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RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Abstract:

This deliverable presents the final humanoid robot setup of the project EYESHOTS, enriched by integrating on the UJI humanoid robot modules from VVCA architecture of partners UG, K.U.Leuven and WWU. We briefly describe the way such modules have been ported onto the UJI hardware and software platform and how the main integration issues have been addressed. The addition of such modules allows complementing and extending the abilities presented in D4.3b, so that the robot is finally able to act on a multiple real object working setup.

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1 Executive summary

In this deliverable we introduce the full implementation on the UJI humanoid robot of the visuomotor behaviors which constitute the bulk of EYESHOTS robotic aspects. The global skills of the robot at the end of the project will be presented in a live demonstration during the final review meeting. Here we describe the theoretical and practical aspects that have been tackled in order to integrate on the UJI humanoid robot the computational modules of partners UG, K.U.Leuven and WWU/Chemnitz, according to the Integration Roadmap submitted after the 2^{nd} annual review meeting. The experimental scenario is an extended version of the *working-desk setup* of deliverable D4.3b, with real world objects, and full 3D movements for both eyes and arm. Please note that, due to revised planning in WP1, and to the additional efforts required by the Integration Roadmap, there has been no porting of the UG anthropomorphic head onto the UJI platform, as initially planned.

2 The basic visuomotor skills of the UJI humanoid robot

The fundamental visuomotor abilities of the UJI robot at the end of the project are the subject of deliverable D4.3b. The theoretical aspects of the underlying computational framework and the conceptual development of the robotic implementation have been introduced instead in previous reports and publications. Here, we provide a brief description on the basic implementation schema that allows the robot to perform the pre-defined and custom actions listed in deliverable D4.3b. The implementation schema is depicted in Fig. 1. There are three sensory/actuation blocks: *cameras* refers to the gathering of visual information by the stereo visual system; *head* represents oculomotor functions, both as eye movements and corresponding proprioceptive information; *arm* deals with reaching movements by controlling the arm joint space. Transformation blocks *Visual/Oculomotor* and *Oculomotor/Joint Space* refer to

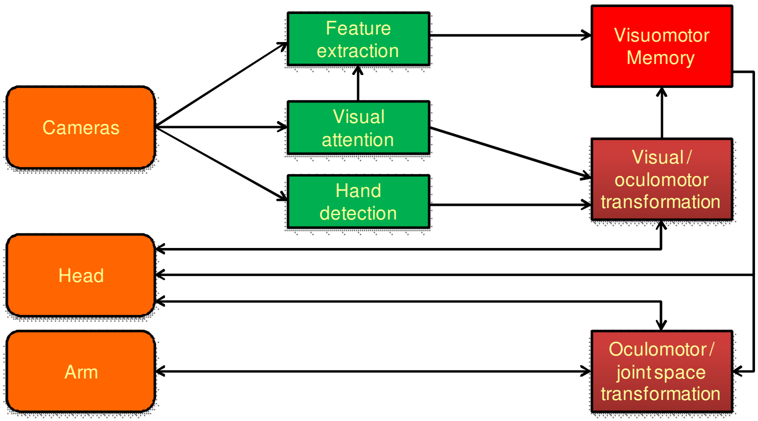

Figure 1: Implementation schema of the UJI humanoid robot visuomotor skills.

the radial basis function structures that implement the sensorimotor coordination of the whole system and makes it adaptable to the environment and to its own body. The *Visuomotor Memory* maintains the record of previous visuomotor states that allows the robot to code for encountered objects in a way suitable for recognition, searching and for performing gazing and/or reaching actions toward memorized targets. The green blocks represent different visual processing utilities, required to properly interface the *cameras* with the red behavioral modules. More details regarding all the modules of Fig. 1 will be provided in EYESHOTS 3^{rd} periodic report. In the next sections we explain how the computational visual modules of EYESHOTS partners have been integrated in the described schema in order to validate them by realizing real-world experiments on a robotic platform, and contextually improve and extend the robot skills.

3 Integration of the computational modules of partners UG/K.U.Leuven/WWU on the UJI robot

Three main computational modules of EYESHOTS WP1, WP2 and WP3 have been integrated in the above framework. They derive from the Vergence Version Control model with Attention effects (VVCA), developed by partners UG, K.U.Leuven and WWU/Chemnitz. The way such modules change the robot visuomotor behavior implementation schema can be observed in Fig. 2. The three modules introduced in the schema are:

V1 UG binocular population response block;

VC K.U.Leuven closed-loop vergence control block;

ORS WWU/Chemnitz object recognition block.

