Publishable Summary

Grant Agreement number:	248623
Project acronym:	**TACO**
Project title:	**T**hree-dimensional **A**daptive **C**amera with **O**bject Detection and Foveation
Start date of the project:	01.02.2010
Funding scheme:	FP7 ICT STREP

Date of the reference Annex I:	24.08.2011
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1 Publishable summary

1.1 Project context and objectives

Project Name: **TACO**	*Start Date*: February 1, 2010
Grant Agreement: **248623**	*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."

TACO developed a **3D sensing system** with **3D foveation properties**, endowing service robots with a **higher level of real time affordance perception** and **interaction capabilities** with respect to everyday objects and environments. The 3D foveation properties were 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 explored control strategies for 3D foveation allowing 3D robot vision that is adaptable with space- and time-variant sampling, processing and understanding. Furthermore the project verified and tested 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.

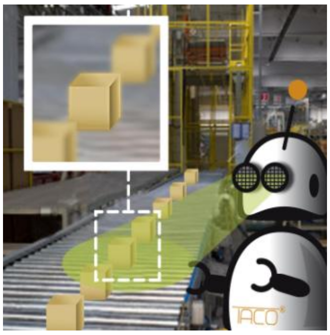

Figure 1: Illustration of the TACO concept

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). Therefore also TACO focused to produce a 3D sensing system, which includes the following three points:

- A novel concept for fast attention level management based on the 3D foveation principle
- 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

Objectives & Overall Strategy

The main objective of the TACO project was 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 TACO project pursued the following **scientific and technological (S&T) objectives**:

- 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 had the following **market and outreach (M&O) objectives**: to provide new technology to the European robotics industry, making TACO knowledge visible within industry and the scientific community and to carry out proof-of-concept validation of the concept.

1.2 Description of the work performed and main results achieved

The TACO project started in February 2010 and ran for 42 months, ending in July 2013. The project has met all of its objectives and technical goals. All deliverables have been achieved and all milestones have been reached.

We have shown that foveation is more than a promising technology, drove the current state of the art beyond former limit, created world class knowledge and implemented our concept in working prototypes. Technical constraints have been overcome. For the first time ever a combination of rapid, controllable micro-mirrors, fast laser distance measurements, foveation software package and scene analysis have been integrated. The complex prototypes suffered naturally from limited maturity of engineering samples but showed, even with restrained parameter space, successfully the potential of TACO technology worldwide.

The development of the project was organised in seven work packages, 6 RTD (WP01-WP06) and one project management (WP07) work package, which will be described in more detail in the following chapters. The progress achieved by all work packages within the 42 months project duration is in line with the initial plan and can be summarized as follows:

In **WP1 – Requirements, Specification and Roadmap** targeted specifications and requirements for the entire project. The different components developed within TACO have been identified and also the proof-of-concept prototype produced within the other work packages was analysed, resulting in deliverable D1.1. This was refined into D1.2 by incorporating information about how the rest of the project evolved, especially with regards to use case specifications.

WP02 - Advanced 3D perception concept detailed the technological realisation of the specification output from WP01, including specification of all hardware and software components necessary for the camera and the interface between them. Major focus was to provide conceptual foundations for the project hard- and software including design studies, model and interface simulations. This included identification and evaluation of different system concepts, refinement of the most promising concept, and definition of software and hardware interfaces as required for seamless system integration in WP3 and WP4. The work led to two deliverables: D2.1 defining the crucial design decisions and interfaces and D2.2 being it´s update.

Within **WP3 – 3D sensing device** the HW development has been finished. All TACO specific subsystems and components were integrated into the final 3D sensor system. The 3D TACO sensor was successfully tested to verify the proof of concept for a MEMS based adaptive 3D-camera. To avoid any failure of the final demonstrator system a more robust operation point, e.g. FOV were set to 30x60°, with reduced performance compared to the originally planned system specification. The final 3D sensor was delivered in May 2013 to the end users to be tested in several use cases. This has resulted in five deliverables: reporting on mirror prototypes (D3.1), system prototype (D3.2), first instrument (D3.3) and final instrument (D3.4 & D3.5).

