D5.1 - Detailed test case description and test plan for sensor

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Abstract:	This document presents the finalised test plan for the TACO sensor providing detail on the testing program and the implementation of the individual tests that will be carried out to gather the data that will be presented in D5.2
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1 Executive Summary

This document records the test program, including details of all the testing to be carried out, that will be used to collect the data needed to create D5.2, the final test report, which will be one of the primary means by which the success of the TACO sensor will be judged.

The TACO Description of Work (DoW) provided examples of the type of tasks that would be used to test the TACO sensor. D1.2 considered these and other partner use cases and employed a selection process to determine a set of use cases that form the focus of the project. These use cases were selected to showcase the unique aspects of the TACO sensor in tasks that could benefit significantly from the TACO advantages and used to derive benchmarks suitable to measure these advantages. Examination of the use cases revealed that many elements such as path and trajectory planning should not be directly tested in the benchmarks as these will not return comparable metrics directly related to the sensor. Further use case examination allowed the core elements that could be affected by the TACO sensor performance in comparison to other sensors to be extracted and developed into a set of use case derived benchmark tests. Duplication between partner use cases was then removed resulting in a set of tests to be carried out by the relevant partners in the originally envisioned settings.

Due to the unique and novel nature of the TACO sensor, it was determined that few existing benchmarks would be relevant in measuring the sensor performance. In addition to the use case derived benchmarks a set of existing benchmarks for similar sensors were selected to provide the characteristics of the low-level hardware performance and a set of new benchmarks were established to characterise the new foveation functionality.

In the time since the DoW and D1.2 were written there have been changes in the expectation of the TACO sensor performance as the device has been developed and changes in the market by the arrival of devices such as the Microsoft Kinect. Furthermore, technical difficulties with the sensor have further reduced the resources available in WP5 so that the testing will now have to take place with a single sensor in 2 - 2.5 months. This document provides details of the testing that is now planned and provides explanations where these have drifted from the definitions given in these two previous documents. Additionally the schedule for this test program is provided along with an updated evaluation of the risks associated with the work package.

2 Document Scope

This document details the test plan that will be used in WP5 to collect the results that will subsequently be used in the writing of D5.2.

The third chapter outlines the benchmarks that will be used in the testing with brief summaries of the use cases from which they were derived. This is largely a recreation of the benchmarks first introduced as part of D1.2, with explanations where test plans have diverged since then.

Chapter four provides a simple test schedule for the period in which the tests will be carried out. The only detail included is which WP5 partner will have the sensor for testing at any given point to allow maximum flexibility during each period with the intention of maximizing useful results.

Chapter 5 lists the risks and contingency measures identified for the WP at this point.

3 Use Cases and Benchmarks

3.1 Capability Areas

The TACO system aims to develop a sensor targeted at improving the operation of robotics and manipulators in real life operating environments. The system will endow the robot platform with the following capabilities:

- Sensor input for accurate interaction and manipulation of objects
- Obstacle detection and avoidance
- Real time localization and knowledge of changing environments and structures
- Human-robot physical interaction

Here, possible areas of application for the TACO sensor are areas inaccessible (or restricted for humans) for reasons of distance (space applications), confined environment (urban search and rescue robots), or dangerous areas (field robotics such as decommissioning or nuclear facility maintenance fields). Other applications also include fields where the tasks are routine and tedious, where robot systems can perform with an excellent level of repetitive accuracy over extended periods of time. Examples of such applications would be in home or factory environments. These applications all require a reliable and rugged sensor that can be applied to robot systems with a various levels of autonomy from fully automatic to operator assistance of teleoperated manipulator systems. However, there are capabilities beyond the robotics segment, such as:

- Faster 3D measurements of industrial objects (e.g. parcels and manufactured goods)
- Inspection of structures (e.g. subsea or land-based)
- Semi-autonomous vehicles (e.g. wheel chairs, cars and trains)
- Security surveillance

3.2 Use Case Gathering and Requirements Establishing Process

The TACO consortium contains both RTD and industrial end user partners. The end users are particularly able to bring to the project knowledge of sensor requirements use for real life applications. This also applied to some of the RTD partners where the state of the art of existing sensor technology has direct bearing on their research.

As a starting point the partners were requested to supply a number of use cases where partners envisioned that the TACO system would be of real benefit. This involved introducing the field of application, the current problem or limitation where TACO could assist. This then lead to how TACO would be applied and would be able to show a definite benefit over the current state of the art of sensor technology

SINTEF, in its role as the technical leader, then reviewed these use cases to verify that they indeed were good use cases for a foveating sensor.

Based on a dialogue with partners, some use cases were selected as good cases thought to exhibit the foveation aspect of the sensor well. This means that they should highlight well at least one of the advantages given by the sensor, as presented in section 5.2.2 in D1.2 [1]. Use cases were adapted accordingly, and the revised version of the selected use cases were presented in section 5.2 in D1.2 [1] and used to derive use case benchmarks presented in section 6.3 of the same document.

