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A developmental approach to robotic pointing via human–robot interaction

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ABSTRACT

The ability of pointing is recognised as an essential skill of a robot in its communication and social interaction. This paper introduces a developmental learning approach to robotic pointing, by exploiting the interactions between a human and a robot. The approach is inspired through observing the process of human infant development. It works by first applying a reinforcement learning algorithm to guide the robot to create attempt movements towards a salient object that is out of the robot's initial reachable space. Through such movements, a human demonstrator is able to understand the robot desires to touch the target and consequently, to assist the robot to eventually reach the object successfully. The human–robot interaction helps establish the understanding of pointing gestures in the perception of both the human and the robot. From this, the robot can collect the successful pointing gestures in an effort to learn how to interact with humans. Developmental constraints are utilised to drive the entire learning procedure. The work is supported by experimental evaluation, demonstrating that the proposed approach can lead the robot to gradually gain the desirable pointing ability. It also allows that the resulting robot system exhibits similar developmental progress and features as with human infants.

1. Introduction

A major challenge in modern robotics is to liberate robots from controlled industrial settings, allowing them to interact with humans and the changing environments in the real-world. For instance, if we require robots to assist the elderly, or to replace humans for the accomplishment of dangerous tasks, robots should possess certain social interaction and communication abilities. However, robots' internal representations are typically foreknown and are often designed for specific environments, robots supported by traditional artificial intelligent algorithms might not work appropriately under unknown environments. An important issue is therefore that robots should be able to create their own internal representations [31]. For this, robotic scientists have applied developmental psychology and neuroscience to produce a novel research topic, "Developmental Robotics". In the field of developmental robotics, it is assumed that a robot system is not programmed for

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specific and fixed tasks, but rather programmed to develop and learn new behavioural and cognitive competence and skills autonomously [2].

Our particular interest is in the control and coordination of a robotic hand-eye system in order to achieve mastery of its local, egocentric space and to perform pointing tasks. The need for this is just as that in an infant's development where the infant's pointing is the first attempt to build a platform of pre-linguistic communication [41,48]. In addition, an infant's early linguistic skills are built on the pointing platform [3,17,27,44]. Therefore, to implement social interaction skills in a robot, it is necessary to establish a developmental learning approach to facilitate the robot with the pointing ability, and also to understand the internal incremental processes during the robot's development. This paper aims to build a robotic learning system that leads a robot to developing from basic reaching movements to possessing the ability of pointing.

In robotics, learning to point may be implemented by a variety of techniques. Much work focuses on developing a robot's ability to respond to a pointing gesture demonstrated by a human. The objective of this work is to enable a robot to generate its pointing gestures. There have been relevant proposals made in the literature. For example, Marjanovic et al. [32] introduced a robotic system, through the use of a RBF neural network, which learns to point towards visual targets. Hafner and Kaplan [14] applied a multi-layer-perceptron network to train a robot to interpret the pointing gestures of another robot. Doniec et al. emphasised that the task of pointing accelerates the learning of robotic joint attention, and created Jacobian matrices to deal with the pointing gestures [11]. Shademan et al. [39] made use of a locally least squares algorithm, based on a Jacobian estimation method, to build a robotic visual-motor learning system. Sheldon and Lee [40] described a developmental approach for implementing a pointing learning framework by creating a schema mechanism. Qu and Grupen also proposed a novel learning framework, in which their robot can learn pointing gestures and manual skills simultaneously [37]. Liu [28] and Liu et al. [29] proposed a fuzzy qualitative framework to describe the robotic arm's sensory-motor problem. Also, Lemme et al. defined two types of robotic pointing pattern using different learning machines to imitate how to point [26]. In their research, Jamone et al. created an interactive learning strategy to build a reachable map that can handle reaching rather than pointing movements [18,19]. It is their latest work that has inspired us to develop a mechanism that helps a robot to generate both reaching and pointing movements.

In the aforementioned robotic pointing research, human robot interactions are not taken into account. However, a human infant gains the ability to point through interactions with his/her parents or babysitters. Over a course of parent-infant interactions, an infant learns how to point. This observation indicates that the learning procedure developed for robotic pointing may also benefit from a course of human–robot interaction. Indeed, human–robot interaction has been considered as an effective learning method to transfer skills and knowledge from human beings to robots [1,4,9,38,50]. The present work follows this theme of thought.

Developmental approach offers the potential to drive a robot learning from the basic reaching movements to the pointing behaviours. Compared with the "Deep Learning" as described in [13], the developmental approach exhibits staged incremental learning ability, which helps reduce the robot's learning complexity. From this viewpoint, we bring more infant developmental features into our robotic learning system. In particular, this paper presents a novel approach emphasising that the robot should mimic the procedure in which a human infant learns to point. This procedure is summarised as follows: (1) trying to reach objects; (2) failing to reach objects; (3) interacting with an adult human; and (4) ultimately knowing how to point. Based on this procedure, we present an implemented human–robot interactive system that reflects the following three desirable features:

- that pointing gestures are mutually comprehended between the human and the robot;
- that infant brain developmental characteristics are applied to create a robotic developmental learning system; and
- that a developmental learning algorithm – "Lifting Constraints, Act and Saturate (LCAS)" – is employed to drive the robot to learn.

This approach reduces the complexity of building human–robot communications, thereby, injecting more psychological and biological inspiration into robotics, and enabling robots to exhibit higher autonomous capability.

The rest of this paper is organised as follows. Section 2 briefly introduces the configuration of robotic pointing gestures. Section 3 describes an experimental robot system and the main implementation issues involved. Section 4 presents the experimental results and discusses their implications. Section 5 concludes the paper and points out directions for further research.

2. Robotic pointing and related work

Recent robotic pointing research reveals no universally accepted definition of robotic pointing gestures. Much of the current work projects the three-dimensional position of an unreachable object into the robot's two-dimensional visual position. In particular, if a robot's end-effectors block the object within the robot's view, the gesture is generally regarded as a pointing gesture [26,40]. Also, the pointing gesture may be defined as the robot's end-effector in the closest position to the object [7]. Other work only indicates that a robot's gaze is linked to an arm gesture, called a pointing gesture [37]. However, we suggest that a pointing gesture relies on the robot operator's understanding also; therefore, only the robot operator can determine the pointing criteria. In light of this understanding, Fig. 1 defines the pointing gesture as to be used hereafter.

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