It is worth mentioning that, although a working interface between Matlab/Simulink and C++ platforms had been provided by UG, for efficiency and homogeneity issues we finally favored a software integration solution in which all modules are implemented in C++ and installed directly on the robot PC. Another important issue in the integration of all modules has been the large interocular distance of the robot eyes, which can generate very large disparities

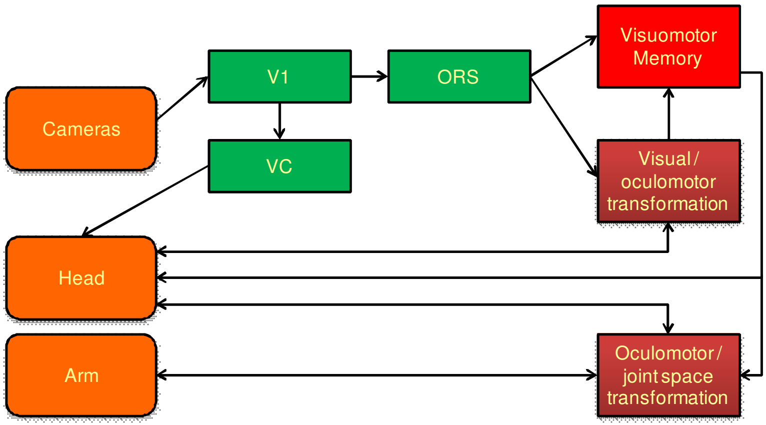

Figure 2: Implementation schema modified by the integration of modules V1, VC and ORS.

that are difficult to manage by the computational modules of the VVCA architecture. This problem has been solved by a careful control of the robot behavior that allows us to maintain disparity within a tractable range, at least for the central image window. Some details on the integration of each of the three modules are described in the following sections.

3.1 Phase 1

In this phase, a C++ version of UG V1 front-end module has been provided by partner UG and integrated by UJI on the robotic system. This module is inspired on the functionality of primate primary visual cortex and computes the energies of a population of Gabor filters that are sensitive to different orientations and phases. Such population coding can be used to compute the disparity map of a visual scene. As a first step, before the integration with other modules, its output has been used by the UJI open-loop saccadic control and by the visual attention module to detect object location. The integration of this module allows the system to operate with real 3D objects.

3.2 Phase 2

A closed-loop vergence control module is added to the system in this phase. This module has also been implemented in C++ by K.U.Leuven, using a linear vergence control for simplicity. The weights of the network are derived by an off-line training phase, performed by the original Matlab/Simulink version of the module on real images gathered by the robot. After the execution of a saccadic movement toward a target object, module VC receives in input the output of V1 in the form of a set of energies extracted by the population of Gabor filters. VC makes use of such visual information in order to perform a finer oculomotor control upon the object surface that brings to zero the disparity in the fixation point. In this way, the ORS can receive a minimum disparity visual information of the foveated object.

3.3 Phase 3

Phase 3 enriches the robot software library with a bio-inspired module for object recognition (ORS) fully developed in C++ by partner WWU/Chemnitz. Module ORS receives in input the response of the V1 module and recognizes the object the system is gazing at, providing

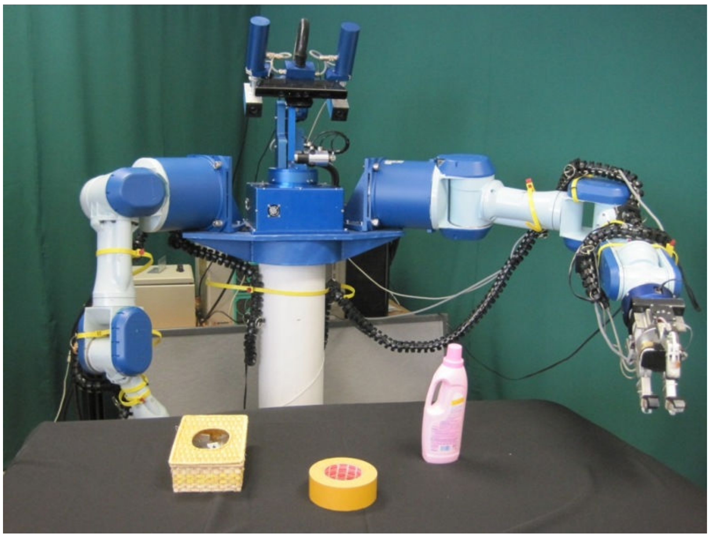

Figure 3: Multi-object experimental setup.

the Visuomotor memory with the exact object identity. The module has also been trained with images provided by the robot. Additionally, the robot own hand has been included in the set of objects to recognize, so that the robot is able to identify visually, without the aid of markers, its own limb. The inclusion of the ORS module allows the robot to work with real multi-object setups, such as in the example of Fig. 3.

3.4 Phase 4

The integration of the version control implemented by K.U.Leuven in Matlab/Simulink on the robot system was not performed due to technical issues that could not be solved in a short time. In fact, the version control module should provide a velocity profile to be followed by the robot eyes to focus on the target. Nevertheless, the maximum control frequency of the robot head does not allow for the speed required by K.U.Leuven version control module. For this reason, the version signal is provided in terms of final position calculated by UJI neural networks. In any case, despite this last point, all target skills have been attained by the integration of the above three modules on the architecture developed by UJI.

4 Conclusion

Summarizing, all but the last of the roadmap integration phases have been successfully carried on, allowing to enrich the general visuomotor abilities of the humanoid robot, through an improved control of eye movements and advanced visual skills. On the basis of these results, the experiments of the final setup, as described in deliverable D4.3b, will be executed on a relatively complex visual environment with real objects, using biologically-inspired computational solutions deriving from the theoretical studies of partners in WP1, WP2 and WP3.