PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Daniele Gatti

XXXII Cycle

Training and Research Activities Report – Third Year

Tutor: Prof. Pasquale Arpaia

1. Information

a. PhD Candidate: Daniele Gatti Master’s degree in Electronic Engineering (cum laude), University of Naples Federico II

b. Doctoral Cycle: XXXII Cycle- ITEE – Università di Napoli Federico II

c. Fellowship type: No fellowship

d. Tutor: Prof. Pasquale Arpaia

2. Study and Training activities

a. Courses

- MSc Course: “Misure Meccaniche e Termiche” Prof. Rosario Schiano Lo Moriello, Naples 04/09/2019, 9 CFU..

b. Seminars

- PhD School: “*Italo Gorini 2019 PhD School*” promoted by the Italian “Electrical and Electronic Measurement” (GMEE) and “Mechanical and Thermal Measurement” (MMT) associations, Napoli, September 2st – September 6th, 2019.

CS Summary

Student: Daniele Gatti — daniele.gatti@unina.it
Tutor: Pasquale Arpaia — pasquale.arpaia@unina.it
Cycle XXXII

	Credits year 1								Credits year 2								Credits year 3									
	Estimated	bimonth 1	bimonth 2	bimonth 3	bimonth 4	bimonth 5	bimonth 6	Summary	Estimated	bimonth 1	bimonth 2	bimonth 3	bimonth 4	bimonth 5	bimonth 6	Summary	Estimated	bimonth 1	bimonth 2	bimonth 3	bimonth 4	bimonth 5	bimonth 6	Summary	Total	Check
Modules	18			9	3		9	21	15							0	15				9			9	30	30-70
Seminars	13	1	7				0.6	8.6	5							0	5				3			3	11.6	10-30
Research	34	4.50	4.50	5.40	6.50	5.50	4.00	30.4	40	9.0	7.5	7.5	7.0	6.0	8.0	45.0	20	11.50	10.0	10.0	8.5	11.5	11.5	63.00	138.40	80-140
	65	5.50	11.50	14.40	9.50	5.50	13.60	60.00	60	9	7.5	7.5	7	6	8	45.0	40	11.5	10	10	21	12	12	75.00	180.00	180

3. Research activity

a. Title

Low-cost indoor positioning and tracking measurements system for augmented reality.

b. Study

My work research in the third year has been the natural prosecution of the previous ones. In particular, the ultrasonic (US) technology and ultra-wide-band (UWB) low-cost sensor fusion for indoor localization has been investigated. The research is focused on how to use low-cost electronics in order to define the position and the target heading measurements in an harsh environments.

In general, the localization problem starts with a preliminary ranging of reference fixed beacon node. After that, the position of a target to be localized, can be extracted by additional measures of the relative distance (spatial or angular), between the beacons and target itself.

The most common positioning algorithms are the triangulation and trilateration. The first uses measured angles to calculate the coordinates of an unknown target position, while the trilateration uses measured distances from beacons to the unknown target position.

In most cases, the inertial measurements unit (IMU) is combined with the position measurement system, in order to track both the position and the orientation of a target
Traditional IMU-based guidance and tracking system exploit several sources of data, such as accelerometers, gyroscopes, and magnetometers.

The gyroscope is a sensor capable of measuring the rotation rate of a body, while the accelerometer is a device which measures the velocity change rate of an acceleration with respect to the inertial frame of the object.
Both the data acquired from those sensors have to be integrate over the time, in order to measure the position.
The magnetometer instead, is a device which measures the strength and direction of a magnetic field.

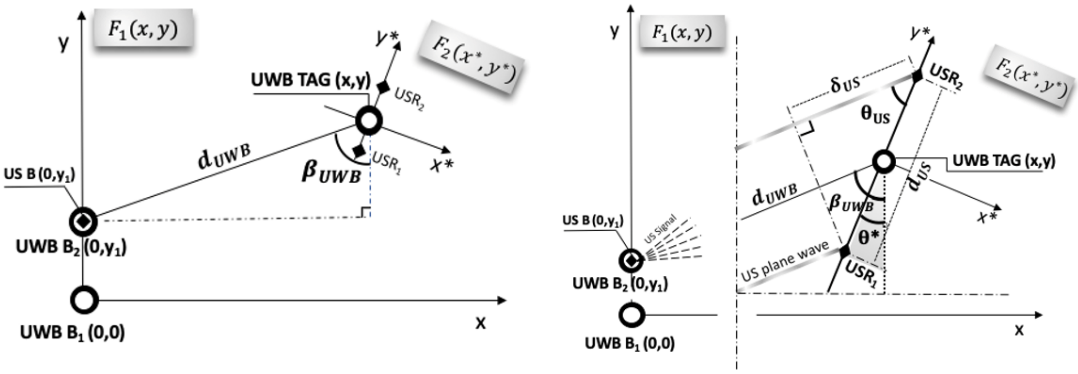
The IMU based positioning measurements system suffers from drift issues in the position estimation. The presence of a bias error, causing the drifting in the position estimation during the integration. Nevertheless, the IMU measurements drift is usually compensated by the position measurements from the positioning tracking system.

