Publishable Summary - Update

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Project acronym:	**TACO**
Project title:	**T**hree-dimensional **A**daptive **C**amera with **O**bject Detection and Foveation
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2 Publishable Summary

	Project Name: **TACO**	*Start Date*: February 1, 2010
	Grant Agreement: **248623**	*Duration:* 36 months
	Project Website:	http://www.taco-project.eu
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Mission of TACO

"To enhance the abilities of service robots by improving the sensing system with real 3D foveation properties. To develop a 3 dimensional sensing system with real 3D foveation properties to increase the ability for the service robot interaction with their natural environment. To develop a three dimensional sensing system with real 3D foveation properties to allow robots to interact with everyday environment in a more natural and human-like manner."

TACO develops a 3D sensing system with 3D foveation properties, endowing service robots with a higher level of motion and affordance perception and interaction capabilities with respect to everyday objects and environments.

The 3D foveation properties are achieved by utilising the power of micro-mirror MEMS technology combined with state-of-the-art time-of-flight methods to ensure a system that is easily mounted on an ordinary-sized service robot or even a robot arm.

The project explores control strategies for 3D foveation allowing 3D robot vision that is adaptable with space- and time-variant sampling, processing and understanding. Furthermore, the project will verify and test the 3D sensing system in a robotic environment, exploring the capabilities of the system to allow the robot to navigate autonomously and interact with a diverse number of everyday objects.

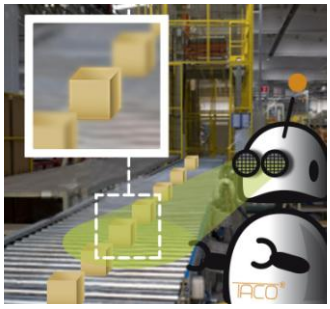

Figure 1: Illustration of the TACO concept

Motivation

The area of robotics is an innovative and growing industry. Currently service robots are adopted to execute works which are dull, dangerous, dirty or dumb. Within the further development of service robots, their functionalities are extended and therefore they can fulfil more sophisticated tasks (e.g. in the fields of cleaning, construction, maintenance, security, health care, entertainment and personal assistance). A novel 3D sensing system will be produced by the TACO project which includes the following three points:

- A novel concept for fast attention level management based on the 3D foveation principle enabled by dedicated sensor hardware.
- A 3D laser scanner sensor based on a miniaturised micro-mirror device combined with time-of-flight measurement technology.
- A software framework for fast object recognition in everyday scenes based on saliency and visual cues, allowing efficient selection of details of interest and control of the foveation process.

The goal of TACO will be a flexible, compact, robust 3D image acquisition device providing high resolution, high quality data for robot real-time operations.

Objectives & Overall Strategy

The main objective of the TACO project is the development of a 3D sensing system with real 3D foveation properties endowing service robots with a higher level of motion and affordance perception and interaction capabilities with respect to everyday objects and environments.

Advantages of the developed project compared to the state-of-the-art systems will be its capability to provide automatic detection based on regions-of-interest and to provide up to 10 times better spatial and/or temporal resolution within these regions of interest.

The specific scientific and technological (S&T) objectives of the TACO project are:

- development of a flexible, compact, robust 3D imaging device;
- achievement of 3D measurements of increased spatial and temporal resolution in detected regions of interest;
- benchmarking of the 3D sensing system on robots in an everyday environment test bed, with interaction with everyday objects.

TACO has the following market and outreach (M&O) objectives:

- provision of a new technology to the European robotics industry
- making TACO knowledge visible within industry and the scientific community
- carry out proof-of-concept validation of the concept

The achievement of the TACO scientific and technical objectives will be measured against an initial set of verifiable indicators, which are constantly being refined and updated in the course of the project in order to reflect the detailed needs and environment of the project.

The above objectives are to be achieved within the three main project phases as displayed in Figure 2 below.

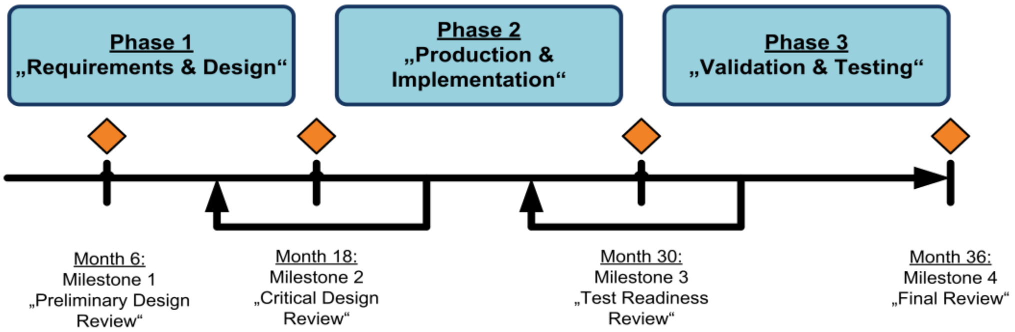

Figure 2: TACO Project phases

Project work is organized to allow for two iterations of system building. At the end of phase 1, the project will have delivered a first version of all technical deliveries. This will allow for system review by both the consortium and the IAB, providing input for adjusting system design for the phase 2.

Technical Approach

The development of the project will be organised in seven work packages:

WP1: *Requirements, Specification and Roadmap.* achieves a common specification of the camera and details the project roadmap for the following work packages.

WP2: *Advanced 3D perception concept:* Performance evaluation and concept studies of critical technologies and design decisions of the necessary camera components.

WP3: *3D sensing device:* builds and assembles the actual camera hardware.

WP4: *Toolbox for adaptive control:* real-time foveation software package for the camera

WP5: *System verification and Testing:* benchmarks and tests the developed sensor.