The following sections are updated versions of these use case chapters from D1.2 reflecting the currently planned testing given the evolution of the sensor, market and time budget that has taken place since it was written. The entire benchmarking plan has also been replicated in this document in 3.4.1 and 3.4.2 to place the benchmark testing that will be carried out as part of work package 5 into context although the existing benchmarks defined in 3.4.1 were completed as part of WP3.

3.3 Selection of Use Cases

This section introduces the use cases that were proposed by the partners. They represent real life applications where each partner envisions that the TACO system would demonstrate a clear and significant advantage over existing technologies. The use cases are arranged to introduce the individual use case, i.e. its area of application, why the TACO system would be of use to the application and how it will be implemented to demonstrate this advantage.

3.3.1 Overview of the Use Cases

3.3.1.1 Augmented Reality and Task Safety

JET (Joint European Torus) is a large magnetically confined experimental fusion reactor near Abingdon, UK. Experiments carried out here advance the field towards the creation of fusion power stations and increase understanding of tokamak design and control. ITER is the international follow on project currently being built in the south of France. In both cases remote handling is used for a variety of reasons, some areas can be highly radioactive, others have hazards such as beryllium dust preventing unsuited access and many components are simply too large for humans to handle.

Currently all operations are performed with a man in the loop due to the high uncertainty in the status, location and condition of components with information of the environment being supplied through the use of 2-d cameras and monitors. Undesirable shadows and contrasts when combined with the standard limitations of camera viewing have a significant impact on human image processing and make depth perception impossible in some circumstances. Moreover, full manual operation has a large impact on operator fatigue rates especially with repetitive tasks.

At the simplest level, data from the TACO system could be used to augment the camera views of the operators giving additional depth cues or could be used to draw the operator’s attention to certain features. At a higher level, data from the TACO sensor could be employed to allow partial automation of the manipulators in some tasks if the necessary level of environment awareness could be provided. In areas which allow a mixture of manual and remote work, this could be accomplished with human or human controlled remote manipulation being performed within its workspace.

As part of the use case gathering and requirements establishing process detailed in 3.2 the core processes relevant to the evaluation of the TACO sensor were identified for each use case. For the collaborative assembly use case put forward by OTL and appearing in the DoW examination revealed that the relevant parts of the use case focused on component localization and grasping. Since these were already well covered by the SHADOW and TUW use cases it was not one of the selected use cases, instead being replaced with this and the 3D inspection use cases. Additionally the weight of the realized sensor would have prohibited the execution of the originally defined task as it is too heavy for the robot that was intended to position the sensor during the task to lift.

3.3.1.2 3D Inspection

Following a campaign of operation within a fusion vessel one of the first tasks for the remote handling operators during a shutdown is to inspect the vessel for damage to the first wall. This involves essentially manually looking for any differences to the structure from prior to the fusion campaign. This may be, for example, cracks to blankets, something being bent, broken or missing.

Inspection operations are performed with a man in the loop controlling an articulated boom mounted manipulator to move the position of the cameras around the vessel whilst inspecting the images on the monitor for visible signs of faults. Initially a video survey is performed which is implemented using the manipulator following an automated trajectory. The video must be manually inspected in the control room to locate areas of further interest, e.g. potential damage sites. Following this either high resolution video or still images (which may be overlaid to create a surface map) may be obtained. The camera will be positioned with a mix of man in the loop and automated control of the manipulator system. The most accurate system uses a photogrammetric camera to obtain accurate 3D position data. This requires targets to be placed onto the surface of components. It would be desirable if an intelligent system such as TACO could be used to obtain accurate position data using just visual cues from features such as edge etc.

Currently used sensor technology requires a significant amount of manual assistance which is tedious, time consuming and prone to errors and missed visual cues. During a shutdown there is a significant cost per hour for any delay, therefore, any new system that can shorten the necessary length of the shutdown is very attractive. TACO could potentially automate this procedure by controlling the remote handling manipulator system to perform a gradual systematic sweep of the vessel wall structure looking for obvious signs of damage. Any detected differences could override the sweep to perform more detailed scans of the area to gain a better indication of the size of the damage.

3D inspection is also performed prior to installing new components. When a new fixing point is required it is welded into position using remote handling means. Currently only approximate positioning is possible (<10mm) and subsequent 3D inspection with a photogrammetry camera obtains accurate values of its actual position before make-up pieces are manufactured to assure that the new component when installed is in its desired location. TACO is thought to be able to significantly improve this process by aiding accurate positioning of the fixing point in the first instance and hence avoiding the requirement of make-up pieces.

