Clothes Perception and Manipulation

D4.1
Binocular Robot Head Implementation and Operating Software

Gerardo Aragon-Camarasa (UG), Paul Cockshott (UG), Susanne Oehler (UG) and J. Paul Siebert (UG)

Version: 2.0
Last Update: 23 - 11 - 2012

Distribution Level: PU (Public)

The research leading to these results has received funding from the European Communitys Seventh Framework Programme (FP7/2007-2013) under grant agreement n^o 288553

Project Number	:	FP7-288553
Project Title	:	Clothes Percpetion and Manipulation

Deliverable Number	:	D4.1
Title of Deliverable	:	Binocular Robot Head Implementation and Operating Software
Nature of Deliverable	:	Report
Dissemination Level	:	Public
Version	:	2.0
Contractual Delivery Date	:	1 - 11 - 2012
Actual Delivery Date	:	23 - 11 - 2012
Contributing WP	:	WP7
Author(s)	:	Gerardo Aragon-Camarasa (UG), Paul Cockshott (UG), Susanne Oehler (UG) and J. Paul Siebert (UG)
Reviewers(s)	:	Sotiris Malassiots (CERTH)

Abstract

Deliverable 4.1 is an output of Task 4.1 in Workpackage 4, and comprises the design and implementation of the principal vision system for he Clopema clothing manipulation robot. This deliverable includes an investigation of potential camera and actuator configurations and the most appropriate configuration identified is used to implement a programmable binocular sensor head. In order to be suitable for quantitative range-finding within the workspace of the CloPeMa two-handed robot, this sensor head must be able to maintain dynamic calibration under active gaze control. The developed binocular vision head is supported by control software operating as nodes within the ROS environment to provide high-resolution stereo-pair image capture, lower resolution binocular streaming video, automatic camera convergence, range-map construction, camera calibration and SIFT feature extraction.

Keywords

robot head, range maps, camera calibration

Revision History

Version	Description	Author(s)	Date
1.0	First draft	University of Glasgow	15 Nov 2012
1.1	Corrected draft	University of Glasgow	19 Nov 2012
1.2	Sent for review	University of Glasgow	19 Nov 2012
2.0	Final version	University of Glasgow	23 Nov 2012

Contents

1 Introduction

Under the remit of Deliverable 4.1 we have investigated suitable low-cost camera and actuator configurations to implement three fully programmable binocular heads, one for each experimental testbed, that are suitable for maintaining calibration by means of photogrammetry and actuator position feedback. These heads have been delivered with existing software, supporting high quality metric range map extraction and SIFT feature extraction and head interface/control. The development of accelerated codes for range map construction is an ongoing process under Task 4.2 Accelerated Range Sensing, the next phase of this research.

WP 4 has two formal deliverables, requiring fewer PMs than the total WP effort. This is because the work on the components that will be developed under this WP will carry on all through the project, by improving these components, incorporating extra features as the demonstrators progress, etc. Additional person months of effort will be expended towards Deliverables D7.2, D7.3 and D7.4, which are the three demonstrators, and WP 4, to which Task 4.1 contributes, prepares components for these demonstrators. Therefore the deliverable described in this report is part of an on-going development process.

Within Task 4.1, Binocular Sensor Head Design & implementation, (M1-M6) (Leader: UG, Contributors: NEO) UG has investigated a small selection of low-cost available cameras (e.g. ranging from Olympus SLR to Logitech Webcam), and low-cost actuator platforms in order to determine a suitable basis for constructing the binocular head. UG evaluated camera functions comprising focus control & exposure control and also returned image quality and the ability to provide binocular streaming on the chosen operating systems and computing hardware platforms. UG has undertaken an initial investigation into the ability of the selected binocular camera configurations to maintain dynamic calibration using the selected cameras and actuators and their ability to image the robot system's working volume.

Based on the above design phase, UG has integrated a basic stand-alone binocular head capable of:

1. Directing its gaze under program control & acquiring stereo-pair images;
2. Delivering calibrated range data based on UG's C3D stereo-photogrammetry package;
3. Delivering SIFT features in full-resolution and foveated modes using UG's existing software.

NEO has facilitated the physical integration of the binocular robot head with the robot arms as detailed in deliverable 7.1.

