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# Goal-oriented behavior sequence generation based on semantic commands using multiple timescales recurrent neural network with initial state correction

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ABSTRACT

In this paper, to build an autonomous robot, we propose a novel scheme for a goal-oriented behavior sequence generation in tasks involving multiple objects. The scheme includes three major functions: (1) visual attention for target object localization; (2) automatic initial state correction based on experience using simple reinforcement learning, and (3) a suitable behavior sequence generation method based on multiple timescales recurrent neural networks (MTRNN). The proposed scheme systematically combines the three different major functions so that the autonomous bi-pad robot can automatically execute tasks involving multiple objects based on high level semantic commands given by human supervisor. The selective attention model continuously catches the visual environment to understand the current states of robot and perceive the relationship between current states of robot and the environment (depth perception and localization of a target object). If the current state is different from the initial state (depth perception and localization of a target object), the robot automatically adjust its current state to the initial state by integrating visual attention and simple reinforcement learning. After correcting the initial state of the robot, the behavior sequence generation functions can successfully generate suitable behavior timing signals, by integrating visual attention and MTRNN, based on the high level semantic commands given by human supervisor. Experimental results show that the proposed scheme can successfully generate suitable behavior timing, for a robot to autonomously achieve the tasks involving multiple objects, such as searching, approaching and hitting the target object using its arm.



## 1. Introduction

To achieve robot behavior sequence generation in tasks involving multiple objects, such as approaching and hitting objects one after the other by a humanoid robot, the visual attention and behavior of the robot need to switch to the objects corresponding to a specified task based on high level semantic commands given by human supervisor at the appropriate time. Humans control gaze shifts and fixations (visual attention) proactively to gather visual information related to the specific task for guiding the movements [1]. In addition, visual attention can effortlessly detect (location) and help to recognize (identification) an interesting area or object within natural or cluttered scenes through the selective attention mechanism with various visual features [2–4]. Based on the previous studies [5–7], the current work examines how a humanoid robot can generate behavior sequence by acquiring adequate visual attention shifts and movement timing with depth information and localization of a target object. We focus on the generation of the timing signals for visual attention shift and behavior shift, such as object attention, approaching, turning and hitting, by understanding the high level semantic commands according to the situation. To implement a robot behavior sequence generation function via learning by examples, the current study considers three important mechanisms: (1) visual attention for target object localization, (2) automatic correction of the initial state for robot to suit the state in the learning phase by reinforcement learning, and (3) a suitable behavior sequence generation based on multiple timescales recurrent neural networks (MTRNN) by coordinating current states of robot and the environment containing the target object [10].

Based on the semantic commands given by a human supervisor, visual attention function can pop-out the salient areas in a natural scene and estimate depth information of a salient area or

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object. Depth information and localization of a target object by the selective attention model are very important to catch the current robot states and to decide whether the current states are same with those of training phase. From understanding of current robot states, the autonomous robot should self-adjust its initial state by considering the proposed automatic initial state correction. A simple reinforcement learning cannot solve the tasks involving multiple objects based on sematic commands. Therefore, after correcting the initial state of robot, the MTRNN is used for behavior sequence generation based on high level semantic commands given by the human supervisor. The proposed method includes an autonomous way to successfully execute the tasks involving multiple objects even in a situation which is different from the training phase. Also, the proposed scheme systematically combines the three different major functions so that the autonomous bi-pad robot can automatically execute tasks involving multiple objects based on high level semantic commands given by human supervisor.

In this work, we extend the work of Yamashita et al. [10] for robot behavior generation tasks involving single object to multiple objects by localizing each object based on its individual characteristics, through time, by visual selective attention proposed by Jeong et al. [7]. All the previous works assume the robot's initial position to be correctly set, so that it can walk a distance, approach the target and generate behavior sequences [5–7,10,11]. Previous research has shown that MTRNN have two different level networks: fast and slow dynamic networks depending on the decay rate of a unit's membrane potential [10]. A set of primitive motor behaviors are acquired in the fast dynamic network, while the sequencing of these primitive motor behaviors are generated by the slow dynamic network based on the high level semantic commands given by human supervisor [10]. In the current model, the function of a sequence generation by a visual attention shift and behavior shift are considered to be attained in the slow dynamics network along with the one for sequencing of the primitive behaviors such as walking to and hitting a target object. The sequences of the visual shift and behavior shift from this slow dynamics network are sent to a hard-wired gaze system and a behavior system to attend a target object and to achieve behavior sequence control through time, respectively. In our experiment, the robot learns to perform visual attention shifts with depth information and behavior shifts followed by acquired behavior patterns through human supervisor; the robot sequentially attends and approaches an object before hitting it and then to the other object based on high level semantic commands given by human supervisor. The proposed model can simultaneously generate the corresponding sequences of goal-directed visual attention shifts and robot movement timing with regards to the current sensory states including visual stimuli and body postures.