The vessel prior to a campaign is completely structured. Detailed models of the vessel exist due to the design process used to create the vessel, which are also used by the VR system to help with the remote handling operations. Variations (i.e. an unstructured condition) from this known state when entering the vessel following a campaign of operation potentially indicate damage to the vessel and areas that the TACO sensor should foveate upon to gain further detailed information, which should be flagged and indicated to the operator.

3.3.1.3 Public Safety

In the public safety sector, robots are an invaluable tool to save lives and prevent people from having to manually attend to suspect devices. After detecting a suitcase, a swab will be passed to the robot (and tracked by the TACO sensor). The suitcase will be swabbed to simulate the search for explosives. Then the suitcase will be emptied until a suspicious object is found. Here, the TACO system will need to identify an object the size of an AAA battery in a cluttered space, then to plan a route to extract it without contact. This use case will test the TACO sensor against a cluttered and unstructured environment with varying light condition.

During the extraction of the object, the foveated region will ensure both a high spatial (for finding the AAA battery for example) and temporal (to track the swab) resolution in the ROI. At the same time data coming from the non foveated region will simultaneously ensure the extraction path avoids any collisions.

UPDATE 26/04/13: Due to the significantly reduced amount of time now available with the sensor (4 weeks) this use case will focus only on the visual servoing required during the passing of the swab to the robot. It would not be possible to set up and benchmark all the other elements of the use case in this time. The visual servoing element of the use case has been retained as it demonstrates a feature of the sensor not covered in the other use cases.

3.3.1.4 Home Grasping

The purpose of this use case is to test the TACO sensor within a domestic environment and to compare its performance against other commercial sensor for the tasks of object detection and self-localisation. A mobile platform with the TACO sensor will be deployed in a domestic environment for this evaluation. These scenarios, specially in object detection where higher resolution data is important, will highlight the foveation capabilities of the sensor allowing the robot to identify objects at larger distances. Because the performance of commercial sensor decreases as the distance to the target increases, the TACO sensor will be able to provide higher quality data representing the object by foveating on regions highlighted by attention and segmentation mechanisms that are likely to contain objects.

Due to the reduced amount of time available for sensor testing, we will concentrate on evaluating the advantages of the sensor for the perception tasks which are tightly coupled to manipulation but without deploying the latter. For instance, we will segment and detect a door handle using foveation but the robot will not actually manipulate the handler.

3.4 Benchmark definition

In order to quantify the performance of the TACO sensor it is intended to verify that each of the S&T project objectives is reached. The main S&T objective from the DoW is 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.*

This main objective is split into the following S&T sub-objectives:

1. Develop a flexible, compact, robust and low cost 3D imaging device providing high resolution 3D data of high quality
2. Achieve 3D measurements of increased spatial and temporal resolution in detected regions-of-interest by developing adaptive and intelligent software for sensor control and 3D foveation
3. Benchmark the 3D sensing system on robots in an everyday environment test bed with interaction with everyday objects

Currently established benchmarks only exist for normal non-foveating sensors. To our knowledge there are no existing standards for benchmarking foveating sensors. In order to handle this three different benchmarking approaches have been chosen:

1. The use of existing benchmarks for similar sensors (i.e. laser scanners) to provide the characteristics of low-level hardware performance (described in section 3.4.1 below)
2. Establish new benchmarks to characterize the new foveation functionality provided by the sensor (described in section 3.4.2 below)
3. The above approaches will be performed on synthetic scenes. A number of use cases will also be selected to benchmark the sensor towards real-world applications (described in section 3.4.3 below)

3.4.1 Existing Technology Benchmarks

3.4.1.1 Optical Resolution/Beam Profile

The system resolution in the lateral direction depends on the following characteristics:

- The distance to the object of interest from the sensor
- The laser beam profile (which itself depends on the above)
- The motion of the mirror in the emission branch during the measurement of a target point
- The precision of knowledge about mirror position (and motion)
- And for the system as a whole on the algorithms used to match the 3D data along vectorial trajectories to fixed grids expected at the camera system user interface.

To achieve the optimal system resolution the beam profile will be measured statically (without mirror motion) using an appropriate high-resolution camera at predefined distances. Also mirror motion and position measurement will be characterized with respect to absolute precision and repeatability (see below). Finally, integral measurement of sensor resolution will be performed on a star-like pattern of black and white triangles converging to the center point (Siemens star). Alternatively, we may choose a characterization by the response of the scanner to a depth or intensity step.

3.4.1.2 Scan mirror positioning

The assessment of the mirror capabilities with respect to static and dynamic positioning will be based on the mirror characterization by FHG-IPMS Repeatability and Absolute Position Error.

The repeatability of the angular positioning will be assessed from 3D image properties (using a fixed image model at different distances) or from mirror characterization results by FHG-IPMS.