2 Robot Head Hardware Delivered

The aim of the binocular robot head is to produce a low-cost, off the shelf robot vision system that integrates high resolution imaging for 3D mapping and range images and low resolution imaging for gaze control and feature extraction. These operational modes

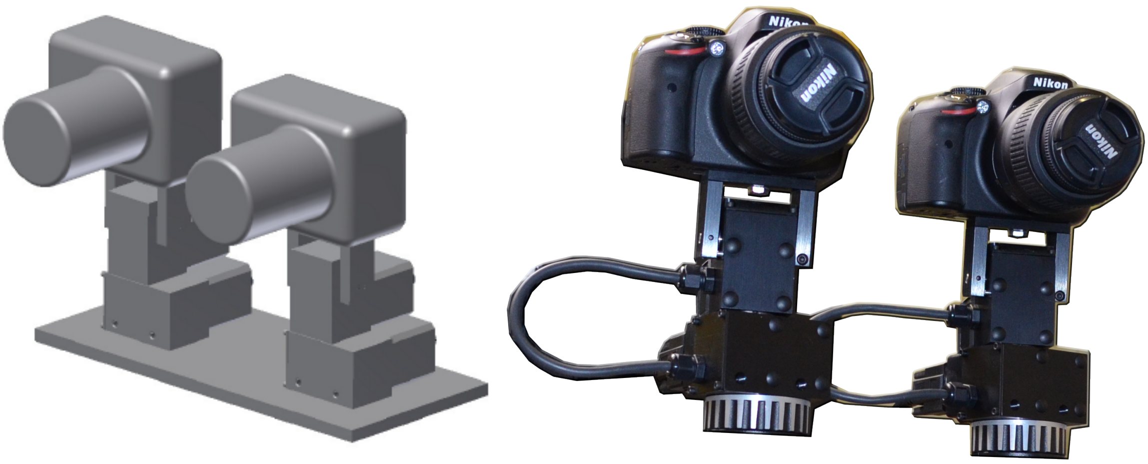


Figure 1: Left: CAD model of the CLoPeMa robot head. Right: Integrated robot head with the selected components.

enable high-level reasoning processes working in conjunction with CLoPeMa dual-robot arm and tactile and RGBD sensors to exploit sensed visual information for the tasks of manipulation and interaction with garments.

Thus the hardware requirements are:

- Low-cost high resolution cameras for 3D /range mappings, feature extraction, binocular vergence and gaze control
- Off the shelf high precision actuator platforms for accurate control of cameras in order to inspect garments
- Ubuntu and ROS (Robotic Operating System) [3] support for capturing and actuation control
- Off-the-shelf mounting platform and ease of integration of the robot head components with the CLoPeMa dual-arm robot

As ROS is fully supported in Ubuntu and both are the official developing environment and operating system for the CLoPeMa project, the robot head hardware has to be compatible with this Linux distribution. Figure 1 shows a CAD model and an example of the integrated robot head delivered. The following sections describes the selected hardware configurations for the CLoPeMa project.

2.1 Cameras

The cameras for the binocular robot head must be low-cost, off the shelf and supported by the software operating system. Current low-cost cameras that can be controlled from a computer and provides the required functionalities are digital SLR and low-end consumer cameras (e.g. point-and-shoot cameras). In Ubuntu, the Gphoto2 library[1] provides

[1]http://www.gphoto.org/

Figure 2: The Nikon D5100 camera as in a normal operation setting.

the software interface to access the capabilities of the camera. After reviewing current consumer cameras (as detailed in Appendix A), it was concluded that the **Nikon D5100**[2] (Figure 2) fulfils the requirements for the CLoPeMa project. This camera features:

- A 16.2 megapixels CMOS image sensor for high image capturing
- 0.3 megapixels (640 by 480 pixels) at 24 fps low resolution image capturing
- 18-105mm VR Lens
- ISO speed range from 100 to 25600
- USB interface for downloading captured images and controlling from a computer
- One-shot AF, continuous AF and manual focusing modes
- 4 fps continuous shooting
- 12bits per colour plane
- ˜800 grams of weight (with lens)

The mounting platform for attaching the Nikon D5100 should provide a #1/4-20 UNC screw thread standard. To that end, the selection of the pan and tilt unit must comply with this constrain. The following section describes the selection of the pan and tilt unit.

2.2 Pan and Tilt Units

The mechanical configuration of the robot head for the CLoPeMa project closely follows a previous active binocular robot head [1] developed at the Computer Vision and Graphics Laboratory (CV&G Lab) at the University of Glasgow as depicted in Figure 3. This precursor robot head consisted of four motorised high-accuracy rotatory stages from Physik Instrumente[3]which are connected to a computer via proprietary ISA motor-drivers. For the CLoPeMa robot head, it is therefore proposed to use this configuration for its modularity and ease of integration with other robotic hardware.

