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Robotic Exploratory Control Via Subcortical Oscillations

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Introduction: Navigation through real-world environments remains a difficult task in intelligent robotics, due to a constantly changing landscape of potential hazards and new information. To address this, roboticists and neuroscientists have turned to the brains and behaviors of rodents — some of nature's most successful explorers — to inspire optimal solutions. [1-2] Most approaches model patterns of activation in the hippocampus and associated circuitry, leveraging rodents' exceptional memory of spatiotemporal sequences for navigation. None, however, have utilized the coupled activity of multiple subcortical regions that balance navigation with regulation (e.g., grooming, immobility), a key optimization that animals use in real-world scenarios. Indeed, activity in the amygdala, olfactory bulb, hippocampus, along with their functional couplings, have been shown to be instrumental during free-roaming and navigation tasks involving potential stressors (e.g., novel objects, fear stimuli, conspecifics, or autonomous agents). [3-5] This recruitment of regions involved in both regulation and exploration reflects the strategy of switching between these behaviors observed in rats during these paradigms. The current research investigates the effectiveness of neural oscillations in these brain regions as control signals for robotic navigation, using the natural hierarchy of rodent subcortical activity as a decision-making architecture for a self-monitoring neurorobotic system. Building such hierarchical control systems with self-regulatory mechanisms is crucial for developing intelligent robotics that perform natural tasks as biological agents do.

Material, Methods and Results: For this study, we utilize PiRat, a rat-sized robot used in several previous rat-robot interaction studies. [3] In our simple paradigm, the robot is equipped with a two-dimensional action space A and a five-dimensional state space S (Fig. 1). We begin our investigation with an offline training procedure using data from previous recording sessions, during which rats with tetrode implants in the CA2 region of the hippocampus (CA2) and stereotrodes in the medial amygdala (MeA) and main olfactory bulb (MOB) were allowed to roam freely in the presence of a conspecific. [3] During offline training, a behavioral cloning (BC) neural network model designed in PyTorch was trained to generate action $a \in A$ based on state $s \in S$ (70/30 train/test split). We then ran the model on the remaining test data, and the actions generated by the model at each timestep were combined into a continuous trajectory of resulting positions. These were compared to the actual rat positions at each corresponding timestep, serving as a metric for how rodent-like the robot's free roaming behavior was. At the current stage of this work, we have learned a state and action space for the paradigm, and are in the development stages of the BC model.

$$\mathbf{S} = \{\mathbf{s} : (\mathbf{x}, \mathbf{y}, \mathbf{M}(\mathbf{LFP_{mob}}), \mathbf{LFP_{amyg}}, \mathbf{M}(\mathbf{LFP_{ca2}}))|\mathbf{x}, \mathbf{y}, \mathbf{LFP} \in \mathbf{R}\}$$

$$\mathbf{M}(\mathbf{x}(\mathbf{t})) = \arg \max_{\mathbf{f}:\in[\mathbf{2},\mathbf{12}]} \mathbf{P}(\mathbf{f})$$

$$\mathbf{A} = \{\mathbf{a} : (\mathbf{v}, \theta)|\mathbf{v} \in [-\mathbf{1}, \mathbf{1}], \theta \in [\mathbf{0}, \pi]\}$$

Figure 1: *State space (S) and Action space (A) defined for behavioral cloning model. Function M denotes frequency with greatest power within the theta frequency band (range chosen based on previous work). [3]*

Conclusion: The defined state and action spaces demonstrate that rodent-like exploratory and regulatory behaviors may be generated via streams of local field potential data from CA2, MOB, and MeA.

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