3.4.1.2.1 Positioning dynamics

FHG-IPMS will characterize and precisely check the mirrors before assembly. Also, the repeatability and precision of dynamic scan trajectories of implemented open loop driving control of the scanning mirror will be measured experimental and compared to simulated result.

The TACO sensor will also be tested after construction by verifying the returned mirror position information in response to the chosen dynamic scan trajectory. The temporal resolution is the pixel period (1 µs).

3.4.1.3 Field-of-view

The FOV of the camera in full-frame operation will be checked by analysis of a camera image of the laser illuminated image region, possibly for different regimes of operating parameters which let expect influence on FOV (as, e. g. operating frequency of the quasi-static axis).

3.4.1.4 Distance measurement

The adjustment of the reception branch with respect to the emission branch is ensured by the operating principle, using the same light paths for emission and reception. The distance measurement error will be tested by repeatedly scanning a single line on a simple (black and white) target. This target will be moved radially away from the camera in measured distance steps. The average distance and standard deviation at each measured point (both as a function of distance) will be calculated and compared to the actual distance. Scanning must be restricted to a small angle around the center of the FOV (or a selected number of directions). Some other situations that are known or expected to show artifacts will be checked.

Measurement of a large radial depth change will test the system step response. This is influenced by a combination of the optical resolution and receiver bandwidth.

The measurement error and step response tests will be repeated using combinations of targets of both very high reflectivity (e.g., retro-reflecting foil) and very low reflectivity.

3.4.1.5 Intensity

The camera's output response to intensity of the received signal will be tested using a target with grey steps of known reflectivity. The intensity results must be proportional to the reflectivity of these steps. Tests will be conducted at a number of discrete distances.

3.4.1.6 Standards Conformance/Environmental conditions/Integral Properties

For adherence to safety standards, please see D2.2, Chapter "Optical System, Laser Safety, Distance Measurement."

Protection from humidity, extended temperature range and mechanical vibration will be addressed in future product development and will, therefore, not be tested. Tests of the TOF circuitry with respect to ambient illumination will be performed. From our design computations we do not expect sensitivity to background light.

3.4.1.7 Size/Weight/Mechanical Stability/Power Consumption

The system size, weight and power consumption are consequences of the final mechanical design which will be part of deliverable D2.2. These will be checked after construction.

3.4.1.8 Software/Camera Interface

Adherence to defined protocols is subject to unit testing. Special treatment will be devoted to laser safety issues as may arise if scanning motion is controlled by software.

3.4.1.8.1 Internal Parameters and Variables/System Monitoring

During the course of the project, we will identify critical parameters and values to be tested; D2.2, D3.3 or D3.4 will contain a list of these parameters.

3.4.1.8.2 Calibration

Calibration is an integral part of system integration and adjustment the accuracy of which will be tested implicitly 3.4.1.4 and 3.4.1.5.

3.4.2 Establishing Benchmarks for foveation

As far as we know, there are no established benchmarks for foveating sensors. We have therefore chosen to define benchmarks according to the S&T Objective 2 of the Description of Work which provide the objective for foveation. The detailed explanation of the objective from the DoW is as follows:

- **Increased spatial and temporal resolution.** A three to ten times increase in spatial and temporal resolution in regions of interest without increased total data rate.
- **Adaptive and intelligent.**
    - Attention will be focusable towards the robot's high-level goals
    - All camera parameters will be continuously tuned for optimal scene imaging through feedback from scene analysis
    - Automatic detection of underperforming attention detectors for improved robustness

We believe these points fully explain the meaning of the S&T Objective 2.
We believe that this is most efficiently benchmarked through the established use cases. We therefore only here provide forward links to which use case benchmarks each objective.

3.4.2.1 Increased spatial and temporal resolution

3.4.2.1.1 Increase in spatial and temporal resolution

This will be benchmarked (amongst others) in OTL's use case on 3D inspection, where the increase in frame rate and temporal resolution will be measured.

UPDATE 26/04/13: In the final sensor delivered to WP5 spatial resolution increasing is limited to increasing the point density in the *y* direction for interesting parts of the image. Live adjustment of the temporal resolution is currently untested but will attempted as part of the WP5 benchmarks if time permits.

3.4.2.2 Adaptive and intelligent

3.4.2.2.1 Attention focusable towards robot's high-level goals

In each use case, the robot will have different high-level goals. Through the different use cases, we will thus see the camera adapt to each situation individually.

3.4.2.2.2 All camera parameters will continuously be tuned for optimal scene imaging through feedback from scene analysis

There are primarily two camera parameters that can be tuned at runtime: Spatial and temporal resolution, plus the Field-of-View. The remaining parameters – such as laser intensity and measurement time – are largely fixed due to hardware and laser safety constraints.

Therefore, we interpret this statement as the ability of the system to adapt the temporal and spatial resolution to the scene at hand and according to the high-level goals of the robot. As we see it, this is implicitly benchmarked through the other benchmarks. We do not therefore see the requirement for additional benchmarks to target this specific detail of S&T Objective 2.