[2]http://www.nikonusa.com/en/Nikon-Products/Product/Digital-SLR-Cameras/25478/D5100.html

[3]http://www.physikinstrumente.com/

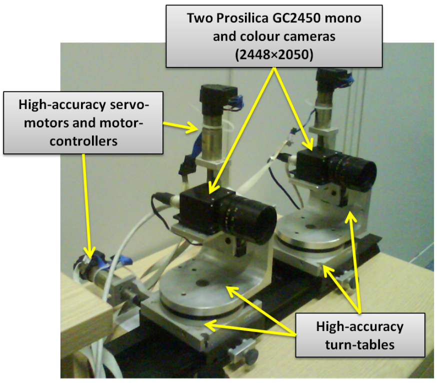


Figure 3: The CV&G robot head.

To that end, the selected pan and tilt units are the FLIR Pan and Tilt Units model number D46[4]. Figure 4 depicts this pan and tilt unit as part of the CLoPeMa head. These units are designed for high-speed, accurate positioning of camera, laser, antenna, or other payloads. Features of the most cost-effective (PTU-D46-70) and delivered units are listed below:

- Maximum payload of 4 kg
- Resolution in both axes: 0.003 degrees (11.57 arc seconds)
- Maximum velocity: 60 degrees per second
- Tilt range: +/- 47 degrees (it can be extended to +/-80 degrees)
- Pan range: +/- 159 degrees (it can be extended to +/-180 degrees)
- On-the-fly position and speed changes
- Self calibration upon reset
- RS-232 interface (ASCII and binary with simple command codes)
- Motor controller integrated
- No gear backlash

3 Robot Head Control Software - Functionality Delivered

ROS is a meta-operating system for the specific purpose of programming and controlling robotic hardware. The only Linux distribution that ROS fully supports is Ubuntu (the official Linux distribution selected for the CLoPeMa project). As detailed in Section 2,

[4]http://www.kanecomputing.co.uk/FLIR_PTU_D46.htm

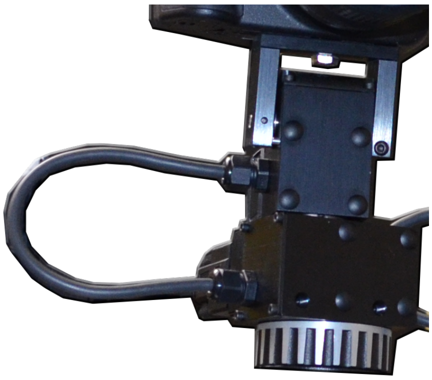


Figure 4: The pan and tilt unit model D46-70 as part of the CLoPeMa robot head.

hardware was selected in order to be compatible with this particular Linux distribution. Therefore, cameras and motor controller drivers are developed under ROS [3]. This robot head is capable of verging its cameras on a point in order to improve range image computation by disparity dynamic range minimisation and also by maximising the overlap of the field of view of the stereo-pair cameras. The software functionality delivered comprises of the ROS nodes listed below:

- Feature Extraction: SIFT features [2] in the Graphics Processor Unit (GPU) [4] for real-time operation for gaze control and binocular vergence
- Cameras drivers: A C++ ROS node was developed in order to provide the required image capturing capabilities for the CLoPeMa project.
- Pan and tilt drivers: These units were interfaced as a C++ ROS node.
- Binocular vergence: C++ ROS node in order to automatically verge the cameras towards a point in real-time. The vergence algorithm is described in [1].
- Graphic User Interface (GUI): C++ ROS node that controls the gaze of the robot head and provides a graphical front end for demonstration purposes.

Figure 5 depicts a ROS graph comprising the above software functionalities in terms of ROS nodes. This graph also depicts the information flow through the ROS architecture. Table 1 details and provides a brief description of ROS nodes developed by the University of Glasgow.

It must be noted that current software technology that provides a software interface for the Nikon D5100 is gphoto2. Gphoto2 is an open-source command line utility (released under the terms of the GNU LGPL) which allows a camera connected via a USB cable to be controlled. This utility can download photos, configure and trigger cameras. Similarly, the manufacturer of the pan and tilt units provided a development toolkit in C++ to communicate and control these units. This toolkit was therefore adapted to interface with ROS in order to offer the functionality required by the system. The operation of the robot head is detailed in Appendix A.

Table 1: ROS nodes delivered.

Package Name	Node Name	Description
RH_cameras	RHcam_left	Interface to the left camera using Gphoto2. This ROS node can provide full and low resolution images as supported by the camera.
	RHcam_right	Interface to the right camera using Gphoto2. This ROS node can provide full and low resolution images as supported by the camera.
	RHcam_headerCameras	Helper node that intercepts an acquisition message in order to set the machine time for synchronisation within the CLoPeMa robot head ROS architecture.
RH_ptu	RH_ptu_node	Interface with the pan and tilt units. This node employs the "tf" ROS package in order to keep track of the coordinate frames of the pan and tilt units.
RH_siftgpu	RH_siftgpu_node	ROS node that computes SIFT features using the Graphics Processing Unit
RH_vergence	RH_vergence_node	This node contains all functions to compute the required disparity to verge the cameras on.
	RH_vergence_main	Main vergence function that receives the computed disparity and computes the required actuator steps in order to verge the cameras on.
RH_mainUI	RH_mainUI	Graphic User Interface that orchestrates all the robot head nodes and provides functions to control manually the gaze of the robot.

