

Development of eye-head gaze control on the iCub robot

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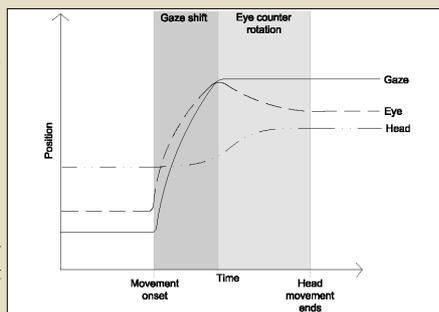
Introduction

A fundamental skill required in both humans and robots is the ability to direct gaze toward a target. Multiple body segments can be used to fixate a target, and here we describe our architecture for gaze control using eye and head movements and its implementation on an iCub robot.

Human gaze control is learnt in infancy and progresses through stages of development which are shaped by constraints on the infant. We describe how constraints are used to develop gaze control in our system, and how they impact on the learning process.

Gaze contributions

Eye and head contributions to gaze shift are generated separately. The eye moves the full distance to the target, whilst the head makes a smaller contribution based on the desired gaze displacement and initial eye position. Both movements are triggered almost simultaneously, but the eye reaches the target first and must counter-rotate to compensate for ongoing head movement.



Development in infancy

The poor visual ability and limited muscle tone of the neonate prevent eye-head gaze control at birth. Rather, the ability develops over time, in stages, as shown by our timeline of infant development [1]. Such stages are important to infant development, and provide useful lessons for robotics. We map the observed stages of development onto the sensor and motor modalities of the iCub. In particular we note that a lack of muscle tone prevents learning of neck control until eye control is sufficiently developed.

	Age post-natal (months)					
	0 (At birth)	1	2	3	4	6
EYES	Move eyes toward diffuse light.	Turn head and eyes toward light source. Stares at light colours. Attracted to novel stimulus 6-10 inches from face. Basic object tracking. Few jerky saccades; fixating on object edges.	More, smooth saccades. Ability to locate within objects.	Gazes at human face. Visual exploration by moving head and eyes. Hand regard. Voluntary control.	Smooth tracking. Fixates on self.	Foot regard. Visual exploration by moving head and eyes. Attracted to novel visual stimulus. Eyes move in unison. Watches falling objects to resting place. Refinement of all eye movements.
NECK	Improved eyeball position control.	Rotation when supported, but insufficient torque otherwise.	General neck movements. Enough torque for short durations. Can tilt to 45 degrees.	Good head control. Increasing mid-line orientation.		
	Increase in torque and position control					

Constraints

The iCub learns the correspondence between sensor and motor spaces using our mapping framework, and stages in development are shaped using the modulating influence of a dynamic constraint network [2].

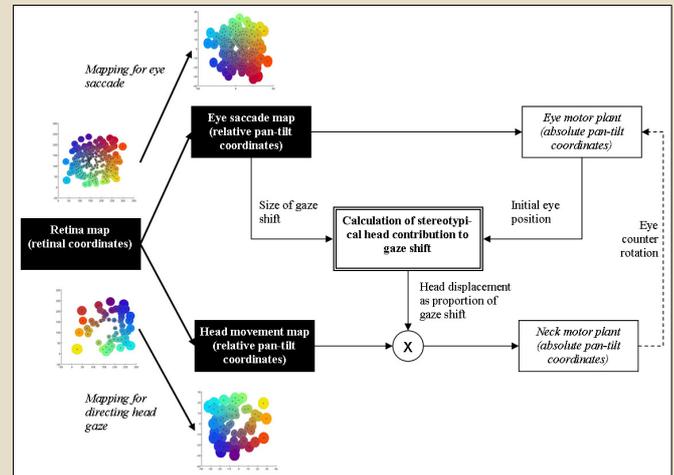
We investigate 2 types of constraint: Type A constraints are derived from the limitations of immature neurological and physiological structures, such as muscle tone, and are thus fairly independent of external factors. They can be effectively measured in terms of a relative temporal framework. Type B constraints can be influenced by external (i.e. sensory and motor) effects and therefore may have more complex roles in development.

References

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- [3] Freedman, E. G. Coordination of the eyes and head during visual orienting. *Experimental Brain Research*, 190, 369-387, 2008.
- [4] Wang, X., Jin, J. A Quantitative Analysis for Decomposing Visual Signal of the Gaze Displacement, In *Proceedings of the Pan-Sydney area workshop on Visual information processing - Volume 11*, Australian Computer Society, Inc., Darlinghurst, Australia, 153-159, 2001.

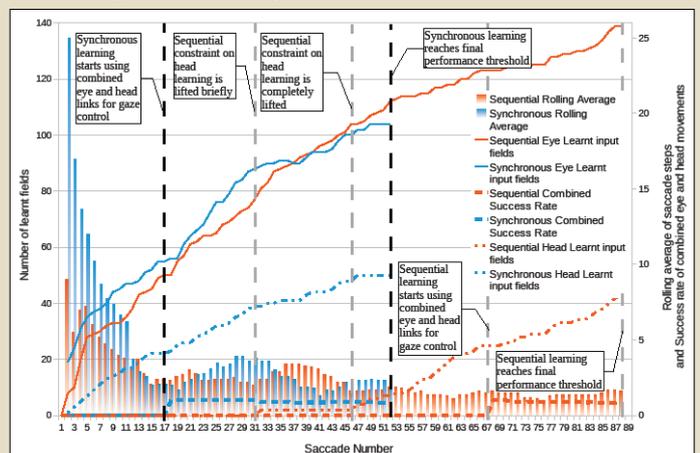
Gaze architecture

Our architecture for gaze control is shown below. It is biologically constrained, using maps to implement a model proposed by Freedman [3], and which uses constraints to shape stages of development. Full eye and head movements to target points are learnt, but the relative contribution of head movements are scaled using algorithms by Wang and Jin [4]. Coloured maps show learnt correlations between eye motor, head motor, and visual spaces.



Results

We have experimented with the iCub learning eye-head coordination using both Type A and Type B constraints as shown below. Sequential results correspond to Type A constraints, using a threshold on saccade accuracy to trigger neck learning. Type B constraints emerge when eye and neck learning is allowed to occur synchronously but early, inaccurate, eye saccades prevent learning of correct neck movements.



Summary

The neural structure of the gaze control architecture suggests that accurate eye control is a prerequisite for learning the impact of head movements on gaze shifts: both eye and head movements are encoded separately, but eye reflexes prohibit learning head-only gaze shifts.

If both head and eye movements are learnt synchronously, correct head movements will not appear until saccades are sufficiently accurate: a Type B constraint. In infants, a lack of muscle tone limits neck movements, allowing the eye to reach well developed levels before neck control is learnt: a type A constraint.

Our gaze architecture enables very fast learning of gaze control on the iCub using both learning methods. Each has advantages, and we are continuing to investigate how both play a part in infant development.