UPDATE 26/04/13: In the final sensor delivered to WP5 live parameter tuning is limited to increasing the point density in the *y* direction for interesting parts of the image. Live adjustment of the temporal resolution is currently untested but will attempted as part of the WP5 benchmarks if time permits.

3.4.2.2.3 Automatic detection of underperforming attention detectors

As described in D4.2, the system will switch to becoming a non-foveating system if more than a certain amount of the scene is deemed interesting. This is due to that the system either is unable to focus on anything, or only detecting noise.

This will be monitored for in the use cases, and reported as this occurs.

3.4.3 Benchmarking Use Cases

The benchmarks above are synthetic, meaning that they do not actually correspond to real-life situations. The following benchmarks are related to the actual use cases, and the experiments that will be carried out in these to quantify the quality of the instrument itself in designated settings.

The experiments per use case are detailed below.

3.4.3.1 3D Inspection & Augmented reality

3.4.3.1.1 Depth Based Damage Detection

This experiment will test whether the TACO system is able to provide a depth map with a defined resolution and in a time quicker than existing sensors.

The TACO system is positioned in a scene that is representative of a post fusion campaign vacuum vessel. The scene contains features over a large depth range. For distances up to 900mm an optical test breadboard will allow accurate positioning of vessel components. The TACO sensor is used to sample the scene in low resolution, high-resolution (specified minimum Ymm, Zmm resolution across the scene) and foveated mode. In foveated mode the sensor will be used to detect the presence of edges with a depth exceeding some threshold as regions of interest and to sample with the same minimum resolution (Ymm, Zmm) just in these regions (low resolution in rest of scene). Note that the resolution may be greater for some samples in the scene but must not be less than this specified minimum resolution. Averaging of depth measurements will be made to thereby increase the accuracy of foveated measurements.

Metrics Used:

- For ranges 0-900mm: The percentage and absolute differences between the known range values and the TACO range data when the TACO camera is in either low-res, high-res or foveated mode.
- The percentage difference in the times to sample the unfoveated (low and high resolution) and foveated scene data

The TACO advantages displayed are:

- Simultaneous high spatial and temporal resolution – demonstrated in the time to sample the data of interest in the scene compared to the unfoveated scan
- Large focus depth range – demonstrated by sampling a large depth range in the scene with a specified minimum resolution
- Improved range measurements – demonstrated by averaging depth measurements for increased accuracy.

UPDATE 26/04/13: While the foveation possibilities available in the sensor delivered to WP5 are not as originally envisaged the test will still proceed largely as planned but with more manual input to the foveation control. The setup will be adapted to ensure there are no objects within around 75cm of the scan head as these are currently understood to be a potential source of artefacts and are best avoided to ensure the smooth running of the tests.

3.4.3.1.2 Point Tracking

This use case will measure how well the TACO system is able to track a moving object and provide accurate dynamic position information to allow augmented reality overlay of important hidden features.

The development robot will be used in the lab environment with a blank wall behind and will separately hold a number of objects representative of a vacuum vessel components. The CAD model of these objects will be known and made available to the TACO system, which it will use to track each object such that dynamic 6DOF position and orientation data can be returned. The robot will move the objects along a number of repeatable trajectories and orientations. This will be repeated with the TACO camera in unfoveated mode with both low resolution (fast scanning) and high resolution (with minimum resolution equal to that in foveated mode). The known position of the objects from the robot kinematics will be compared to the TACO data.

Metrics Used:

- The percentage and absolute differences of the object position from robot kinematic and TACO data when the TACO camera is in either low-res, high-res or foveated mode.

The TACO advantages displayed are:

- Simultaneous high spatial and temporal resolution – The scanning needs to be performed at such a rate to keep track of the moving item while still providing accurate information about the corner positions.
- Object Tracking

UPDATE 26/04/13: In the sensor delivered to WP5 orientation tracking is not currently possible and foveation is limited to a number of pre-defined trajectories that can be selected based on suitability and switched between on-the-fly but at limited rates. The robot will still be used to move the objects and the sensor data will be logged so that an assessment on the possibility of a user process to recreate the object trajectories can be carried out off-line.

3.4.3.2 Public Safety

3.4.3.2.1 Swab Localization – amount of background light

The first part of this experiment will be to determine how much background light the TACO sensor can cope with whilst providing acceptable data.). This maximum level of light will be reached when we have less than 6mm accuracy in the FOVEA, using oversampling, at 1m of the sensor, for a maximum std of 2. This is half the width of the smallest object we want to detect (the AAA battery).

We hope to show that the TACO sensor is able to work well with much more background light than the Kinect for example. Once we have this maximum level of light, we'll continue the experience experiments in these conditions.