WP6: *Dissemination, Exploitation and Standardisation*

WP7: *Project management*

Description of the work performed and results in the first project period

TACO has set the scope for building three possible distinct success stories: Competitive adaptive 3D acquisition hardware, innovative 3D attention for real-time sensor control, and a novel foveating 3D sensor combining the two.

The work has been based on simultaneously performing use case investigation, competitive analysis and sketching different system architectures. Together, this work concluded into a sensor architecture (and system architecture allowing the consortium to proceed independently.

The main requirements conclusions were that in order to be competitive with other 3D sensors, the TACO system needed to be capable of providing both high spatial resolution and frame rate (albeit not simultaneously), and that the foveation software should enable the user to control the real-time adjustment of resolution in an intuitive manner. Furthermore, it appeared that sensor speed and field-of-view would be of prime competitive importance; that foveation and imaging would be based on adaptive-resolution raster scans; and that the range data provided by the sensor itself would be the prime source for region-of-interest detection.

Based on these conclusions, the consortium has developed a sensor breadboard prototype and initial MEMS mirrors. This enabled further specification, experimentation on and design of central components,. An important discovery was made in that the designed mirror would not robustly allow for array operation, meaning that alternative designs had to be investigated. Furthermore, early integration work resulted in an awareness of the importance of system latency.

The specification process was continued to specify the actual vision algorithms to be used for detecting regions-of-interest. The main conclusions were that 3D data should be the primary source of scene information, and that a mixture of top-down and bottom-up methods would give the best performance. On an implementation level, most work has been focused on building the real-time system which accepts and processes data from the sensor, together with selected region-of-interest detection operators. Early integration testing has been performed to verify realtime system performance.

Throughout the project, end-users – SHADOW and OTL– have consistently provided input for the RTD partners (IPMS, IPM, SINTEF, TUW) towards requirements and expectations.

Main achievements in the research field

TACO contributes primarily to three research fields: Foveating sensors, micro-mirror technology and 3D attention mechanisms. The main achievements in year one are mostly on a conceptual and specification level. Year two of TACO will see these concepts be implemented and demonstrated.

Within foveating sensors, TACO's primary contribution has been to present a detailed, overall concept and plan for implementing a foveating micro-mirror based 3D laser scanner suitable for mounting on vision-capable robots. The combined and interlinked specification of both hardware and software components means that better choices can be made both on an overall level, and a detailed level.

In particular, this relates to a precise definition of how a foveating 3D laser scanner should operate to be of best use for robotics. In our view, the TACO sensor is primarily a significantly improved 3D range camera, not a complete robotic vision system. This basic consideration has several implications:

- The sensor should not solve the complete vision problems (i.e. complete object recognition), but instead only solve enough of the vision problem that 3D data acquisition can be controlled in a sufficiently precise manner. The main vision loop will be running on the robot, and the sensor should support this as well as possible.
- The sensor must degrade gracefully in cases where foveation cannot bring any advantages – when the whole scene could be considered interesting. In our case, the sensor will start operating similarly to a normal range camera in such cases.
- The primary advantage of a micro-mirror based 3D laser scanner towards existing sensors will be data quality, field-of-view and speed. The hardware specification needs to reflect this through the design of MOEMS mirrors and TOF technology; and that foveation is performed internally in the unit and not through external oculomotoric control.

For micro-mirror technology, the main achievements relate to three separate designs of MOEMS mirrors that will push the state-of-the-art of micro-mirror technology. The performance of these mirrors – in term of aperture, deflection angle and speed - will push MOEMS state-of-the-art.

For 3D attention mechanisms, the primary contributions relate to the selection of algorithms that bring value to end users, and that can be easily configurable to new tasks. The selection criteria – generic, fast, robust – combined with the focus on primarily using range data as the information source has provided a novel overview of reasonable and useful foveation strategies.

Comparative assessment with state-of-the-art

Three fields are relevant for comparison: 3D imaging hardware, attention and foveating sensors.

The 3D sensor hardware market is now a rapidly expanding market. The introduction of the Microsoft Kinect system has now brought 3D imaging into millions of homes. Time-of-flight cameras are also becoming cheaper and smaller. However, there is still no sensor hardware that can rapidly provide the detailed and accurate 3D information that TACO will be able to provide. By using 3D laser scanning, TACO can provide significantly better and more complete spatial resolution than other sensors. Foveation makes the same hardware deliver relevant data significantly faster than otherwise possible.

Within attention, there is still little work done on using range data as the primary source of attention information. Most existing approaches base themselves on high-resolution color cameras, possibly augmented with 3D laser scanner information. The use of 3D data as the primary source of for attention calculation opens up for a much more natural way of specifying how the sensor determines regions-of-interest. TACO also contributes to this research field by focusing on using low-resolution image to predict where high-resolution data is required (instead of opposite way around), and by having as its primary goal not to replicate the human eye, but provide added value to use cases.

Compared to the field of foveating sensors, TACO is one of the first systems to both provide 3D data and to not rely on additional sensors to determine regions-of-interest. TACO will provide robotics with a better and more natural way of acquiring high-resolution 3D data for unpredictable scenarios.

The TACO Consortium

The objectives of the TACO project will be achieved through collaboration within a very strong consortium based on a team with outstanding scientific, engineering and manufacturing qualifications: Technikon Forschungsgesellschaft mbH (AT), The Shadow Robot Company Limited (UK), Oxford Technologies LTD (UK), Technische Universität Wien (AT), Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung E.V. (DE), Stiftelsen SINTEF (NO), CTR Carinthian Tech Research AG (AT). Together, they represent a vertically integrated consortium, with excellence from MEMS hardware components, time-of-flight sensors, 3D image analysis software to robotic industry applications.

Figure 3: The TACO Consortium

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