Similarly, the same drift issue is present also for the orientation measurements. In fact, when the gyroscope is not under-going any rotation, an angular error which grows linearly with the time is present, due to the bias error and the integration process.
The accelerometers were used to compensate this gyroscope drift for the pitch and roll static orientation.

The magnetometers were used for the static yaw angle estimation and for the dynamic assessment of all angles.
The magnetometer measurements are necessary for both the yaw angle estimation and the dynamic assessment of all angles during a position evaluation. In particular, they are useful for the yaw drift correction. However, magnetometers are not reliable in harsh magnetic conditions due to the hard and soft iron effect (e.g. presence of the residual magnetic field in the metal object).

c. Research description

The proposed method is a free-magnetometer heading estimation, based on UWB location system and the US measurements. The UWB was adopted for the distance measurements and then, the position was computed by the trilateration technique, combined with an Extended Kalman Filter (EKF).
The heading was estimated by measuring the phase-shift between two received US signal and by applying the standard sine-fit algorithm. I decided to combine the ultrasonic system whit the UWB, by mixing the information from both the systems: the ultrasonic technology for the heading measurement and the ultra-wideband for the distance measurements [1].



(1a) (1b)

In Fig.(1a) the geometrical measurements problem is sketched. Two frames (F_1, F_2) were considered. In the frame F_1 two UWB beacons (UWB $B_{1\text{-}2}$) and one US emitter are placed. In the frame F_2 one UWB beacons (UWB TAG) and two US receivers ($USR_{1\text{-}2}$) are placed.

The heading θ* in Fig.(2b) is equal to:

$$\theta^* = \beta_{UWB} - \theta_{US} \; (1.1)$$

Where:

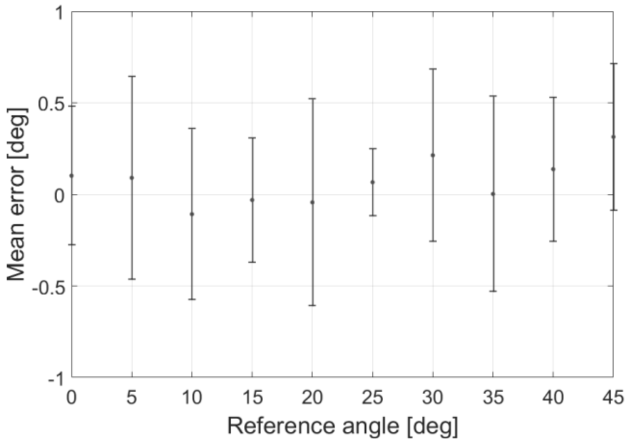
$$\beta_{UWB} = \cos^{-1}\frac{y - y_1}{d_{UWB}}, \theta_{US} = \cos^{-1}\frac{\delta_{US}}{d_{US}}$$

The β_{UWB} is the correction terms from the UWB measurements. The d_{US} is the distance between the US receivers, and the distance δ_{US} is the phase shift of the received plane wave.
Considering a sinusoidal output voltage from the USRs, the δ_{US} can be written as a function of the received cosine signal phase difference δ_{φ}.

$$\delta_{US} = \frac{\lambda\delta_{\varphi}}{2\pi} = c\delta_t$$

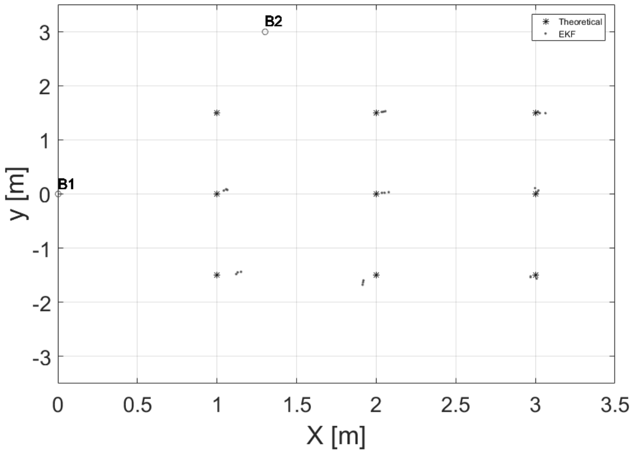
Where λ is the US wavelength, δ_{φ} the phase difference, c the speed of sound, and δ_t the US plane wave time difference between the waves arrivals at the US receivers. The δ_t can be computed through the zero-crossing method or the phase difference measurements technique. However, this latter technique offers bad performances in the presence of noise in the received signal. For this reason, I decided to explore the application of a three parameters sine-fit algorithm in order to extract the phase difference of the ultrasonic received signal.