	Ground Truth		Kinect	TACO (Unfoveated)	TACO (Foveated)	
	Position	Orientation	Deviation from Ground Truth	Deviation from Ground Truth	Deviation from Ground Truth	Gain from unfoveated*
Normal room lighting						
Medium photo lighting						
Full photo lighting or direct sunlight depending on conditions.						

*Gain from unfoveated: difference between the foveated and unfoveated deviation

3.4.3.2.2 Swab Localization – different trajectories

We'll be using the maximum convenient light decided by the first part of the experiment.

The experiment will test how much accuracy is gained by foveating on the swab and compare it with the Kinect sensor and the TACO sensor in non-foveating mode. The experiment will be run using different approach speed and trajectories for the swab.

The scene features a suitcase that contains a suspicious object. Scene data is recorded, with the Kinect, with the unfoveated TACO sensor and with the foveated TACO sensor. The data is processed offline and used to estimate the position of the swab using a developed algorithm. In addition, the time necessary for acquisition is measured. The results are compared to the known position of the swab. This will give the following table of results:

	Ground Truth		Kinect	TACO (Unfoveated)	TACO (Foveated)	
	Position	Orientation	Deviation from Ground Truth	Deviation from Ground Truth	Deviation from Ground Truth	Gain from unfoveated*
Simple linear slow trajectory						
Faster linear trajectory						
Faster more complex trajectory						

*Gain from unfoveated: difference between the foveated and unfoveated deviation

This will demonstrate the increase of accuracy when using the foveation, as well as the robustness of the TACO sensor in different light conditions.

3.4.3.3 Home Grasping

3.4.3.3.1 Self Localisation

In the self-localisation use case, the hypothesis being tested is:

- The (raw) data of the TACO sensor produces localisation results (when fed into a state-of-the-art localisation algorithm) at least as good as from commercially available sensors

The TACO sensor along with commercially available sensors will be mounted onto a mobile robot. The sensors will be spatially as close to each other as possible so that they capture the same part of the scene. The sensors' viewing direction is the motion direction of the robot and tilted towards the ground to capture the space directly in front of the robot.

The robot will be moved along a known trajectory and the TACO sensor data as well as data from the commercially available sensors will be recorded. After that, the recorded data (odometry and one range sensor's data at a time) will be fed offline into a self-localisation algorithm. Because the robot is equipped with a SICK laser scanner close to the ground level, we will evaluate self-localisation by comparing the generated map and the robot's pose between the different sensors and the SICK laser scanner.

3.4.3.3.2 Object Detection

The foveation capability of the TACO sensor enables more accurate object detection when compared to the fixed-resolution commercially available sensors and sooner object detection from greater distances.

Objects with different shape properties will be placed on a table: cup, bottle, toy as well as two basic geometries (cylinder and cube). A robot with the mounted sensors will move towards the table and stand still in front of it for an additional amount of time (to cover the aspects of dynamic and static sensor as well as varying object distances). Several scene configurations will be recorded increasing the complexity for the task of recognition (increasing occlusion or adding clutter). The same will be done for a door scene, where the interesting object is the door handle.

3D models of the objects will be used to train the object detectors as well as to annotate the scenes with ground truth data (identity and 6DoF pose). Each scene will be recorded with the TACO sensor as well as commercially available sensors. The recorded point clouds (of one sensor at a time) will be fed into object recognition software. We will evaluate (1) if the recognition was able to identify the object or not and (2) the deviation in pose of the recognition results with respect to the ground truth data (offline).

The hypothesis being tested in this use case, is that available high(er) spatial resolution makes it easier to recognize the objects due to a more accurate representation of the object's surface.

3.4.3.3.3 Obstacle Detection

Due to the limited time availability for the tests as well as the similarity to object detection use case, we will not provide any experiments for the task of obstacle detection.

3.4.4 Use-Case Demonstrations

In addition to the above mentioned experiments, we will attempt to conduct demonstrations where possible. These are intended to convey a realistic sequence of events where the TACO sensor has a central role. These do therefore not provide quantitative information, but rather demonstrate the sensor in practical use. The following three subsections detail the demonstrations planned during D1.2, due to the reduced time available for testing these will be considered lower priority than the activities providing quantitative results.

3.4.4.1 Public Safety – Full Demonstration

The public safety experiments discussed above will be combined to visually demonstrate the process of using the TACO sensor to allow remote operations to deal with a suspicious object.

A scenario will be setup that features an open case containing a suspicious object. Using TACO sensor data a Shadow robot hand will semi-autonomously find and remove the object. First the sensor data will be used to identify the open bag. It will then foveate on a swab which is being passed to it by a human. The robot will take the swab, return to the case and use this to sample the open case and contents (simulating the checking for explosive materials). The swab will be returned back to the human. The sensor will then be used to analyse contents and locate the suspicious object in this unstructured environment. The suitcase will contain other items, such as clothing, which the robot hand will move in order to locate the suspicious object. Once located the sensor will foveate on the object of interest and the robot hand will remove it from the suitcase.

