INSPEX: Integrated Smart Spatial Exploration System

Suzanne Lesecq, Laurent Ouvry, Marc Correvon, Gabriela Dudnik, John Barrett, Alan Mcgibney, François Birot, Hugues De Chaumont, Richard Banach, Jean-Marc Van Gyseghem, et al.

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S. Lesecq, L. Ouvry, Univ. Grenoble Alpes, CEA, LETI, Minatec Campus, France
M. Correvon, G. Dudnik, CSEM SA, Neuchâtel, Switzerland
J. Barrett, A. McGibney, Cork Institute of Technology, Cork, Ireland
F. Birot, H. de Chaumont, GoSense Lyon, France
R. Banach, Univ. of Manchester, School of Computer Science, Manchester, U.K.
J.-M. Van Gyseghem, J. Herveg, Univ. of Namur, Namur, Belgium
C. Jackson, S. Buckley, SensL, Cork, Ireland
A. di Matteo, V. di Palma, STMicroelectronics Srl, Naples, Italy
C. Ó'Murchú, A. Mathewson, Tyndall National Institute, Cork, Ireland

1 Introduction and objectives

A large amount of work has been recently done on obstacle avoidance systems for autonomous vehicles. To detect different types of obstacles across the full range of possible lighting and weather conditions, the obstacle detection systems usually combine multiple subsystems including LiDAR, radar, IR and optical. The data from these subsystems is merged with vehicle orientation and navigation subsystems. These systems are typically heavy, power hungry, and require high computational capabilities.

INSPEX partners have asked themselves "what if we could miniaturise an obstacle detection system like this and reduce its power consumption so that it could be portable/wearable?" This is very challenging but it would open many new applications in, for example, assistive guidance for the visually impaired, human guidance in low visibility conditions (night, smoke, fog) obstacle detection for small or humanoid robots, and small drone obstacle detection for obstacle avoidance procedures.

This encapsulates the objective of INSPEX: to combine several range sensors with an IMU, environmental sensing, signal and data processing, wireless communications, energy management and user interface, all in a miniature, low power, small size, light weight device (Fig. 1), with a flexible system integration methodology that will allow the INSPEX smart spatial exploration system to be applied to a range of different application areas.

Fig. 1: INSPEX objective – integrating automotive all-conditions obstacle detection system [1] in a portable/wearable device

INSPEX first demonstrator targets the Visually Impaired and Blind (VIB) community, and field tests will be conducted. Therefore, *ethical issues* must be considered. Moreover, the device being connected, *privacy* concerns must be addressed right at the design phase (privacy-by-design).

The VIB use-case is seen highly demanding in terms of *miniaturisation*, *integration* challenges, *power efficiency and needs for communication with the smart environment*. Indeed, for this particular application, the INSPEX mobile detection device (Fig. 3) should not exceed **200gr** in weight and **100cm^3** in volume. **10 hours of lifetime in continuous use** are expected with an initial target for power consumption smaller than **500mW**. Obstacle location will be provided *via* an extra-auricular headset with Augmented Reality 3D Audio interface.

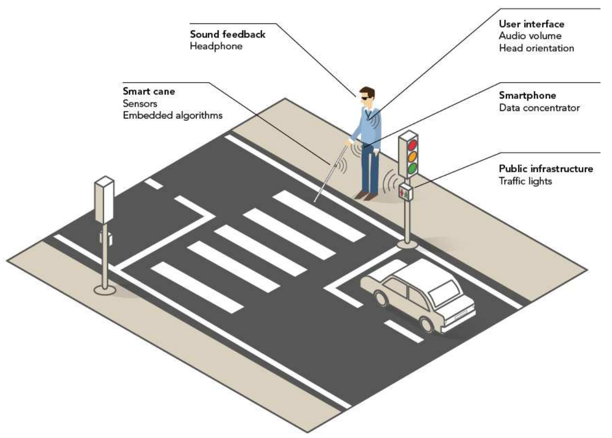

Fig. 2: initial demonstrator – Development of a spatial exploration system to detect obstacles in the surroundings for VIB

2 First architecture attempt

The INSPEX system is split in 3 devices with a *modular architecture* that provides its versatility (Fig. 3). The *mobile detection device* will integrate several range sensor technologies (i.e. LiDAR on chip, MEMS ultrasound, UltraWide Band (UWB) Impulse Radar) brought by the partners and optimised in the course of the project in order to fulfil the overall power budget. The choice for these range sensing technologies is conducted by the capability of the final mobile detection device to detect a large variety of obstacles (in shape, size, material, and colour) in different environmental conditions (temperature, humidity, luminosity, visibility) and particular situations (holes, stairs). The INSPEX system will function under various weather conditions (e.g. rain, snow, sand) over a large temperature range (typ. -20°C to 40°C) but also in low visibility conditions (e.g. night, dust, smoke, fog). An *environmental sensing module* will help reconfigure the system depending on these environmental conditions.

