Executive Summary Report

SCRIPT

SENER Concept Receiver for Indoor Positioning Techniques

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1 EXECUTIVE SUMMARY REPORT

SENER Aeroespacial Concept Receiver for Indoor Positioning Techniques (SCRIPT) is a technological demonstrator that takes advantage of new technological developments in location systems based on wireless technologies, in combination with new techniques for position estimation and data fusion for ubiquitous indoor positioning.

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SCRIPT is an innovative solution for a Cost-Efficient Indoor Positioning with Sparse Local Infrastructure:

- Offering mass-market wireless technologies based on low-cost COTS HW.
- Wireless technologies which are complementing GNSS to cover indoor environments.
- Inertial and position measurements to enhance the resilience of the positioning solution.

The fusion of commercial technologies approaches the challenged quasi-ubiquitous indoor positioning accuracies:

- UWB (Ultra-Wide band) that enables fine time resolution, which allows identifying direct path received signal, mitigating multipath effect very effectively.
- WiFi RTT (Round Trip Time) taking advantage of the widespread use of WLAN access points that allows use of simple infrastructures.
- Bluetooth is widely adopted in consumer market and supports AoA/AoD with relatively simple HW.
- The CTTC's (Centre Tecnològic Telecomunicacions Catalunya) GNSS Receiver is expanded to include high sensitivity algorithms in signal acquisition.
- The activity investigates the potential of 5G waveforms for ranging and direction of arrival estimation by a 5G emulation.

The capacity of developing navigation algorithms for data fusion are key aspects covered in SCRIPT. Fusion navigation solutions based on ranging, direction of departure (DOD) and direction of arrival (DOA) and GNSS based on single and multiple anchors and peers for outdoor-to-indoor scenarios are developed.

Our own concept in the field of data fusion for indoor/outdoor location, based on a Sigma Point Kalman Filter (SKPF), the hybrid filter that combines a particle filter with the classical Kalman filter, is used. The SW Receiver applications are implemented based on Open-Source SW.

Peer to peer/Collaborative positioning algorithms, exploiting ranging and/or Angle of Arrival /Angle of Departure (AoA/AoD) data between different Remote Units, are deployed as well.

The GNSS receiver solution is based on GNSS-SDR (see https://gnss-sdr-org), an open-source implementation of a multi-system, multi-band GNSS receiver defined by software and running in real-time on a Xilinx Zynq MPSoC (Multi-Processor System-On-Chip). The MPSoC features a quad-core 64-bit ARM Cortex-A53 processor and an FPGA, among other peripherals. The use of an MPSoC allows us to run GNSS-SDR in a low-power processor while offloading the most resource intensive computational tasks to the FPGA. The main features of the receiver are:

- The receiver can process any combination of GPS L1 C/A, Galileo E1b+c, GPS L5 and Galileo E5a signals in real-time.
- The receiver works in normal sensitivity mode and high sensitivity mode. When working in high sensitivity mode, the receiver acquires and tracks GNSS signals down to 20 dB-Hz in real time.
- When working in high sensitivity mode, the receiver process Galileo E1b+c and Galileo E5a signals in high sensitivity mode while simultaneously processing GPS L1 C/A and GPS L5 signals in normal sensitivity mode.

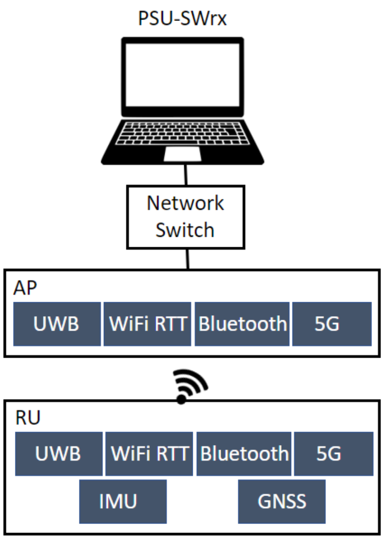
The FPGA implements one high sensitivity acquisition FPGA IP core and several tracking multicorrelator FPGA IP cores. The high sensitivity GNSS receiver that uses Galileo E1b+c and Galileo E5a signals in high sensitivity while simultaneously using GPS L1 C/A and GPS L5 signals in normal sensitivity. The receiver can also process Galileo E1b+c, Galileo E5a, GPS L1 C/A and GPS L5 signals simultaneously in normal sensitivity. When working in high sensitivity the receiver directly acquires and tracks Galileo E1b+c signals down to 20 dB-Hz. The receiver uses the tracking status of the Galileo E1b+c signals to track the Galileo E5a signals in high sensitivity mode.