First we'll determine the acceptable levels of background light, proving the resistance of the sensor to varying lighting conditions. While foveating on the swab, we'll focus on testing the accuracy and speed of the TACO sensor. The TACO sensor will continually monitor the full FOV and will detect movement around the suitcase as an additional safety measure demonstration. Any detected movement will immediately pause the robot motion.

UPDATE 26/04/13: Due to the significantly reduced amount of time now available with the sensor (4 weeks) this use case demonstration has to been reduced in line with the changes outlined in 3.3.1.3. As the use case benchmarking now focuses only on the swab element the demonstration will do the same.

3.4.4.2 Home grasping – Full Demonstration

The TACO sensor can be meaningfully used in the context of a home robotics scenario. Due to its foveation capability and large field of view, it can replace several conventional sensors that would be used simultaneously otherwise.

A typical scenario from a home robotics setting will be showcased. A mobile robot with the mounted TACO sensor moves through a home-like environment. The sensor data will be used for self-localisation, mapping and object detection. It will be shown that the sensor is capable of foveating on relevant regions of the scene in order to identify objects of interest as well as that the raw data is good enough to perform self-localisation and to deploy attention and segmentation algorithms to guide the foveation mechanism.

Concretely, the robot starts in one room of this environment, moves along a corridor, encounters a closed door (detect its handle through foveation) and waits until it opens. After that it continues its tour into the entry hall and into the kitchen, where it will stop in front of a counter with several objects (among them a cup) on it. In the course of this tour, the robot will perform self-localisation and mapping and will detect the objects of interest (a “door handle” in the corridor and the “cup” on the counter).

The demonstration will result in a video showing the robot with the TACO sensor mounted onto it moving through the environment as well as the results of the foveation software's processing results. The idea of the demonstration is to show that the TACO sensor can be used for the various tasks of a home robot i.e. selflocalisation and mapping as well as object detection.

3.4.4.3 Augmented Reality & Task Safety – Full Demonstration

This will demonstrate that the TACO system and robot system can allow improved and safe performance using augmented reality

The experiment will take place within a fusion vessel mock-up and will include an operator controlled development robot for task manipulation. The operator will be performing a simple assembly task, installing a component onto the vessel wall. The four manufactured mock-up vessel tiles (discussed in 3.4.3.1.1 Depth Based Damage Detection) will be mounted to the vessel wall mock-up with the assembly site located in the centre. The component will have assembly features on the rear which must interface with features on the vessel wall (i.e. dowels and holes). Due to space constraints and camera positions the assembly features are not always visible but are necessary to allow the operator visual feedback of the relative position of the component with respect to the vessel wall. The TACO camera will be mounted at a fixed location and will be used to track the object and with the robot system will overlay an AR representation of the features. As in the 3.4.3.1.2 Point Tracking use case, markers will be positioned on the robot end-effectors to allow effective tracking. The TACO system will scan the full field of view in low resolution. This will be done both to determine the regions of interest (where a high resolution scan will take place) and also to detect when a possible collision may occur and both inform the operator (using AR overlay) and halt the robot motion.

The TACO advantages displayed are:

- Simultaneous high spatial and temporal resolution – The TACO system will provide accurate data on the moving object while also monitoring the full scene to detect motion.
- Adaptability – When a possible collision is detected the TACO system will adjust its foveation to obtain more accurate data as required.
- Object Localisation and Tracking

UPDATE 26/04/13: The three weeks available for the OTL use case benchmarks tests and demonstration will not be sufficient to create an external system compatible with the realised TACO data if the tracking of markers is not possible and integrated it with the VR viewing system. If tracking is possible then data will be collected during the testing for use in generating a demonstration video, without tracking the demonstration will not be possible within the available time budget.

4 Test Schedule

	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29	Week 30
SINTEF	■													
TUW		■		■									■	■
SHADOW						■	■	■	■					
OTL										■	■	■		
IPM (Safety Fix)			■											
GA					■									

Table 1: Test Schedule

5 Risks and Contingency Measures

For an exact breakdown of risk categories, please refer to the risk matrix in Table 4.

