An IMA-based Centimeter Precise Positioning for Smart Mobile Devices in Hostile Environments

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***Abstract*— The growing use of multi-positioning systems is contributing to improve the coverage and the accuracy of the positioning services. We have combined real-time image analyses embedded on smart mobile devices to improve the availability and the accuracy of positioning services in indoors and outdoors environments. We have leaded a study on several cameras from the market to measure the impact of brightness, the distance and the angles (tilt and azimuth) from cameras to markers, the positioning accuracy, the fluidity of calculus and the number of markers being processed simultaneously. A first test scenario, conducted inside a blind room being enlighten with conventional lights, show a positioning error varying from 2 to 5 % when the distance and the angle does not exceed 7 meters and 150° respectively. Two others experiments were conducted. The first one, by monitoring an AR-Drone with 2 cameras (front and down), a GNSS actuator, and a disseminated Wi-Fi infrastructure positioning system, we have demonstrated the feasibility and the pertinence combining multi-positioning systems (GNSS, Wi-Fi and image marker analysis) to better match a 2D marker database, and provide an improved accuracy from 8 meters outside (GNSS) and 4 meters inside (Wi-Fi) to centimeter precise positioning.**

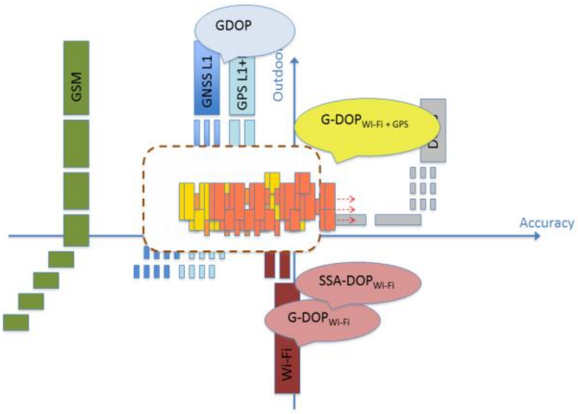
Keywords-component; indoor positioning, positioning algorithm, QR-TAG, natural marker, multi-positioning system, image analysi.

I. Multi-Positioning Systems Enriched with Image-Marker Analysis ?

During the last decade, the human or mobile terminal positioning become, more and more, a key software-market development pillar. The growing use of multi-positioning systems is contributing to improve the coverage and the accuracy of the positioning services. When combined with the diversity of new actuators and smart sensors on hand held devices, cooperative and multi-positioning systems are yet perfectible and expensive.

As presented in Fig.1, among the principal Positioning Systems widely used we have the GSM-based ones, the GNSS-based ones and the Wi-Fi-based ones. When used alone or combined, they tend to cover indoor and outdoor environment, offering and improving an accuracy ranged between 200 meters are less in urban canyon, to 1 to 8 meters in public hall and rural areas [1]. Aside last half-decade scientific researches, which address geometrical and signal analysis to better switch from one PS to another more accurate one's, very first hybrid and combined positioning systems are emerging [2]. In this paper we investigate further Image Marker Analysis (IMA), as a software component, to be associated with camera embedded on the mobile device. The couple (IMA software component, embedded camera) has undoubtedly the more promising potential to improve the ratio accuracy of the combined positioning system over the cheaper price of an additive SoftWare-HardWare component (see orange block displacement represented in Fig. 1 when associated.

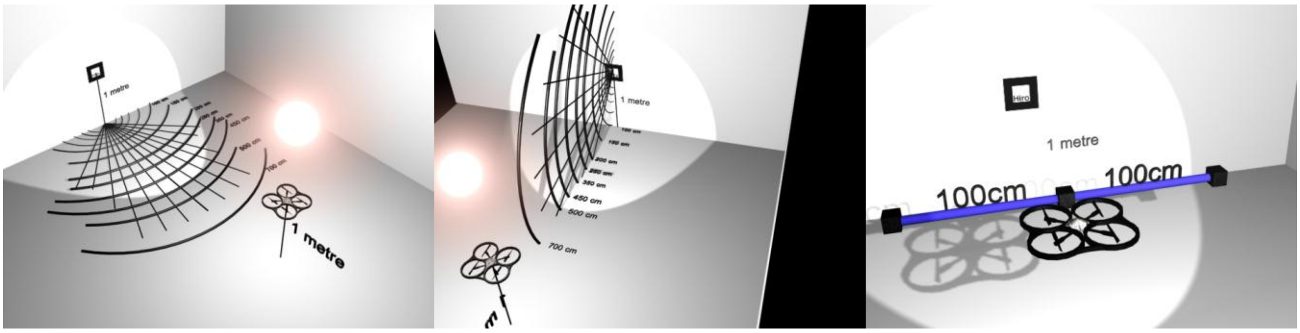
We propose to combine real-time image analyses embedded on smart mobile devices to improve the availability and the accuracy of positioning services in dash environments (indoors and outdoors environments).