Observing the equation (1.1) the heading uncertainly has two contribute, one from the β_{UWB} estimation and another from the US θ_{US} heading measurements. The different contribute has been studied separately.
First, the US uncertainly contribute is considered.
For the received US signal, the damped sinusoid model (according to the sensor response) and an SNR = 40 dB was assumed. The US receivers distance was assumed $d_{US} = 5\,mm$ according with to the ambiguity phase condition $\delta_{US} < \frac{\lambda}{2}$ considering 25 kHz frequency for the US signal.



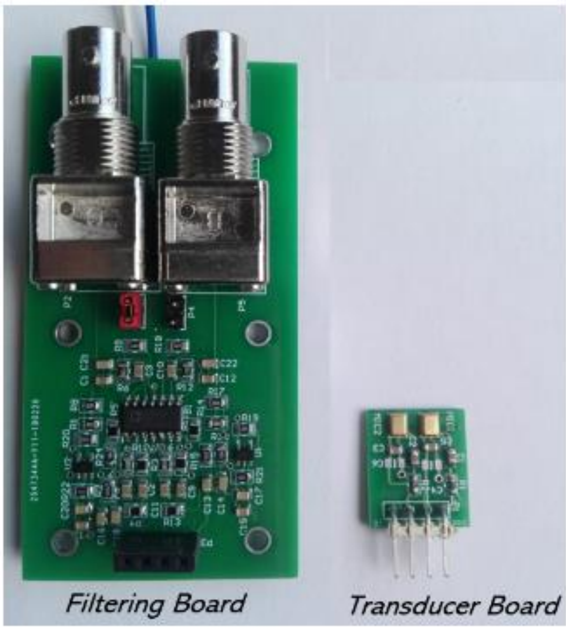
The maximum mean error is $\varepsilon_{US} = 0.31[deg]$ with $\sigma_{US} = 0.57\ [deg]$ standard deviation.

The β_{UWB} uncertainty contribute was computed by studying different target positions in the reference frame. A grid of nine different positions were considered:



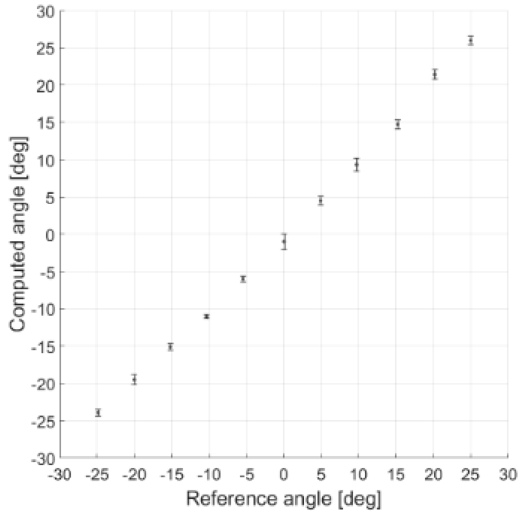
Ten consecutive measurements were considered for each position in order to evaluate the β_{UWB} uncertainty contribute together with the uncertainty on the target position. According to the *DecaWave-DW1000* UWB module specification, for the distance measurements noise evaluation, a standard deviation of $\sigma_d = 10\ \ [cm]$ was assumed.
The mean difference between the reference position "$*$" and the EKF output is $\varepsilon_{EKF} = 11.5\ [cm]$ with a $\sigma_{EKF} = 5.0\ [cm]$ standard deviation. The maximum mean error is $\varepsilon_{\beta UWB} = -1.1\ [deg]$, and $\sigma_{\beta UWB} = 1.2\ [deg]$ standard deviation.

The US heading system has been prototyped and metrologically characterized. One custom board with two MEMS ultrasonic microphone and, two analog filtering board has been designed and realized, as it is shown below .



During the research work, also a low-cost goniometer was developed.
The low-cost goniometer is based on an high-precision potentiometer and a mechanical precision rotative system. The low-cost goniometer deterministic error is of 0.70 degrees and 1-σ repeatability of 0.06 degrees.
The device was developed in order to validate the proposed heading system.

The meteorological performance of the proposed heading measurements system is of 1.2 degrees maximum deterministic error with 1-σ repeatability of 0.8 degrees. Those values are comparable with the state of the art magnetometer-based heading systems.
The measured angle with respect to the estimated and standard deviation for each measurement is sketched:



The algorithm was implemented on ARM STM32F3 in order to test the computational cost. Two records of 1000 samples, digitized at a sample rate of 5 MSa/s, were considered. The sine-fit cosine and sine coefficients were calculated offline and stored in the microcontroller flash memory, in order to reduce the computation time. A throughput of 505 Sa/s was achieved, with the 85% time effort arising from the sine-fit algorithm, and the remaining part mainly from the heading calculation.
The integration of the complete system (UWB and US Heading system) with the accelerometer and the gyroscope is needed in order to improve the accuracy of the measurements.

Products

d. *Paper submitted*

[1] P. Arpaia, U. Cesaro, D. Gatti, N. Moccaldi, "Ultrasonic heading measurement under strong magnetic interference" Submitted on IEEE TIM.

4. Conferences and Seminars

5. Activity abroad

I didn't spend time abroad.

6. Tutorship

I didn't a tutorship activity.