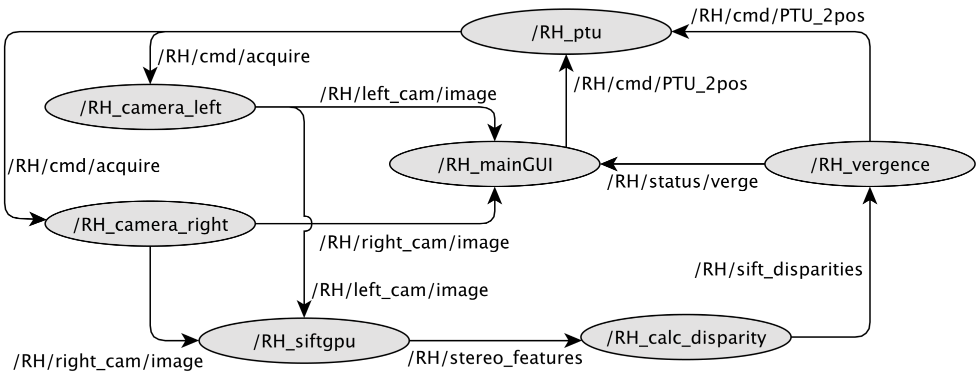


Figure 5: ROS graph architecture of the CLoPeMa robot head.

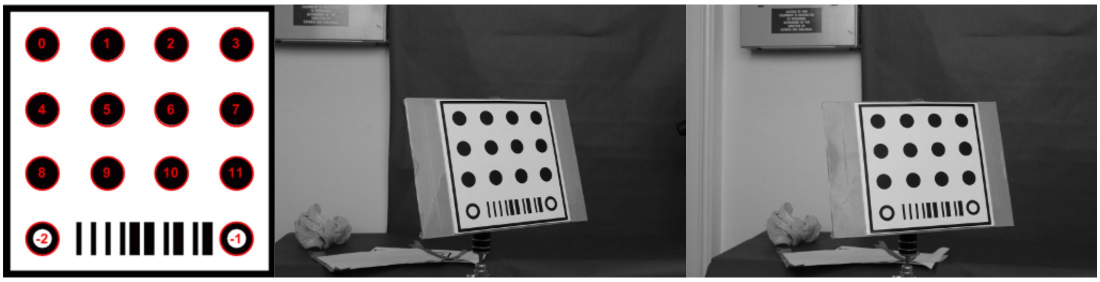


Figure 6: From left to right: C3D calibration target with circle enumeration, samples of left camera and right camera calibration images.

4 Range Imaging & Calibration Software - functionality delivered

The robot head has been equipped with software support for stereo-pair image matching and stereo-camera calibration based on the integration of the University of Glasgow's proprietary stereo photogrammetry package, C3D, in two ROS nodes of the system. The C3D matcher finds stereo-correspondences between the left and right camera images, which are outputted as horizontal and vertical disparity maps, and then used to create a range image aligned with the left camera imaging plane. Disparity maps and range images can be used to calculate the world coordinates for each point in the scene. Due to the real-time requirements of the robot system, C3D has been configured to match the images at quarter resolution, reducing the processing time from approximately 20 minutes for 16 Megapixel resolution stereo-pair images to just under one minute for 4 Megapixel resolution images.

To enable C3D to produce accurate range images, C3D requires calibration parameters for both cameras of the robot head. In order to recover these calibration parameters C3D requires a set of left and right camera images of C3D's calibration target, shown in 6. The calibration will produce two calibration files, one for each camera, *lefcal.tcl* and *rigcal.tcl*. These files contain the extrinsic and intrinsic parameters for each camera in form of rotation and translation parameters, principal point, focal length, and pixel size in meters in the x and y direction. When range images require to be produced, these calibration files are automatically loaded into C3D.

5 Schedule of delivered items

Table 2 summarises the delivered items. In that respect, the robot head, for this deliverable, is able to extract SIFT features in either full and foveated resolutions in order to verge the cameras on a point (Figure 7) and, in consequence, to compute 2.5D range maps from the verged stereo configuration (Figure 8). As the robot head is able to change observation points of both cameras, it is required to maintain calibration for range extraction regardless the direction of the cameras. This extra feature is difficult to complete until the robot head is integrated with the dual-arm robot and the CLoPeMa robot is in operation. An estimated date of completion of this feature is indicated in Table 2.