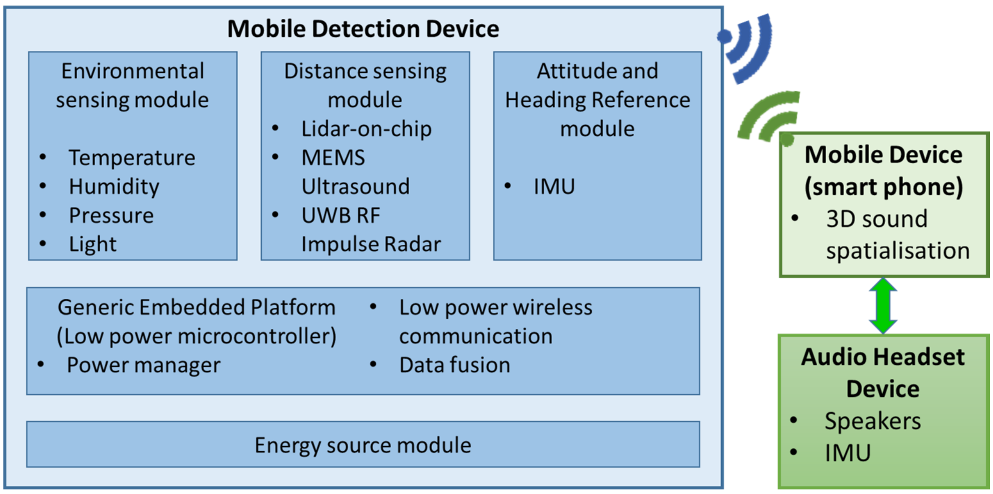

Fig. 3: INSPEX modular system architecture

A *low-power microcontroller* will fuse data from the range sensors and build the Occupancy Grid (OG) environment model which is a spatial partition of the external world into a set of cells [2], each cell containing the probability to find an obstacle at the cell location. Classically, Bayesian fusion [3] or evidence combination [4] are used for data fusion. As they require floating-point computation, their integration on highly constrained embedded platforms is not possible due to their associated large power consumption. INSPEX will instead make use of integer computation [5] to decrease the power consumption associated with data treatment.

Being part of the IoT, the INSPEX system must offer connectivity to smarter environments. *Context-aware communication* capabilities will provide the user with a collaborative fabric of smart objects, giving the ability to determine the context of moving objects and to dynamically blend user experiences. A *power manager* will help expand the system autonomy. The number of range sensors powered-on will be dynamically adapted as a function of the available energy or of the environmental conditions, leading to an adaptation at run-time of the obstacle detection algorithm. The power manager will be verified using *formal methods* to ensure its proper design and functioning.

3 Range sensors implemented in the mobile detection device

Four state-of-the-art range sensors are brought by the partners to the project, namely, a MEMS ultrasound sensor (STM), a short range large field-of-view LiDAR-on-chip (CSEM), a long range narrow field-of-view LiDAR (Tyndall, SensL), and an UWB RF radar (CEA). Their organisation will be application dependant, e.g. to ensure the full coverage of the person height to better alarm the user on potential dangers.

MEMS ultrasonic transducers (MUT) are used e.g. in non-destructive testing, speed sensing, collision warning, automation, flow metering (Doppler) and medical imaging. Depending on their actuation, capacitive MUTs (CMUTs) and piezoelectric MUTs (PMUTs) can be chosen. PMUTs have a lower power consumption than CMUTs, which can require a polarization voltage of around 200V. PMUTs are based on either bulk piezoelectric ceramic (with poor acoustic coupling to air or liquids) or on piezoelectric thin films (PZT, AlN) allowing them to be integrated into MEMS technology. When arrays of the latter are formed, ultrasound transducers allow the technology limits of conventional bulk ones to be overcome. 2D array MEMS transducers can be miniaturised to produce real-time proximity signals. Moreover, by using pulse-echo Time-of-Flight techniques, ultrasonic MEMS can work over 1m range with sub-mm ranging accuracy. In INSPEX, a piezo membrane MEMS (PMUT) together with its driving ASIC [30] will be optimised and integrated in the *Mobile Detection Device*.

Thanks to the huge market of the smartphone and the embedded cameras, small size and low power LiDAR are, and will be in the very near future, the best candidates for the autofocus (AF). Their range and bandwidth are compatible with the VIB use-case that targets obstacle detection within a range from less than 1 meter (short range) to 3-5 meters (long range). Such a technology is compliant with low power and low size requirements. INSPEX will optimise two LiDARs brought to the project by partners. The first one will be a long range LiDAR with a field-of-view of 2.2°. Its prototype has been demonstrated with a range of up to 21m [6]. This is a single channel laser and the objective is to reduce the size by developing a chip based solution for the electronics. In conjunction with the miniaturization of the single channel module in order to increase the field of view, a 64 channel array version will be developed using the same electronics platform as will be used for the single channel version. The second LiDAR is a short range one with a large field-of-view based on an off-the-shelf component. Currently this commercial on-chip sensor allows to look at a single point in the range of up to 2m and is designed for camera auto-focus solutions. A fully footprint compatible 2nd generation will be developed and integrated in INSPEX. This sensor is looking at 9 independent measurement points with a field of view of 30° and a range of up to 3m. It will allow faster scanning of the near proximity with increased spatial resolution.

Integrated CW or FMCW RF radars for presence detection already exist in the field of for instance domestic security or obstacle detection in the automotive domain. In domestic security, the requirement being to detect a presence, a large scale variation of the electromagnetic echo strength is enough to get sufficient detection probability. Such limited bandwidth Doppler radars hardly provide precise range information useable in dynamic obstacle tracking systems. In the automotive field, obstacle detection radar, usually operating at 24 or 77GHz, are optimised for performance (range, angle), at the expense of higher cost, high directivity and power consumption of more than 500mW [7]. UWB RF radars have also been successfully applied in healthcare applications, especially for respiration rate estimation of static humans, where sensitivity to very small movements is the key specification, but the measurement range is not adapted to (moving) obstacle detection needs. Smart white cane solutions integrating an RF Radar do not exist today at product level. At R&D scale, one can only find early demonstrators [8]. INSPEX objective is to integrate a UWB RF radar sensor in its detection device with performance of 20m sensitivity range. It will have up to 100Hz refresh rate for high performance tracking of moving targets, 15cm range resolution, 60° azimuth aperture, coarse angle of arrival estimation, and approx. 100mW of power consumption. The form factor will be divided by 4 for the sensor to be compatible with integration in the envisioned *Mobile Detection Device*.

4 Acknowledgements

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