GDOP and SSA-DOP designate respectively geometric and signal strength attenuation dilution of precision criteria. When suffixed with Wi-Fi and GPS-Wi-Fi, that characterizes the associated positioning system.

Figure 1. Accuracy and Coverture of Principal Positionning Systems

In the sequel, first we introduce the experimentation we have conducted on several cameras from commercial market, in order to measure the accuracy of our combined multi-positioning system. Second we describe two other experiments being conducted, one demonstrate the feasibility and the pertinence to combine a GNSS-Wi-Fi and IMA multi-positioning system in a realistic scenario when navigating through a continuous outdoor and indoor itinerary. The other is an augmented reality based audio-guide being experimented to better assist a roman amphitheater visit. We finally conclude and present the perspectives of future works.



On the left, horizontal positioning variation of the camera always oriented to the center of the 2D-QR-TAG, on the middle, vertical variation's one, and on the right, lateral positioning variation 'one with the camera orthogonally oriented to the front wall.

Figure 2. Descriptive schema of horizontal and vertical measurements of euclidian distance between a frontal AR-drone camera and a 2D-QR-TAG.

II. Real-Time QR-TAG analysis allows a centimeter accuracy in indoor environment

We have leaded a study on several cameras as those available on AR-Drone, Samsung Galaxy Tab, and Android smartphones to measure the impact of brightness, the distance and the angles (tilt and azimuth) from cameras to 2D-markers, the positioning accuracy, the fluidity of calculus and the number of markers being processed simultaneously.

Real Euclidian distance Drone::QR-TAG (in cm)	**10**	**30**	**50**	**80**	**100**	**150**	**200**	**250**	**350**	**450**	**500**	**700**
Estimated distance (in cm)	10,3	31,5	55,2	88,4	110,3	158,1	220,1	261,3	362,2	462,2	514,3	726,4
NY-Artoolkit confidence ratio (in %)	98	86	87	75	75	68	64	59	56	58	57	52
Error value (in cm)	0,3	1,5	5,2	8,4	10,3	8,1	20,1	11,3	12,2	12,2	14,3	26,4
Error ratio (in %)	3	5	10,4	10,5	10,3	5,4	10,05	4,52	3,48	2,71	2,86	3,77

a) Distance error evaluation of the frontal AR-Drone camera-based positioning estimation

Real euclidian distance Drône::QR-TAG (in cm)	**10**	**30**	**50**	**80**	**100**	**150**	**200**	**250**
Estimated distance (in cm)	7	34	60,2	72,9	130,2	154,3	225,1	not estimated
Error value (in cm)	3	4	10,2	7,1	30,2	4,3	25,1	not estimated
Error ratio (in %)	30	13,3	20,4	8,9	30,2	2,86	12,55	not estimated

b) Distance error evaluation of the ventral AR-Drone camera-based positioning estimation

TABLE I. Distance error evaluation of the frontal and ventral AR-Drone camera-based positioning estimations

A first test scenario, conducted inside a blind room being enlighten with conventional lights, show a positioning error varying from 2,71 to 5 % when the distance and the angle does not exceed reasonably 7 meters and 150° respectively.

Fig.2 schematizes the manner the measurements were performed to study the camera-based positioning error of an AR-drone. The 3 following tables recapitulate the collected data (in cm) and the estimated distances and errors.

The first table is established through an extended NY-Artoolkit QR-TAG algorithm, in a blind room only highlighted with a common 60w lamp. This algorithm provides on-the-fly the positioning evaluation of one to 5 visible QR-TAG. The luminosity is computably improved. These initial measures show the interest to use common embedded camera to help establishing centimeter precise positioning. Also, the confidence ratio provided by NY-Artoolkit library appears not correlated to the accuracy of the QR-TAG positioning. The sub-table 1.b) confirms the previous 1.a), even using the low quality ventral camera of the AR-Drone. In Table 2, the horizontal and vertical placements of the mobile AR-Drone device are varying. The estimated positions are even better than those obtained in the previous benchmark. The error is in a millimeter range if we vary the tilt (sub-table 2.a), with a stable 1 meter high placement of the frontal camera, in front of the 2D-QR-TAG.