Risk Nr.	**Description**	**Probabiliy** (SM * | MD | LG)	**Impact** (SM * | MD | LG)	**Contingency plan**	**Risk category**
1	Damage to system during tests	V.SM	V.LG	Extra care taken with sensor, especially when in transit. Consortium to be notified straight away if damage occurs. Damage to be assessed and one of the following options utilized. • Testing continues with damage having been assessed as having limited performance impact and no safety implications. • Repairs on site under guidance of the hardware partners. • Return to hardware partners if necessary. Use cases prioritized in case reduced time does not allow for all testing to complete.	E1
2	System does not perform as expected	SM	LG	Consortium to be notified straight away if unexpected performance is discovered. Significance of the deviation to be assessed and one of the following options utilized. • Testing continues with divergence having been assessed as having limited performance impact and no safety implications. • Modifications performed on site under guidance of the hardware partners. • Return to hardware partners for modification if necessary. Use cases prioritized in case reduced time does not allow for all testing to complete.	D2
3	Insufficient time to complete all tests	SM	LG	Use cases prioritized in case time does not allow for all testing to complete.	D2

Table 2: Risks and Contingency Plan

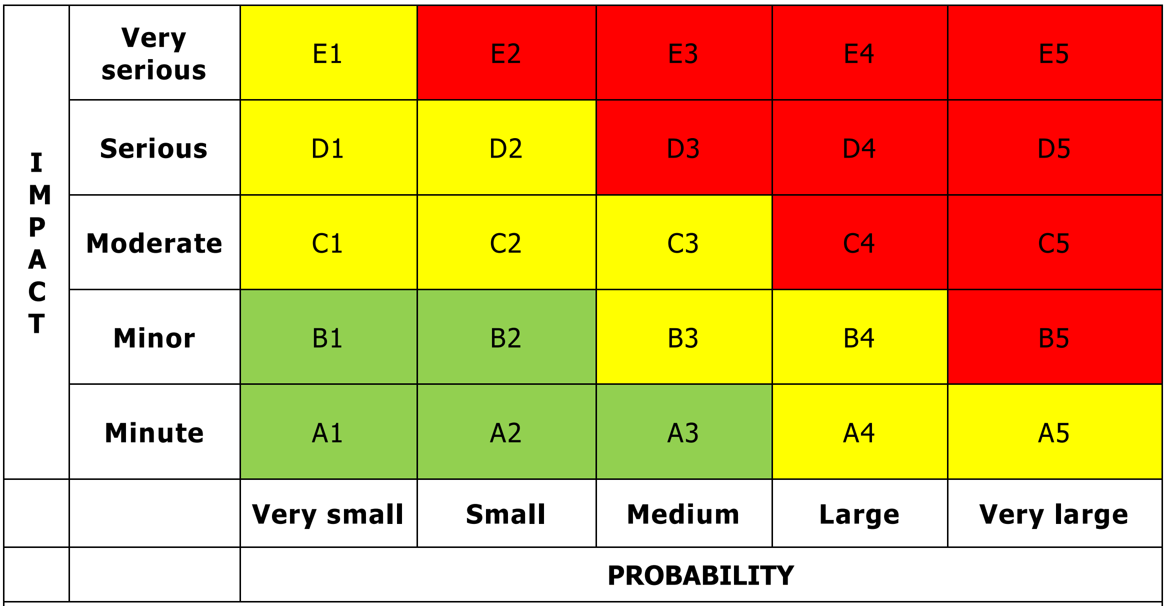
*SM=Small, MD=Medium, LG=Large

The DoW identified 3 risks for the WP. These can be seen in the following table with updates.

#	Risk	Contingency plan	Update
5.1	Damage to system during tests.	Backup system constructed in WP3.	No backup available. New mitigation detailed above in Table 2.
5.2	System does not pass laser safety tests.	Proceed with lab testing. Depending on the reason of failure, it may be possible to make small modifications to the system (reduce laser power, mask spots where beam would pass if mirrors block, etc.) that would still permit to test the system in real-world situations without endangering the main project time line.	System has passed laser safety tests but requires an upgrade to combine maximum performance with safety which is scheduled to take place in week 19.
5.3	System does not perform as expected	Thorough design reviews in WP2 will lower this risk. Close cooperation between partners during phase will allow for understanding and possibly correction of possible deviations.	D3.5 provided a summary of the realized sensor. While not meeting the original specification the realized specification is known and will be tested against. New mitigation detailed in Table 2.

Table 3: DoW Identified Risks

RISK MATRIX



IMPACT	**Very serious**	E1	E2	E3	E4	E5
	Serious	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Minor	B1	B2	B3	B4	B5
	Minute	A1	A2	A3	A4	A5
		Very small	**Small**	**Medium**	**Large**	**Very large**
		PROBABILITY				

Colour		**Description**
Red	🟥	Unacceptable risk. Immediate steps to reduce the risk.
Yellow	🟨	Under constant consideration. Revision of risk at fixed intervals.
Green	🟩	Acceptable risk. Annual revision of risk.

Table 4: Risk Matrix

6 List of Abbreviations

TACO	Three-dimensional Adaptive Camera with Object Detection and Foveation
DoW	Description of Work
WP	Work Package
TOF	Time Of Flight
FOV	Field Of View
ROI	Region Of Interest

7 References

[1] TACO Deliverable D1.2, Roadmap and final requirements specification, WP01, June, 2012.