Table 2: Delivered Items

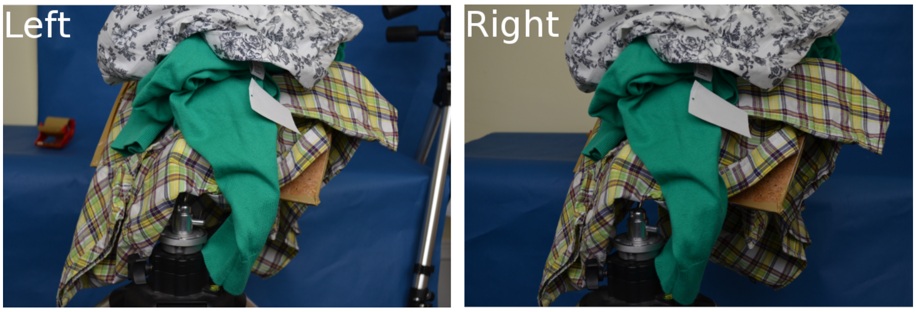
Name	Date	Description
Robot head hardware	29, October 2012	The components of the CLoPeMa robot head were provided to the partners. These components consisted of two pan and tilt units, two pan and tilt controllers, two Nikon D5100 cameras and cabling, manuals and accessories
Robot head software control in ROS	31, October 2012	A description of ROS nodes has been provided in Table 1
Robot head camera calibration and range extraction	27, November 2012	ROS nodes that are part of the photogrammetry module as described in Section 4.
Dynamic calibration of the robot head (ongoing investigation)	24, January, 2013	Integration within the Robot Head ROS architecture. These extra functions will be integrated and will not require further integration within the dual-arm robot and overall software architecture.

A Robot Head Hardware Survey

A.1 Cameras Survey

The selection of the cameras for CLoPeMa was based on the ability to deliver high-quality images for 2.5D range image capturing and they must be supported in Ubuntu. Low-cost and off the shelf cameras can be categorised in three main: *webcams*, *compact system cameras* and *digital DSLR cameras*. Table 3 details its features, advantages and disadvantages of each category.

In order to capture high resolution images while maintaining a low noise from the sensor of the acquired data, it was therefore determined that a DSLR camera was the most suitable camera for producing high quality 2.5 range images. The selected camera, as described in Section 2.1, is the Nikon D5100 since this model provides the required functionality for high quality imaginary while the price is still within the budget of the CLoPeMa project. Ongoing investigation o n the selection of more suitable cameras for



(a)

(b)

Figure 7: (a) Image pair captured from the robot head. (b) Anaglyph of the left and right camera images verging on a point in a pile of clothes. An anaglyph is a composed colour image where the left camera is mapped to the red channel and the right camera to the green and blue channels.

Figure 8: Example of a range map.

Table 3: Camera categories considered.

High-end Webcams (e.g. Logitech HD C910) [Prices range from 100 to 125]		
Features	**Advantages**	**Disadvantages**
- Maximum resolution of 2592x1944 pixels (5 megapixels) for still capturing - HD video (1280 x 720 pixels) - Carl Zeiss Optics - High-Speed USB 2.0 - Stereo microphones - YUY2 (YUV 4:2:2) and MJPG compression options - Programmatic control of motorised focus (12 discrete focus steps), exposure, brightness and ROI.	- These cameras can be easily interfaced with ROS through the Universal Video Class (UVC) driver in Linux. UVC_STEREO[5] package in ROS can potentially provide synchronised stereo capture capabilities. - Image capturing at full resolution is at 10 fps using YUV 4:2:2 image format	- Salt and pepper noise is present in captured images due to the low-cost design of the image sensor (i.e. analogue-to-digital converter errors) - This noise therefore decreases the quality disparity maps, range maps and 2.5D models of clothes.

Compact System Cameras [Prices range from 250 to 625]		
Features	**Advantages**	**Disadvantages**
- CMOS sensors from 10 to 24 megapixels - High-Definition Video - Built-in wide angle-zoom lenses - Optical/Electronic driven lens stabilisation - Automatic and semi-manual control of focus, aperture, ISO and shutter priority - From 1.2 to 60 fps of continue shooting	- Compact system cameras are low-cost - Lightweight - Standard mounting interface - Stereo synchronisation based on software (e.g. threaded execution in ROS)	- Partially supported in gphoto2 (i.e. their functions that can be programmed are limited[6]) - Quality of the integrated lens depends on the manufacturer. In the market, there exists cameras with interchangeable lenses but they are not supported in gphoto2 - Limited manual operation; e.g. focus is usually automatically controlled which results in a highly inaccurate system capable of maintaining dynamic calibration for 2.5D range capturing.