TABLE II. DISTANCE ERROR EVALUATION THOUGH ANGLE PLACEMENT VARIATION OF THE FRONTAL AR-DRONE CAMERA

Angle \ Real euclidian distance Drone::QR-TAG (in cm)	10	30	50	80	100	150	200	250	350	450	500	700
45°	1,2	1	1,2	2,1	2,6	2,8	1,6	0,24	1,3	0,1	0,01	0,08
60°	0,01	1,001	1,0002	1,001	1,01	1,0002	1,0002	1,004	1,002	1,0007	1,002	1,00009
90°	1,002	0,01	1	1	1	1,000007	1,00001	1	1,0006	1,0002	1,002	1,00006
130°	1,13	0,983	0	0	0	0,7	2,6	1,1	0,1	1,1	2,01	0,8

a) **Distance error evaluation of the frontal AR-Drone camera-based positioning estimation by varying the tilt**

Angle \ Real euclidian distance Drone::QR-TAG (in cm)	10	30	50	80	100	150	200	250	350	450	500	700
30°	10,01	30,02	50,1	80,1	100,3	x	x	x	x	x	x	x
45°	10,3	31,1	50,09	81,1	101,06	147,1	201,6	250,24	348,7	450,1	x	x
60°	11,01	31,09	51,01	82,1	101,1	150,03	200,04	251,02	350,8	450,3	501,01	702,06
90°	10,02	30,01	50	80	100	150,001	200,002	250	350,2	450,1	501,02	700,04
130°	10,3	31,1	51,03	80,1	100,06	147,08	201,6	250,24	348,7	450,2	x	x
150°	10,01	30,02	51,1	81,1	100,3	x	x	x	x	x	x	x

b) **Distance error evaluation of the frontal AR-Drone camera-based positioning estimation by varying the azimuth**

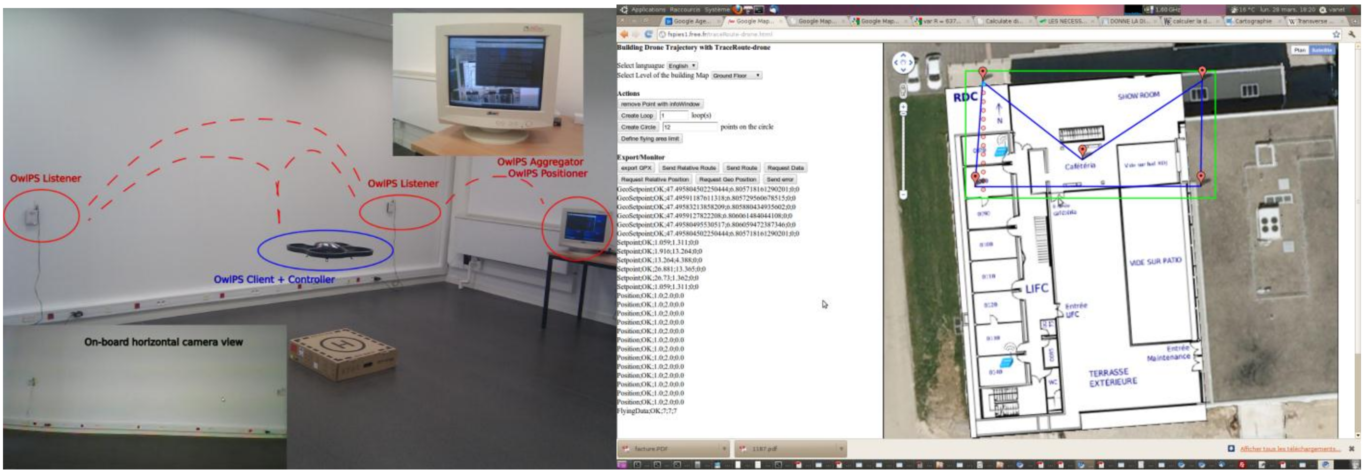
The estimated errors never exceed 2.5 centimeters if we vary the azimuth (sub-table 2.b), with a stable 90° tilt placement of the frontal camera, that means orthogonally to the font wall where the 2D-QR-TAG is.

III. TOWARDS MORE COMPLEX SCENARIOS TO BETTER EVALUATE THE PERTINENCE OF IMA AUGMENTED MULTI-POSITIONING SYSTEM

Figure 3. Two screenshots of a multi-positionning prototype which merge GPS positionning with Wi-Fi's one and our Real-Time Image Marker Analysis based positioning algorithm

Two others experiments were conducted. The first one (see Fig.3), by monitoring an AR-Drone equipped with 2 cameras (frontal and ventral, a Global Navigation Satellite System based positioning system (e.g. gps), and a disseminated Wi-Fi infrastructure positioning system, we have demonstrated the feasibility and the pertinence combining multi-positioning systems (GNSS, Wi-Fi and image marker analysis).