As validation is a fundamental element, SCRIPT integrates a Remote Unit (RU) on a robotic autonomous platform. This own platform incorporates a navigation system based on GNSS, LiDAR, odometry and inertial are used to provide a ground truth to contrast the results obtained by the SCRIPT RU estimated positions and the Robotic system paths.

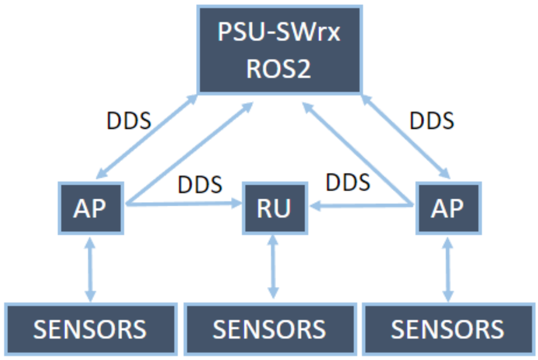
This approach ensures proper performance assessments to fine-tune the implemented solutions as allows testing campaigns to be conducted in a structured realistic environment: outdoors, light-indoor (close to buildings) conditions or indoor conditions.

The system is composed of four main elements: a Processing and Storage Unit (PSU), Access Points (APs) and Remote Units (RUs).

The PSU is a laptop computer that receives all positioning information and process the data by its SWrx, the software receiver. The communications with the APs and RU units in the system are performed over Ethernet (in the case of the APs) and Wi-Fi (in the case of the RUs). A router enables connexions between PSU and APs by wire, to minimize the propagation times. The PSU also host an NTP/PTP server that allows all units (both APs and RUs) to be synchronized by a single time reference. PSU-SWrx is connected to the Robotic platform WiFi hotspot.



SCRIPT HW Architecture block diagram



SCRIPT Communication Topology

The ROS (Robot Operating System) is the development framework for communication. ROS2 is built on top of DDS (Data Distribution Service for Real-Time Systems) allowing distribution of information among system elements.

APs are the access units placed in fixed positions (Anchor) and include:

- UWB: Decawave's anchor
- Bluetooth: Silicon Labs' mainboard and antenna array
- WiFi-RTT: Compulab's Wild Router

APs' routers are wired-connected to PSU-SWrx via Ethernet where data is broadcasted and listened by every unit (AP/RU/PSU-SWrx) via DDS.DDS is used for demonstrator communications. Fig. 2 describes the communication topology:

RUs are primarily designed to calculate their position. A RU is composed of:

- Wi-Fi RTT Module: Compulab's Wild Router
- Bluetooth Module: Silicon Labs' tag
- UWB Module: Decawave's tag
- 5G NR Emulator
- GNSS Receiver Module: CTTC GNSS SW HW Receiver and UBlox

RUs are installed on the Robotic platform with no connection between the RU devices and the platform's hardware.

The SWrx in the PSU implements the Positioning Estimator responsible for the estimation of the position of each RU. The Positioning estimator uses all data received from RUs and APs and calculates the most likely solution for the position of all RU.

As the data received from the RU and AP are asynchronous, the DATA FUSION FILTER receives the information with a time tag to know how to process the received data. The RU Position Estimation is calculated only with the data available when it is executed but considering the time instant in which each measurement was collected.

Since UWB and Wi-Fi RTT technologies are two-way ranging signals, it is possible to estimate the relative position between RUs. Therefore, when multiple RUs are available, both AP-RU and RU-RU data are available to the DATA FUSION Filter. The DATA FUSION Filter implements peer-to-peer /collaborative algorithms, exploiting ranging and/or AoA/AoD data between different RUs.

