1 Introduction

This document reports on observations made while letting the system develop following the first 5 months of development, in connection to the child's vision. Data collected by both the sensorimotor learning (i.e., eye/head/gaze maps) and the object perception learning (i.e., object space/feature maps) will later be plotted to show the progress being made to the sensorimotor coordination and how it is affected by the slowly developing vision. The aim of this document is to provide an idea of saturation types and levels that could potentially be used in the system. Hence, along with a qualitative description of the performance, statistics are given at the end of each month.

2 Developmental from month 0 to month 4

The following 6 metrics that show a potential in being used to define saturation are included:

- Eye or head good links; this is the number of links that have reached a confirmation threshold and have proved their ability to lead to successful saccades between fixation points.
- Eye or head links; this is the sum of all links present in the eye or head map. There is no guarantee that all of these links have been confirmed enough times, but it gives an indication of the saturation in terms of field connectivity in the eye or head maps.
- Rolling average; this is the mean of the 10 recent step counters for a saccade (stepcounter is incremented when a link between fields is travested) saccade.
- Gaze fields; the number of gaze fields in the sensorimotor gaze space.
- Object space fields; the number of object representations in the object space (i.e., new gaze space).
- Object to feature mappings; number of connections between features and object representations in the object space.
- Combi successes; number of successful attempts robot was able to utilise eye+head links in order to saccade while learning.

The observations below give an idea of the expected results of the sensorimotor (SM) development using developing vision. Notice that for each new month, the SM learnt datasets are used to top up, whereas the object perception once are cleared (I assumed that the robot forgets of all previous object representations and by starting from scratch, it would rebuilt the same knowledge, hopefully in a more refined way).

2.1 Month 0

The vision in this month is seriously underdeveloped when compared to the following months. The eyes have difficulties locating a target for fixation and even when they do, a slight movement of the eyes dramatically affects the ability to locate and fixate on targets. In turn, the saccades do not generate good number of links. This is due to the very limited FOV and effect of acuity.

The vision library returns mostly bright targets and targets in motion. Coloured targets are rare and edges are almost impossible to detect at this month. That makes the robot spend most of its time babbling and non-fixating, whereas the object perception mechanism stays idle for a long time. As it is hard to fixate on targets, the majority of eye links that are created initially lead to particular gaze directions, which gives the impression that the babybot "comfortably" spends more time observing the same area of blur targets.

When the number of good links is 5-6, the SM system enjoys more fixations and the object perception mechanism is then able to collect features as well as to compare observed areas in the objects' space. The number of both SM's and object space fields increases as more eye links are created. Still, SM's gaze map is found to exceed the object perception one in size (11/3).

Final statistics after 40 minutes of run:

1. Eye good links: 7
2. Eye links: 19
3. Last rolling average reported: 0.4
4. Gaze fields: 11
5. Object Space fields: 3
6. Object to feature mappings: 14 (mostly bright patches)

2.2 Month 1

Bright and motion targets are easily detected. The previous SM learnt dataset allows gaze fields to be added faster as saccades are now easier to perform. The less narrowed FOV and the better acuity have a slight impact to the object perception mechanism; it almost immediately creates 3 object representations and mappings for each one of them. Still the poor acuity does not allow the system to link multiple features with the same object representation simultaneously.

Similar to month 0, the chance of losing a target before collecting features is noticeable. Coloured targets and targets with edges are not detected, whereas large bright patches make the brightness map active. Motion is also picked up.

Existing object representations are triggered as the robot still prefers to roll its eyes back to previous gaze areas. This is due to the limited number of eye links available in the SM part of the system, coupled with the system's inability to detect multiple targets on the scene (narrowed FOV and locked head joints).

It was observed that due to the wider FOV, multiple features were selected for an object representation once. Again, the robot spends most of its time doing eye babbling and not being able fixating too much. If a decay-based-on-TS algorithm was in place, the representations would have been pruned from the short term memory.

As expected the saturation metrics do change but not dramatically, as the vision-related conditions did not change much between month 0 and month 1. The rolling average has improved to 1.1 as a result of generating more eye links on top of the previous month's data.

