Publishable Summary

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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**
Grant Agreement: **248623**

Start Date: February 1, 2010
Duration: 42 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.

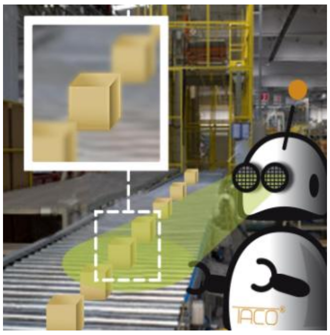

Figure 1: Illustration of the TACO concept

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:

- provide 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. Based on testing and evaluation necessities, the TACO Project Consortium requested to extend the overall duration of the TACO project by 6 months to 42 months in total.

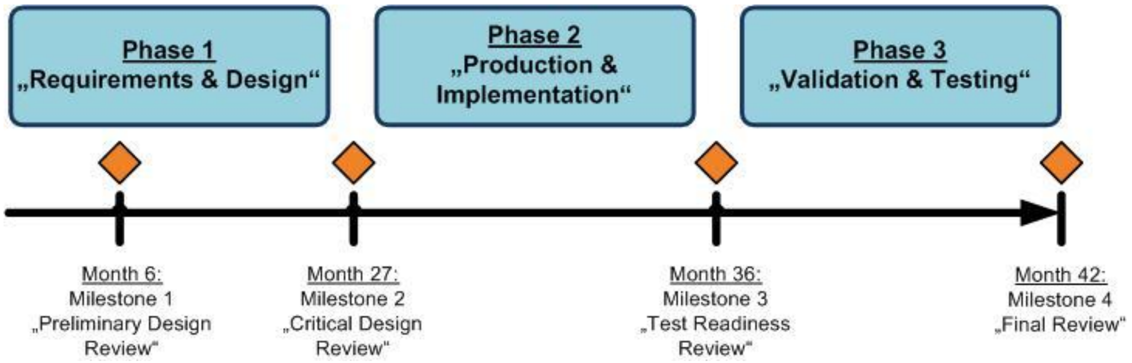

Figure 2: TACO Project phases

Technical Approach

The development of the project is organised in seven work packages, 6 RTD and one Project management work packages listed hereafter:

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 done and the results until now

The TACO project started in February 2010 and is going to run for 42 months. During the first project phase the focus was on simultaneously performing use case investigation, competitive analysis and sketching different system architectures. This work concluded into a sensor architecture and system architecture allowing the consortium to proceed independently. Within the 2nd period main focus was laid in building the actual software and hardware as designed in the first project period, and towards the end, critically reviewing the design. The work performed in the different work packages within the first and second project year can briefly be summarized as follows:

In **WP1 – Requirements, Specification and Roadmap** target specifications and requirements for the entire project have been defined. The different components developed within TACO have been identified and also the proof-of-concept prototype produced within the other work packages has been analysed. A first version of the system specification was submitted in time. Refinements especially with respect to the use case descriptions and specifications have been done. Furthermore, benchmarks for the software part of the system have been defined in the first project phase. Within the second project period refinements especially with respect to the use case descriptions and specifications have been done. The comparative analyses were updated with new sensors on the market and benchmark planning was updated according to the refinements in the use cases.

WP2 – Advanced 3D perception concept provided information on possible sensor capabilities to WP1 and WP1 detailed system requirements for the selected use cases back to WP2 in the first period of the project. In this context, competitive analysis from WP1 and information from hardware RTD partners has been used to set target specifications for the system hardware, provide concise information on system concepts and expect system performance to the consortium. Feasible methods for perception computation and sensor control have been identified and the suitability of the overall system software concept for real-time performance has been validated. In the second period of the project WP02 provided D2.2 "Design study final revision", which gave an update and revision to D2.1 "Design study first revision" deliverable filling in implementation details, in particular for the optical unit and safety aspects for the hardware. With respect to foveation software, interface changes between hardware and foveation software have been included in D2.2. Changes on the architectural level have been addressed in WP04. The objectives of the WP02 have been reached and, apart from possible continued updates to interfaces and specifications, work in WP02 has terminated.