Table 4: Continuation of Table3

DSLR cameras [Prices range from 435 to 750]		
Features	**Advantages**	**Disadvantages**
- CMOS image sensor from 10 to 32 megapixels - Real-time low resolution preview (some cameras) - 18-105mm Vibration Reduction Lens - Manual/Automatic ISO speeds range from 80 to 35000 - USB interface for downloading captured images and controlling from a computer (using gphoto2) - From 4 to 10 fps continuous shooting - ˜800 grams of weight (with lens)	- Low signal-to-noise ratio - Ability to capture RAW image data as acquired by the sensor - High-quality image capturing - Simple to interface - PC controlled tethered shooting using gphoto2 under Ubuntu - Interchangeable lenses for different scene settings during the course of the CLoPeMa project - Automatic and manual operating modes - A wide range of flash units can be adapted for different lighting conditions	- Relatively more expensive than compact system cameras and webcams - These cameras require external power supply for long periods of use - These are heavier than machine vision cameras or webcams - Relatively slow image capture and download due to the image resolution

Figure 9: The PT785-S pan and tilt unit.

the project is currently undertaken; for example, *android based compact cameras.* The sensing capabilities of these android cameras are integrated within the operating system which provides a rich set of controlling/feedback commands through the API. These configuration can potentially facilitate dynamic calibration and focus control.

A.2 Actuation Control Survey

As mentioned in Section 2.2, the structure of the CLoPeMa robot head followed a previous developed system in the CV&G Lab at University of Glasgow. The following subsections describe different configurations available in the market.

A.2.1 Aluminium PT785-S Pan / Tilt System

The PT785-S[7] head system (Figure 9) consists of two R/C (Radio Control) servo motors mechanically linked with a gearbox in order to support a maximum load of ˜2.7 kg. The frame is made of durable aluminium which only weights ˜800 grams. Its features are listed below:

- Plug-and-Play with any low cost motor controller
- Closed-loop feedback system and high precision (specified by the motor controller)
- 400 degrees of rotation on each axis
- Adjustable frame, aluminium hollow shafts

A low cost motor controller for this system that has support in ROS and Ubuntu is: *Phidgets Advanced Servo 8-Motor (Model: 1061)*[8]. Its features are listed below:

- Controls up to 8 servos
- USB Interface

[7]http://www.robotshop.com/eu/productinfo.aspx?pc=RB-Sct-174&lang=en-US
[8]http://www.robotshop.com/eu/phidgets-8-servo-controller.html

Table 5: PT785-S plus phidget motor controller

	Model	Price Unit
Pan / Tilt head	PT785-S	328.43
Servo motor controller	1061	80.32
Power Supply 12V2.0A	Generic	8.92

- C++, VB, Java and others, plus Ubuntu and ROS support[9]
- Resolution of 125 steps/deg (˜0.008 degrees = 28.8 arcsec), 15 bit word size
- Velocity Limit: 640 degrees per second

A complete robot head system for the CLoPeMa project would consist of:

Total cost of building one robotic head (comprising 2 PT785-S, one motor controller and power supply and cameras not included): **746.10** inc. VAT plus **53.68** shipment (estimated). Total cost of building 3 robot heads for each partner (cameras not included): **2337.86** incl. VAT plus 138.98 shipment (estimated).

Identified drawbacks:

- Gears backlash
- Highly unstable structure for the CLoPeMa dual-arm robot due to the deceleration of the robot during emergency stops; i.e. the structure might fail during operation as components are not specifically designed to withstand high torsion/bending forces.
- Motors are made of low-quality materials as they are for R/C applications.

A.2.2 Physik Instrumente (PI)

PI rotary stages are designed to be high-resolution. While selecting the components of the CLoPeMa robot head, it was considered the use of these rotary stages as the CV&G robot head consists of these rotary stages. These rotary stages offer an off-the-shelf solution for integrating and developing the robot head. PI UK provided two possible solutions for the project:

Total cost of building one robot head with Solution A (comprising 4 rotary stages and four drivers, cameras not included): **13,674.29** (incl. VAT) (shipment not included) Identified drawbacks of Solution A:

- Motor driver cannot be daisy chained; therefore, 4 RS-232 are required for PC connection
- Expensive

Total cost of building one robotic head with Solution B (comprising 4 rotary stages and one driver): **18,374.36** (incl. VAT) (shipment not included)

Identified drawbacks of Solution B:

- Expensive

[9] http://ros.org/wiki/phidgets

Table 6: Solution A

	Model	Price Unit	Description
Motorised rotary stage	M-660.551	2,920.29	Max velocity: 720 degrees/sec, max. load: 2 kg, unlimited travel, accurate positioning, incremental encoder (4 rad resolution), lightweight, no lubricants and non-magnetic.
Motor driver (1 axis)	C-867.OE2	495.65	Linux support, Dynamic PID controller, RS-232 interface, stand-alone operation, external power supply.

