Horizon 2020 PROGRAMME *ICT-01-2014: Smart Cyber-Physical Systems*

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D1.7
Final report

1. DOCUMENT INFORMATION

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Authors	O. Deniz (UCLM)
Responsible Author	Oscar Deniz (UCLM) e-mail:Oscar.Deniz@uclm.es phone: +34 926295300 Ext.6286
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3. ABSTRACT

This public deliverable represents the final high-level report of Project Eyes of Things. As such, the deliverable is deliberately brief, since detailed reports have been already delivered to the EC, most of them being public (27 of 36). In fact, no other summarized report such as this one is available. This report is structured as follows. In Section 4 we reproduce the intended goals and idea of the project. Section 5 provides a brief account of the project developments. Finally, Section 6 concludes with the major results.

4. EYES OF THINGS

Currently, computer vision is rapidly moving beyond academic research and factory automation. With the appropriate platforms and tools, the emerging possibilities are endless in terms of wearable applications, augmented reality, surveillance, ambient-assisted living, etc.

Vision, our richest sensor, allows mining big data from reality. While the number of image sensors deployed across all products in the world is a small fraction of the total number of sensors deployed, the amount of data generated by them dwarfs the amount of data generated by all other types of sensors combined. This has a cost, vision is arguably the most demanding sensor in terms of power consumption and required processing power. That challenge has been for the first time addressed in project Eyes of Things. Our objective in the project is to build a power-size-cost-programmability optimized core vision platform that can work independently and also embedded into all types of artefacts. The envisioned open hardware is to be combined with carefully designed APIs that maximize inferred information per milliwatt and adapt the quality of inferred results to each particular application. This will not only mean more hours of continuous operation, it will allow to create novel applications and services that go beyond what current vision systems can do.

5. PROJECT DEVELOPMENTS

The first half of the project was devoted to the specification and development of the platform itself, both in hardware and software. Hardware progressed through successive iterations of the board, starting from the interconnection of a number of separate development boards that were already available at the start of the project. A full stack of software was developed in parallel. A number of capabilities that were not in the original proposal, notably deep learning inference, were added to the platform.

The interim review before the EC was passed successfully. Apart from the technical side, other aspects were also considered, such as privacy and efforts in dissemination.

During the second half of the project, there were delays caused mostly by the complexity of the hardware. Also, problems and delays arose in relation with the main camera to be interfaced. As a risk-contingency measure a third low-power camera was also interfaced to the board. In the end, the main camera was also interfaced successfully, so the EoT board can ultimately use three different types of cameras (the original camera supplied in the development boards, the main low-power camera and a back-up low-power camera). The four project demonstrators were also developed during this second period.

All throughout, the projects' privacy concerns were duly addressed thanks to the collaboration of an Ethics Board. An advisory board also assisted in guiding the exploitation. During the course of the project, two of the partners (out of the eight in the Consortium) were acquired by larger companies.

In the following we list the main deliverables that contain detailed information at the end of the project:

Number	**Title**
D1.4	Final technical report
D1.5	Final financial report
D1.6	Final ethics review report
D4.1, D4.4, D4.7, D4.10	EoT application, Demonstrators 1-4
D4.2, D4.5, D4.8, D4.11	Configuration application, Demonstrators 1-4
D4.3, D4.6, D4.9, D4.12	Test report, Demonstrators 1-4
D5.5	Dissemination and exploitation report

6. RESULTS

The main result is a reference HW/SW platform for embedded computer vision, see the following Figure.