Within the first period of the project **WP3 – 3D sensing device** has realized the prototypes for reception electronics and laser pulse generator, the breadboard demonstrator, and the driver including position feedback for the breadboard demonstrator. In contrast to DoW the preferred MEMS concept for TACO is based on a gimbals 2D micro-mirror scanner design with quasi-static actuated frame and resonant inner mirror, because it enables a better compromise and improved sensors properties regarding the use cases and requirements defined in WP1. During the 2nd period *(i) design, (ii) fabrication and (iii) test* of all individual hardware components (MEMS scanner, TOF electronics, optical scan head, drive electronics etc.) were finalized. The system integration of hardware components was started as well to realize the first TACO sensor system. Unfortunately, during final system integration, the most critical mirror in the device failed (identical but less-critical mirrors kept working). This meant that D3.3 (the first integrated prototype) had to be submitted as an intermediate version for the review. However, the final version of D3.3 is expected to be ready for the review meeting.

WP4 – Toolbox for adaptive control implemented some foveation features and evaluated many more for implementation on the TACO platform in the first project period. Furthermore a running Matlab prototyping and development environment that works in real-time was implemented. 14 simulated data sequences have been recorded consisting of a total of 2136 frames of 3D data points. Detailed UML diagrams highlighting feature requirements of the TACO sensor have been provided by the use case owners of WP1. The work during the second period has consisted of two major activities:

1. Scene analysis for performing foveation has been developed, implemented and tested on simulated data.
2. TACO sensor's control loop is developed, implemented and tested on a sensor hardware simulator, and is performing real-time sensor control and foveation based on scene analysis.

The primary focus of the second project period has been developing features for doing scene analysis with the purpose of making the TACO sensor foveate on the areas interesting to the user. Both top-down and bottom-up foveation strategies have been explored, guided by use cases. Due to delay in the sensor hardware, WP4 has only been able to work towards a sensor simulator and on simulated data captured with a commercially available laser range time-of-flight scanner. The foveation software is however ready for integration with the TACO hardware as soon as it is ready.

Although **WP5 – System Verification and Testing** has not officially started yet, however supporting work already conducted within WP1 and WP4. Therefore ideas of the required environments that will be constructed within WP5 to test the TACO system for the developed use cases were developed. Furthermore, tests on some subcomponents of the TACO sensor have been already performed. During the 2nd period a use case experiments template which was designed to help partners to define in detail each experiment that will be performed within the use-case and a requested project extension were created. OTL has further been working on how to obtain realistic surface property data of a post fusion campaign vacuum vessel. Overall four mock-up vessel tiles representative of a post-fusion campaign vacuum vessel have been produced.

WP6 – Dissemination, Standardisation and Exploitation disseminated the project achievements and results. Monitoring of the project website, creation of the internal communication infrastructure and supporting of individual partner activities was also part of this work package.

WP7 – Project Management was responsible for the effective organisation of the project and covered the relevant management components.

The impact and use of results:

TACO will have an impact on hardware level, software level and system level:

- The **hardware** will be capable of robustly providing 3D data of high resolution, frame rate and quality. Particularly outdoors and in other challenging environments, no other sensors are capable of providing data of the same quality and speed. For robotics, this will open up for new applications and allow robots to be used in everyday situations, both indoor and outdoor.
- The **foveation software** further increases the acquisition speed and can provide an initial scene understanding for use by the robot. In addition, it provides an open framework for new methods of foveation. Particularly for robots performing object interaction, this will enable better resolution, recognition and precision.
- On **system level** we have developed a 3D sensor system that provides 3D data with higher quality, robustness and speed than any other comparable sensor. This is due to the joint effort of both the software and hardware, which aid each other in improving both quality and speed. This will have a clear impact by enabling robots to robustly and rapidly see well in 3D, enabling new possibilities particularly within object interaction.

We have identified paths forward in scaling the technology towards mass-market opportunities, which can allow a future broad impact of the developed TACO technology. This can allow for future broad adaption of MEMS based foveating 3D laser scanners.

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

TACO Disclaimer

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