WP4 – Toolbox for adaptive control has designed, developed, implemented and tested a realtime control loop for controlling the micro mirrors on the TACO sensor hardware. Foveation algorithms have been developed to detect which regions are of interest in order to give these areas attention, i.e. foveate on these regions. The attention algorithms are both static (analyzing one data frame individually) and dynamic (sequences of data frames, video). Work within WP4 has resulted in four deliverables: D4.1 (realtime mirror control system), region-of-interest detection (D4.2, D4.4) and user documentation (D4.3).

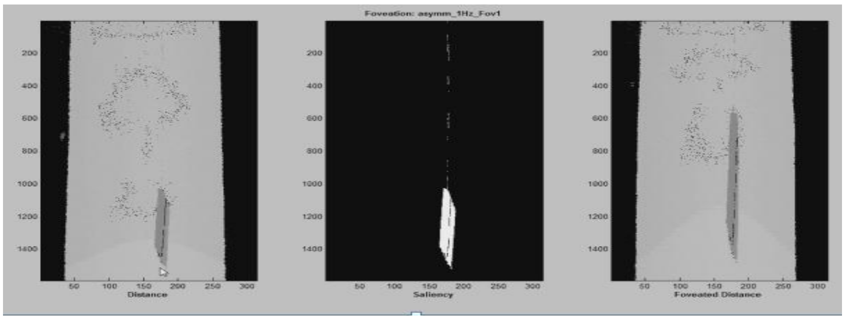

Figure 2: Example of real-time foveation on TACO sensor data. Left: Un-foveated range data. Middle: analysis results showing interesting areas as white. Right: Foveated range data zooming in on the object of interest.

WP5 – System Verification and Testing has derived and successfully executed a test program for the TACO sensor hardware and software based on the use cases defined in D1.2, the revised expected abilities of the sensor and feedback from the project reviewers and the Industrial Advisory Board. This program has allowed an objective evaluation of the sensors performance against real-world tasks in addition to a suite of synthetic tests to measure the sensors key parameters. This has resulted in a test plan (D5.1) and results of its execution (D5.2).

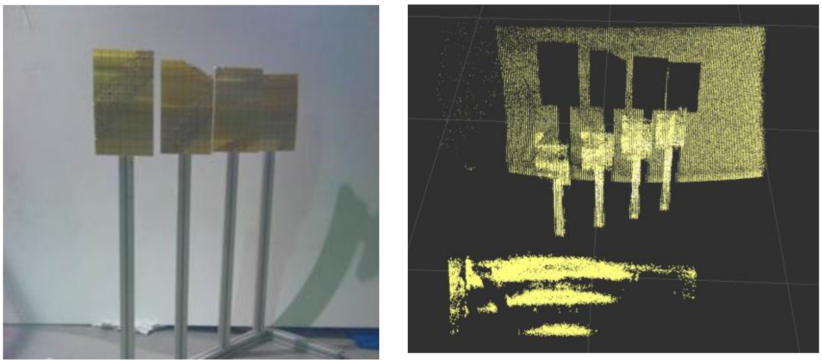

Figure 3: Example use case setup (left) and a corresponding frame of TACO data (right)

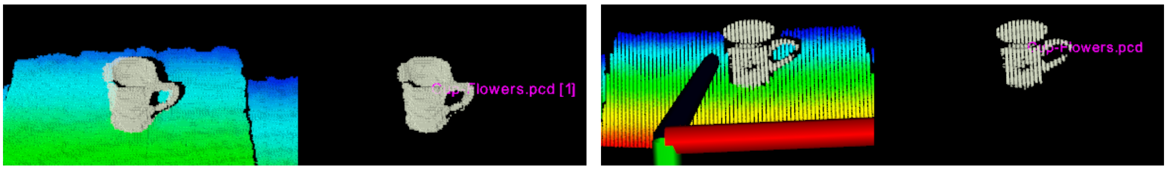

Figure 4: Example of a comparison test with the Microsoft Kinect (left) and TACO (right) point clouds used for successful object recognition