Final statistics after 35 minutes of run:

- Eye good links: 13
- Eye links: 44
- Last rolling average reported: 0.9 (has been 1.1)
- Gaze fields: 28
- Object Space fields: 4
- Object to feature mappings: 12 (mostly bright patches)

2.3 Month 2

Acuity improvement allows only large coloured areas to be detected. Still, brightness and motion filters return a good number of targets. Previous SM learning allows the eyes to follow existing links and show a less babble-related behaviour compared to previous months.

Although fixation seems more precise due to acuity (the fixation point is closer to 0,0 on the retina), the vision is still blur enough and targets are missed frequently.

The FOV did not change dramatically, but acuity allows the vision library to be more precise when it detects bright areas. This does not hold for edges' filter, which is still unable to detect targets. Collecting multiple features at the same time is rarely observed.

Compared to month 1, existing mappings tend to be used more often. This does not increase the size of the mappings list but it does let existing mappings to be updated with new data. This is a result of the system being more accurate in terms of vision, rendering it able to trigger feature fields more precisely.

The system reports existing fields within the object space to be reused in less than 10 seconds. That is an indication that the system becomes more active in eye movement and that saccading consists of less random babbling. For the human observer, the robot gives the impression of having a better overall understanding of its gaze space as it utilises learnt links to fixate between known areas more often.

.. stats were overwritten :(

2.4 Month 3

The colourmap is now active as smaller coloured objects can be seen. The head is also unlocked so that the system is able to perform some VOR activity. It is still difficult to remain concentrated on a fixed target for a while. Gaze and object spaces are expanded. Fixations on coloured targets are achievable.

Final statistics after 35 minutes of run:

- Eye good links: 14
- Head good links: 10
- Eye links: 73
- Last rolling average reported: 0.7
- Gaze fields: 78

- Object Space fields: 12
- Object to feature mappings: 14 (mostly bright and coloured patches)
- Combi success rate: 0.5
- Combi successful: 1

2.5 Month 4

Similar to the previous month, now the acuity allows colours to be detected, hence the colourmap is found to be active. The VOR mechanism performs some head babbling with the eyes fixating and compared to the previous month this activity is able to provide more head links than before. As the SM learning top up the previous datasets, sensorimotor coordination is better and performs saccades more precisely.

It is found that the object perception does get a small share of time during the experiment, as VOR occupies most of the time. Most of the times, when potential objects are located existing mappings are used.

SM-wise, the system does perform better than all previous months. The SM maps are now significantly populated. Observing the performance the system indicates that object observation mechanism should be given more time as compared to the SM.

Final statistics after 35 minutes of run:

- Eye good links: 20
- Head good links: 64
- Eye links: 91
- Head links: 115
- Last rolling average reported: 1 (reported more than that during the month)
- Gaze fields: 93
- Object Space fields: 6
- Object to feature mappings: 9 (mostly bright and coloured patches, almost 50-50
- Combi success rate: 0.666667
- Combi successful: 3

3 Discussion

It is clear that not all saturation matrics make (the same) sense for all months of the development. Rather, a combination of them could be used for each month. The system at the moment supports different saturation types to be utilised so incorporating the final types/thresholds will be easy.

Furthermore, VOR and other head learning activities do consume a lot more time than the object perception mechanism. The latter should therefore be given extra time to populate the maps.

To conclude, from the data gathered the following points can be made and reasonably justified:

- The underdeveloped vision does have a significant impact to the sensorimotor learning.
- Colour and edges detection appears in the system after month 2. Till then, brightness and motion are the features that drives sensorimotor learning.
- Knowledge about objects is re-built at each month with a gradually better precision in both amount of features (feature fields and corresponding mappings are reused when the system is more mature) and the ability to locate the objects in the object space (refined fixations).
- Mastering head movements and exploring a wider gaze space (unlocking of head/wider FOV) impressively develops sensorimotor control. Yet, more time is required in order to learn about objects which suggests that artificial play important.