Trials started by characterisation tests of the COTS technologies under indoor conditions. Tests allowed exercising independently those technology, evaluating how both distance and obstacles in the line of sight (LoS) may affect their performance:

- UWB ranging measurements have good performance both in LoS and no-LoS conditions until a 30 meters distance, where this accuracy drops, and measurements are not always available.
- Wi-Fi RTT ranging measurements were worse, especially under no-line-of-sight conditions but ensures data availability even for 60 meters distances.
- Bluetooth angle of arrival measurements (elevation and azimuth) accuracy strongly depends on sight conditions. Good performance under LoS conditions until 15 meters distance.

Sparse Infrastructure trials are performed with one AP in static conditions, combining ranging and angle of arrival measurements. Preliminary tests show a horizontal 2D position accuracy of less than 1 meter (95-perc) under LoS conditions, up to a 10-meter distance between AP and RU.

The following tables show the final results obtained for different scenarios. These setups include tests with 1 and 2 APs, in indoor and outdoor conditions, for different technologies combinations and APs arrangements:

Indoor Frontal Setup	RU1 (Dynamic)		RU2 (Static)		RU3 (Static)		RU4 (Static)	
Route	RMS	CDF 95	RMS	CDF 95	RMS	CDF 95	RMS	CDF 95
1AP Ranging + AoA + Collaborative	2,55	5,61	1,74	2,83	3,74	8,15	5,62	11,19
2AP Ranging + Collaborative	1,66	3,40	0,52	0,98	1,51	2,49	2,46	4,40
2AP Ranging + AoA	1,26	2,27	0,60	0,84	0,36	0,46	0,19	0,36
2AP Ranging + AoA + Collaborative	1,19	2,24	0,68	1,13	0,43	0,70	0,85	0,79

Indoor test results. 2APs configuration with frontal APs arrangement.

Outdoor Diagonal Setup	RU1 (Dynamic)		RU2 (Static)		RU3 (Static)		RU4 (Static)	
Route	RMS	CDF 95	RMS	CDF 95	RMS	CDF 95	RMS	CDF 95
1AP Ranging + AoA + GNSS(x4) + Collaborative	1,45	2,57	0,67	1,16	1,16	2,45	1,63	3,40
2AP Ranging + AoA + Collaborative	1,25	2,13	0,53	0,87	0,54	0,87	0,52	0,88
2AP Ranging + AoA + GNSS(x2)	1,28	2,17	0,53	0,89	0,56	0,88	0,53	0,87
2AP Ranging + AoA + GNSS(x2) + Collaborative	1,25	2,13	0,55	0,87	0,60	0,92	0,55	0,93
2AP Ranging + AoA + GNSS(x4)	1,27	2,19	0,54	0,91	0,57	0,89	0,54	0,87
2AP Ranging + AoA + GNSS(x4) + Collaborative	1,24	2,12	0,53	0,86	0,58	0,90	0,55	0,90

Outdoor test results. 2APs configuration with diagonal APs arrangement.

The positioning results change considerably depending on whether the unit to be traced moves or remains static. For static units an error with an RMS and CDF%95 of less than 1m can be achieved. For dynamic units, at the speeds used in this project (pedestrian), an error with RMS < 1.20m and CDF95% <2.25m can be achieved, although it may also vary depending on the environmental conditions.

When APs do not cover the working area, an absolute positioning solution such as GNSS allows to increase the working area indefinitely.

WiFi RTT and emulated 5G when parallelly working with UWB only add noise to the solution since they are measures of the same nature but with much lower accuracy.

Collaborative data is of great help if there are correctly located RUs. If not, data can lead the system to a great instability, as seen in the case of the indoor test where one of the static units (RU2) reported an erroneous AoA data, and the other two were too far away.

One of the key features of the project is the Line-of-Sight (LoS) condition detector. Radio frequency measurements are strongly affected by this condition, causing a strong degradation of them. With this detector, a correct evaluation of the weight that a measurement should have before entering the filter is achieved.

SCRIPT can be easily scalable to much more populated networks with a larger number of remote units and anchors. This increase in density undoubtedly improves the performance obtained, thanks to collaborative positioning and the existence of more known references.

The potential applications of this development are practically unlimited, applications for locating and monitoring people or objects in limited service areas, such as in industrial automation, search and rescue operations, digital health (e-health) and in the entertainment industry. Environments that call for very high accuracy (<1m) and quasi-ubiquitous indoor coverage (<10m).