WP6 – Dissemination, Standardisation and Exploitation was responsible to disseminate and exploit the project achievements and results. Activities done in this area have been the following: Monitoring and updating the TACO project website, fostering cooperation activities with related projects, publications (~ 38 peer-reviewed publications, 7 other publications & 7 press releases) in academic and technical magazines, presentations and publications at more than 32 both academic and industrial international conferences (eg. ISOT 2012, IROS 2012) and workshops (5), publication of periodically TACO newsletters (3 issues), TACO press releases, a TACO Public Project Information Factsheet, a TACO project leaflet, a TACO promotion video released on YouTube, project design rules, a dissemination plan and a Final TACO dissemination poster. Furthermore an internal communication infrastructure has been set up. In addition other dissemination activities have been carried out by TACO partners, such as 3 exhibitions, 11 presentations, 7 publications, 4 thesis and many more. The project was granted an exhibition booth at the ICT2013 in Vilnius.

WP7 – Project Management was responsible for the effective organisation of the project and covered all relevant management components. Some of the main achievements have been: organisation of meetings (GA & technical meetings, review meetings), periodic reporting including financial reporting and distribution of tranches, monthly EB-telcos, monitoring of the work plan (QMR-reporting), supporting partners in everyday issues etc.

1.3 Final results & their potential impact and use

The TACO project`s main objective was to develop a **3D sensing system** with real **3D foveation properties** endowing service robots with a higher level of real time affordance perception and interaction capabilities with respect to everyday objects and environments. The achievement of the TACO scientific and technical objectives was measured against an initial set of verifiable indicators, which were constantly being refined and updated in the course of the project in order to reflect the detailed needs and environment of the project. Now at the end of the project a **3D foveating laser scanner**, the TACO sensor, is available and working. TACO has facilitated numerous novel interesting technologies such as rapid, controllable micro-mirrors, fast laser distance measurements and a foveation software package and scene analysis. The sensor demonstrates these technologies and (some of) the possibilities of 3D foveation. The TACO results have been realized through multiple steps and marked by four major milestones (Figure 5).

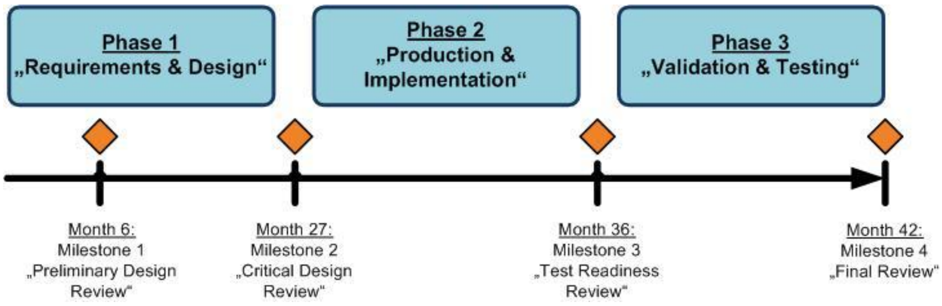

Figure 5: TACO Project phases

The impact and use:

TACO has an impact on the hardware level, software level and system level:

- The **hardware** is 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 opens up for new applications and allows 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 has 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.

1.4 The TACO Project Consortium and Website

The objectives of the TACO project have been 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 represented a vertically integrated consortium, with excellence from MEMS hardware components, time-of-flight sensors, 3D image analysis software to robotic industry applications.

Figure 6: The TACO Consortium

TACO Disclaimer

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