This paper is organized as follows: In Section 2, we present the problem definition and the proposed neuro-robotics architecture, which is combination of a stereo visual attention system, reinforcement learning for correcting the initial state of the robot, and a behavior system using a dynamic neural network model known as MTRNN. The experimental setup and results are presented in Section 3 followed by discussion and conclusions in Section 4.

## 2. Proposed behavior sequence generation model

### 2.1. Problem definition of behavior sequence generation with multiple objects

Nowadays, commercial robots (like NAO and DAWIN) are provided with libraries that already include control functions, and thus we do not need to consider the low level motor signal

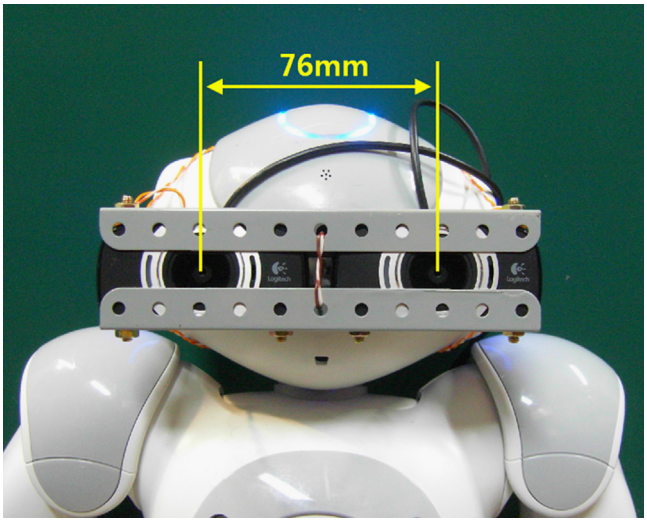


**Fig. 1.** Stereo camera module on NAO's head.

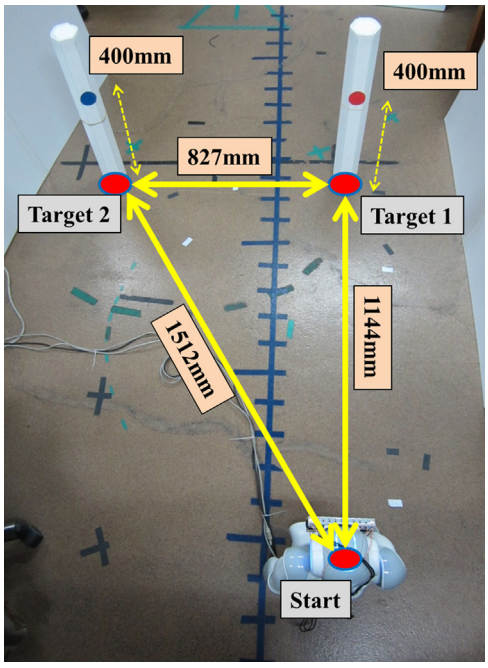


**Fig. 2.** Workbench for robot experiments. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

generation for controlling the commercial robot. In commercial robot, the behavior can be precisely generated by pre-implemented functions. Therefore, to achieve the desired goals based on the high level sematic commands, it is enough to construct a sequence of behavior patterns by some machine learning techniques. In the tasks involving multiple objects, to attend and hit a specific target object at each time step, visual attention should be changed at a suitable timing to pop-out the target object within natural scene. For example, in the task “hit the red pillar first and then the blue pillar”, the visual attention command is to attend red pillar before hitting the red pillar. After hitting the red pillar, the visual attention command should change to the blue pillar. Therefore, the proposed model should understand the timing of visual attention shift for target object among the multiple objects. The proposed model can generate suitable behavior sequence by understanding the high level semantic commands (for example, find a red ball and kick the ball, then