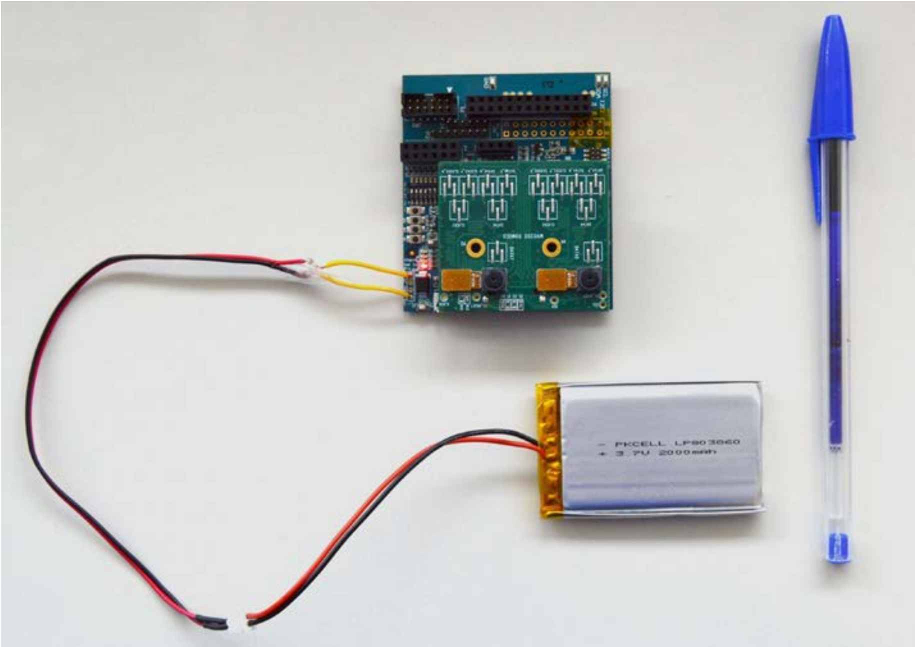

Figure 1. EoT board connected to a LiPo battery

EoT aims at providing the first proof-of-concept that advanced vision can be embedded in a small form-factor which can be used standalone and embedded in other artifacts. This has required a carefully-selected conjunction of multiple low-power technologies, both hardware and software. The key hardware element is the ultralow-power Myriad 2 processor by Movidius (acquired by Intel). Notable features include deep learning inference, low-power WiFi with both lightweight messaging and video streaming, sending of alarms to smartphones/tablets, local microSD storage with encryption, USB 3.0, internal battery charger, audio connector, DIP switches, LEDs and buttons, IMU, etc. The board can currently interface 3 different cameras. Physical Board dimensions are: 48x56mm. Both hardware and most of the software is open source. More technical details on EoT are available at www.eyesofthings.eu and in the following journal paper:

> "*Eyes of Things*", O. Deniz et al. Sensors (Basel). 2017 May 21;17(5). pii: E1173. doi: 10.3390/s17051173.

Four demonstrators are available at the end of the project:

- In one of the platform demonstrators, a doll uses the board (embedded into the doll's body and head, including the rechargeable battery) to recognize, using deep learning inference, one of 6 possible facial expressions. All of this is done locally in the doll. Our estimates are that the device could be doing this inference continuously for up to 13 hours (4000mAh battery).

- In another demonstrator, a headset is built for museums that automatically recognizes the painting a visitor is looking at and provides info via audio. The EoT board in the headset also connects with a smartphone App which allows multimedia/interactive experiences. The system was piloted in the worldwide renowned museum Albertina in Vienna.
- Peephole monitoring demonstrator: Before leaving home, the user attaches the EoT-based device to the peephole and configures it through a smartphone app. The device will continuously monitor for motion or faces in front of the door, sending alarms and pictures to the user's smartphone. The device does not need cables, since it functions with its own rechargeable battery. Furthermore, the device will also detect tampering events (e.g. attempts to cover the peephole) and generate alarms. Besides these instant alarms/notifications the devices also records video clips of the detected events and send them to the user on demand.
- Flexible mobile camera demonstrator: This demonstrator is actually a set of functionalities useful for surveillance and including additional functionality provided in the cloud using images captured by the EoT device.

EoT is having an impact worldwide in terms of being the first proof that always-on computer vision processing at the edge is possible. Other similar platforms are now being developed, particularly with the same EoT focus on flexibility and open source. Partners in the Consortium are currently collaborating with a number of them.

A start-up company Ubotica Technologies set up by Consortium partners' ex-employees is currently taking advantage of the EoT reference platform for multiple third-party projects, including one project with a prominent European organisation. This company has acquired the necessary license for commercial development of products based on EoT. Ubotica is therefore in a perfect position to develop solutions that use EoT as a reference, and to accomplish their objective of offering such system integration services to a large number of customers. The Myriad-2 chip at the center of EoT is a complex device to master, integrate with other electronic components and deploy. This includes the complex software associated to the processor, sensors, communications and optimized vision and deep learning inference. Again, Ubotica already has the expertise to develop EoT variants in the shortest time.

Also, at least one of the demonstrators has shown a clear commercial potential and at the time of writing a new Consortium is being set up to prepare a proposal for a new project that should make the last steps toward productization.

A number of entities have acted as Early Adopters of the EoT technology. French multinational Thales is using EoT for its internal technology research purposes, particularly as an image processing and analysis platform for medical equipment (which have strict wattage limits). Other early adopters are using it for projects in mobile robotics, headsets and to develop variant vision boards. Finally, EoT has been also used by academia (external to the Consortium) in work leading to published research.