range of agonistic and associative behaviors [12,13], including spatial grouping and activity patterns. Specific nocturnal social interactions include allegroom, alternate click calls, follow, and pant-growl.

> *"They move slowly and deliberately, making little or no noise, and when threatened, they stop moving and remain immobile…. Slow Lorises have an unusually low basal metabolic rate, about 40% of the typical value for*

placental mammals of their size, comparable to that of sloths." [14]

Alarm calls have not been observed among Slow Lorises although 8 different other types of communication calls have been noted [12,13]. Olfactory communication is an important channel, via urine marking or scent glands embedded in their elbows and anus. Although postural/facial communication is limited, grin and bare-teeth displays are in evidence, with the later present during agonistic and play behaviors [13].

Ethological studies have recorded the activity budgets and positional behaviors of the slow-climbing Mysore Slender Loris [15] and the Slow Loris in captivity [16]. The ethogram for the Slender Loris includes the following behaviors: Inactive, travel, forage, feed, groom, and other (e.g., auto-play hanging, vocalizing, urine washing and marking). Very slow movement is observed during cautious sitting, standing, or hanging, sometimes with freezing of the animal lasting on the order of hours. They have been observed to move swiftly when on the ground moving between trees [15].

Other studies elaborate the behavior of the Philippine Slow Loris [17]. Another report details the animals foraging behavior [Nekaris 2005]. All of this data provides insights drawn from biology into the design of slow-moving bio-inspired behavior-based robotic controllers capable of navigating and existing within arboreal settings for tasks such as surveillance and plant tending.

4 REGARDING ROBOT DESIGN

When designing a robotic platform it is crucial not just to consider the mechanism and algorithms themselves, but rather how the design acknowledges the task and environment in which it resides. Nature has designed biological systems similarly. The arboreal applications we are addressing seems a perfect match for the quality of slowness: the robot must remain on duty for extended periods requiring energy efficiency while the task environment changes (i.e., the plants themselves) but slowly in comparison to the needs for action. Instead of forming a parasitic relationship with the biosphere, a symbiotic relationship involving mutualism and commensalism, can be utilized where the robots execute a small set of arboreal behaviors that vary over the seasons and follow the maturity of the flora. Addressing the needs of the plants at optimal times due to the near ever-presence of the SlowBots for agricultural tasks may ensure the highest quality yields possible with low maintenance and attention by human workers. Behavioral time budgets for the robots will vary on a seasonal basis as the tasks required themselves change. Motivational factors such as individual traits, object specific attitudes, moods as embodied in circadian rhythms, and emotions will also be investigated for their relevance, drawing on our extensive research in this area (e.g., [19,20]).

Our group has a rich history of turning ethological studies into robotic platforms including behaviors derived from frogs [21], praying mantids [22, 23], dogs [24] wolves [25,26], birds [27,28], squirrels [29], primates [30] and humans [31,20] among others. The time-tested process utilized in transforming ethological models into working robot systems appears in Figure 3 [32].

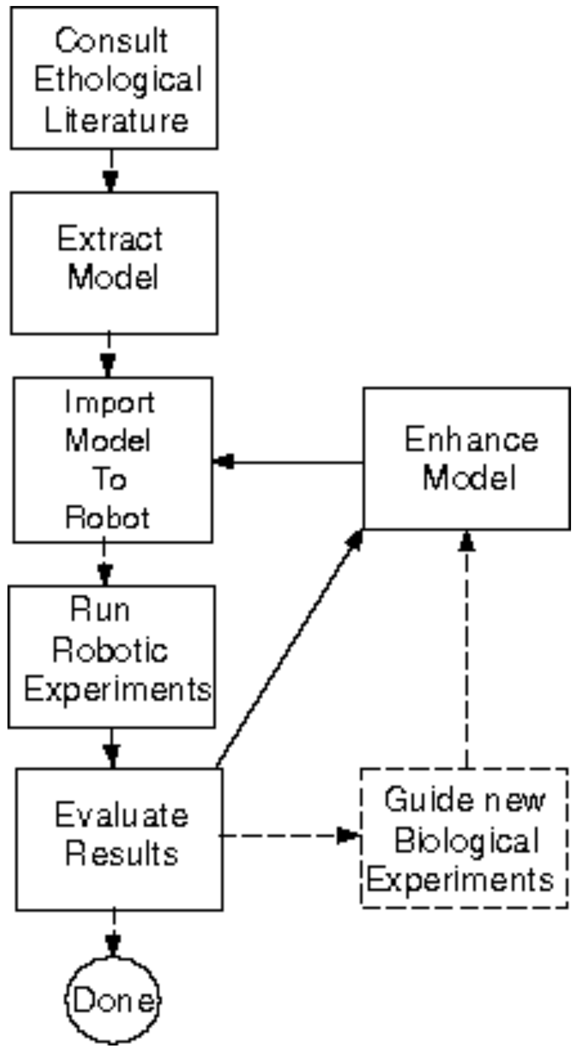

Fig. 3. Ethologically Guided/Constrained Design for Robotics Systems

We intend to utilize a similar process for the creation of arboreal SlowBots.

4 CONCLUSION

Biology provides both an existence proof and strong motivation for the development of robots that are inherently slow. Two successful examples include the tree sloth and the Slow Loris, both of which are quite successful in their respective ecological niches, specifically arboreal jungle-like environments. We believe that by understanding the behaviors of these animals we can create durable, persistent, and energy efficient robotic platforms.

To accomplish the implementation of a bio-inspired SlowBot, we intend to pursue the following agenda:

1. Conduct a behavioral analysis of the sloth and the Loris to determine the appropriate behavioral suite for the robot.
2. Develop the design concept for an arboreal robot(s) based on the sloth and/or Slow Loris
3. Conduct simulation studies and analyze results prior to the physical instantiation of the robot.
4. Implement on a real robotic testbed.
5. Test in a range of settings from laboratory to a large-scale test setting (Naval Research Laboratory's Tropical High Bay, Greenhouse at Atlanta Botanical Gardens, University of Georgia Agricultural Station, local vineyard, or similar test facility).
6. Iterate on design as necessary.

The underlying goal remains to provide robotic systems capable of remaining on task and surviving in natural settings for extended periods of time.

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