Such association allows reducing the complexity how better



On the left, the flying drone streams two image flows captured by the frontal and ventral cameras and transmits them to a server. The AR-drone also captures the Wi-Fi signals and the GPS signals when available. So that the Image Marker Analysis based positioning algorithm is integrated in a multi-positioning system. This multi-positioning system is a Femto-st prototype being developed since 2011. It is realized extending the OwIPS system [1] with a GPS positioning module.

On the right, a screenshot of the OwIPS monitoring tool is presented. It transmits the complex itinerary of the flying drone through outdoor and indoor environment.

match a 2D marker database when envisaging an IMA-based positioning system. This association provides also an improved accuracy from 8 meters outside (GNSS), and 4 meters inside (Wi-Fi), to centimeter precise positioning.

As a use case we deployed OwlPS [3] near Numerica building, which hosts our research OMNI team of the DISC department of Femto-st Institute. We especially deployed it indoor, in a large room (10:50m - 6:5m) with four Wi-Fi APs (Fonera 2.0 running OpenWRT Kamikaze, which is an embedded Linux distribution) fixed to the wall near each corner of the room. The APs include a Radiotap-enabled Atheros Wi-Fi chipset [5],

Analysis based algorithm is activated after either the GPS module, or the Wi-Fi's one, delivers an initial positioning estimation. Then the Real-time image analysis is performed concurrently to the Wi-Fi gps combined positioning system. When a QR-TAG is identified, then the positioning estimation is switched to the IMA-based positioning algorithm.

This experimentation was very conclusive and demonstrated the feasibility conceiving and realizing a centimeter precise positioning system based on QR-TAG positioning analysis, on the fly. It refines Wi-Fi and GNSS based positioning in hostile environments.

On the left, a view of the roman amphitheater of Mandeure (France, Doubs). On the right, the image marker analysis is performed to superpose a stable 2D animations to the real-time image acquisition.

configured with the MadWifi tools [6].

The aggregation and positioning software modules are both installed on an Asus EeePC running Debian GNU/Linux. Finally the located device is a Parrot AR.Drone [4] which is a quadricopter running an embedded Linux kernel. This drone integrates horizontal and vertical cameras and an Atheros Wi-Fi chipset. The sub-figure Fig. 3.left shows an annotated photograph of the room and hardware. The superimposed image in the bottom-left corner is the view of the drone's horizontal camera.

All the modules communicate through an ad-hoc network; this is possible because the Wi-Fi interfaces of the APs support running several modes (ad-hoc and monitor) simultaneously. If the Wi-Fi interfaces are single-mode only, a wired (Ethernet) network can be set-up, or a second Wi-Fi interface can be added on the APs.

A roadmap is sent from a web interface (see sub-figure Fig. 3.right) to the software running inside the drone. The positions computed by the system are then used by this embedded software to allow the drone to move by itself, following the roadmap provided by the user.

As a realistic scenario, we disseminated several QR-TAGs of various sizes in the hall of Numerica building and in the described room indoor. Hence, the underlying Image Marker

Figure 4. Three screenshots of a reality-augmented audio-guide prototype which integrates a very first Real-Time IMA-based positioning algorithm.

The second and recent experiment conducted has adapted the IMA-based positioning algorithm with 2D key points' natural markers to better position a Galaxy Tab smartphone and apply a virtual 3D animation above a real picture of a roman amphitheater.

This experimentation has shown that our approach, based on 2D QR-TAG or natural marker analysis, allows an accurate positioning, and allows to insert a stable 3D-animation within smartphone augmented reality applications.

IV. CONCLUSION AND PERSPECTIVE

In this paper we have reported a combined real-time image analyses embedded on smart mobile devices to improve the availability and the accuracy of positioning services in indoors and outdoors environments. We have leaded a study on several cameras from the market to measure the impact of brightness, the distance and the angles (tilt and azimuth) from cameras to markers, and the positioning accuracy. A first test scenario, conducted inside a blind room being enlighten with conventional lights, show a positioning error varying from 2 to 5 % when the distance and the angle does not exceed 7 meters and 150° respectively. Consecutively to two other experiments we have demonstrated the feasibility and the pertinence combining multi-positioning systems (GNSS, Wi-Fi and image marker analysis) to better match a 2D marker database, and provide an improved accuracy from 8 meters outside (GNSS) and 4 meters inside (Wi-Fi) to centimeter precise positioning.

These results were so promising that we are currently involved in a 3D-reality-augmented audio-guide demonstrator project. There, several additive studies are required. First, it is necessary to appreciate the fluidity of calculus of the IMA-based prototypes, and the number of markers being processed simultaneously. Second, the natural markers considered in this paper are 2D-markers which are not exposed to deformation. We have to investigate further 3D markers.

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