Table 7: Solution B

	Model	Price Unit	Description
Motorised rotary stage	M-061.PD1	4,573.29	Max velocity: 90 degrees/sec, unlimited travel, ultra high positioning, zero backlash, rotary encoder: 2048 counts/rev, DC-motor with gear head (ratio of 29.6:1).
Motor driver (4 axes)	C-843.412	3,715.23 / 4 = 928.80 each axis	Velocity and acceleration profiles, dynamic PID controller, dedicated PCI communication for all axes, UNIX support, and synchronised movements between the four channels.

Table 8: FLIR Pan and tilt unit

	Model	**Price Unit**
Pan / Tilt Unit	PTU-D46-70	2,342.15
AC/DC Power supply	Custom accessory	102.43

A.2.3 FLIR MCS Pan and Tilt Units

Features of these units were described in Section 2.2. Thus, a complete robot head system for the CLoPeMa project would consist of:

Total cost of building one robotic head (comprising 2 PTU-D46-70 and power supplies): **5,866.99** incl. VAT (shipment not included). Total cost of building 3 robot heads: **17,597.05** incl. VAT (shipment not included). A C Language Programmer's Interface is required (for fast binary communication); therefore, it has to be included in order to control these units. This Interface costs 170+VAT and it has to be added to the above prices. As pointed out in Section 2.2, the PTU-D46-70 is selected since the price/features trade-off is greatly reduce. That is, these units provide the precision required to move the cameras towards objects with high accuracy while preserving the repeatability of the system in overall.

B Control Software Operation

The control of the robot head consists of 3 windows displaying the left and right camera images and an anaglyph depicting the stereo registration between both cameras while the system verges on a point. Figure 10 shows a working session with the robot head under Ubuntu. In order to operate the system, it is needed to start the ROS manager (e.g. *roscore*, issued in a terminal window) and the following nodes (in this order and as typed on a terminal window):

1. *RH_mainUI*
2. *RHcam_left*
3. *RHcam_right*
4. *RHcam_headerCameras*
5. *RH_siftgpu_node*
6. *RH_vergence_node*
7. *RH_ptu_node*

It must be noted that it is required to verify that each node has been successfully initialised. After the pan and tilt units are set in home position, the "*RH_vergence_main*" node has to be invoked. This node depends on some parameters that are set by "*RH_ptu_node*"; otherwise, this node will send an error.

Interaction with the robot head is controlled by means of the "Left camera" window. Three operational modes can be established set as listed below:

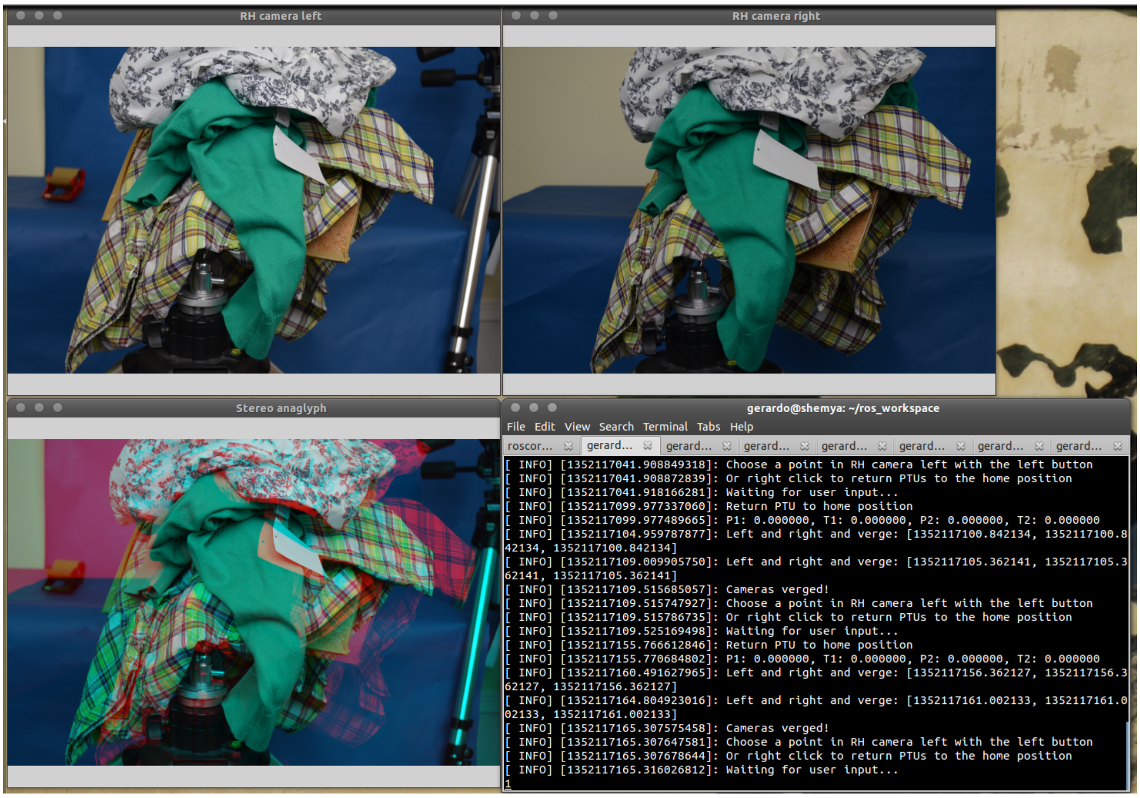


Figure 10: Working session of the software of the CLoPeMa robot head.

- Left mouse click on a point in the “Left camera” window: The gaze of the robot head can be therefore controlled by selecting a point on the window (i.e. clicking on a point in the window). The robot will then capture images, extract SIFT features, compute the disparity between SIFT features between cameras and calculate the required actuator steps to bring the cameras into convergence. This sequence continues until the disparity between is minimised and the system is ready to receive another command specified by the user.

- Right mouse click in the “Left camera” window: This will command the pan and tilt units to return to home and the system will automatically verge on the cameras following the above procedure.

- Middle mouse click in the “Left camera” window: This mode sets the capture mode of the cameras; e.g. full or low resolution images. Thereafter, the user can select one of the above operational modes.

The operation of the system can be stopped by issuing “Control+C” on every terminal window running a ROS node. A more detailed description on the installation and operation of the robot head can be found at: `http://clopema.felk.cvut.cz/redmine/projects/clopema/wiki/Clopema_robothead`

C Range Imaging & Calibration Operation

C3D has been integrated into ROS as a single package *RH_C3D* that contains two main nodes *RH_stereomatcher* and *RH_calibration,* that undertake range imaging and calibration respectively. These two nodes must be run on the same computer. The *RH_stereomatcher* node uses the stereo-pair images released by the *RHcam_left* and *RH_right* nodes. A stereo-pair of green channel images is extracted from each RGB stereo-pair input from the binocular sensor head, and the green channel data is passed as input data to the C3D matcher. C3D outputs horizontal and vertical disparity maps and a range image for each stereo-pair input, and these outputs are then released by the *RH_stereomatcher* node to the ROS system to be used in other nodes.

The calibration files needed in the C3D range imaging process are created by the *RH_calibration* node. The *RH_calibration* node will save locally 20 calibration image pairs from *RHcam_left* and *RHcam_right* nodes in TIFF format and then invoke C3D. The user has then to open a new session in C3D to process the directory containing the calibration images. Once the session has finished loading the calibration images, the user has to access the C3D settings from the Tools menu and set values for two parameters in the calibration tab, "Force Target" to "true" and select "planeDomino2 53" from the bar code drop down menu, before starting the calibration process from the "Tool" menu. After the calibration process finishes, the calibration images should be visualised in C3D to verify if all the circles of the calibration targets have been correctly detected and identified in the left and right pair. If in a single stereo-pair of calibration images the circle finder detects and labels less than 13 of the 14 circles in either image of the input pair (see 6 for circle enumeration, from -2 to 11), then this pair should be excluded from the calibration process. In case images have to be excluded, close C3D and via the command terminal the option to exclude specified image pairs will then be offered to the user. After having excluded faulty image pairs, C3D will restart, which will then require the user to reload the session. For the final calibration, in the C3D settings calibration tab, set "Force Target"to "false" and start the calibration from the "Tool" menu. When the calibration process has been concluded C3D has to be closed and, via the command terminal, it must be confirmed that the calibration has finished. The node will then copy the calibration files over to *RH_stereomatcher*.

References

[1] Gerardo Aragon-Camarasa, Haitham Fattah, and J Paul Siebert. Towards a unified visual framework in a binocular active robot vision system. *Robotics and Autonomous Systems*, 58(3):276–286, March 2010.

[2] D G Lowe. Distinctive image features from scale-invariant keypoints. *International Journal of Computer Vision*, 60(2):91–110, 2004.

[3] Morgan Quigley, Ken Conley, Brian P Gerkey, Josh Faust, Tully Foote, Jeremy Leibs, Rob Wheeler, and Andrew Y Ng. ROS: an open-source Robot Operating System. In *ICRA Workshop on Open Source Software*, 2009.

[4] Changchang Wu. SiftGPU: A GPU implementation of scale invariant feature transform (SIFT). http://cs.unc.edu/ ccwu/siftgpu, 2007.