PAPER TEMPLATE

TAXISAT: A driverless GNSS based taxi application capable of operating cost effectively

Oihana Otaegui[1*], Olivier Desenfans[2], Lauriane Plault[3], Arnaud Lago[4]

1.Vicomtech-IK4, Pseo Mikeletegi 57 20009 San Sebastian, Spain, +34 943309230 ootaegui@vicomtech.org

2. M3Systems, Brussels, Belgium

3. Capital HighTech, Bordeaux, France

4. Robosoft, Bidart, France

Abstract

Although automatic and driverless vehicles do operate nowadays most of these systems are currently guided by railways, fiberglass or magnetic wires. More recently, a few demonstrations have been undertaken in order to demonstrate the capabilities of satellite based navigation systems to clear the roads from such heavy infrastructures. TAXISAT aims at developing a new driverless GNSS based taxi application capable to operate cost effectively, safely and with a high reliability within private circumscribed sites whatever their topographic configurations are. The key innovation features of TAXISAT vehicles consist in its navigation system which take advantage of the EGNOS and GALILEO capabilities themselves augmented through hybridation with COTS inertial sensors, odometers, and SLAM technology. TAXISAT therefore aims at demonstrating a low cost, reliable and secure driverless vehicle hybridizing EDAS, GNSS and visual SLAM technologies improving the integrity, reliability and availability of the unmanned driving services even in case of temporary canyoning or tunnelling. Additionally TAXISAT is not only a software module capable of handling with different nature of sensors but a low cost commercial solution (sensors + SW + mapping) for being used in any unmanned transportation system.

Keywords:

GNSS, EDAS, EGNOS, ADAS, visual SLAM, Unmanned Driving

TAXISAT Concept

Satellite localization based unmanned vehicles are a present reality but the cost of their GNSS based navigation equipment remains a brake on the wide adoption of these vehicles. Moreover, these kind of vehicles have reduce their velocity when driving along “urban” scenarios and as soon as ‘light’ canyoning effects are observed. As a result, end users are not satisfied with this kind of experiences.

Therefore TAXISAT faces the development of sophisticated GNSS algorithms to be hybridized with inertial sensors and odometers on one hand and with visual SLAM sensors on the other hand should allow improving the integrity, reliability and availability of the TAXISAT services even in case of temporary canyoning or tunnelling.

State of the Art

There are two main technology pillars for the development of unmanned transport systems: GNNS sensors and Video Analysis This paper describes the development of an integrated IMU, GNSS and image recognition sensors for unmanned driving.

Low cost, high sensitivity GNSS sensors can be used in urban areas, however the accuracy of the position can be substantially degraded. The combination of low cost, IMU and GNSS receiver is therefore promising. Another significant issue with low cost IMUs is heading error. At the start of navigation, an initial heading measurement is required which is difficult to obtain. Expensive IMUs can be used to derive an initial heading by measuring the rotation of the Earth, however low cost sensors are not sufficiently sensitive to do this.

The problem of recovering relative camera poses and 3D structure from a set of monocular images is in computer vision known as Structure From Motion (SFM) [1]. Many researchers have presented solutions for SFM using perspective and omnidirectional cameras (see e.g. [2]). Closely related to SFM is the problem of Simultaneous Localization and Mapping (SLAM), which aims at estimating the motion of the robot while simultaneously building and updating the environment map. SLAM has been most often performed with other sensors than regular cameras, however in the last years successful results have been obtained using single cameras alone (see [6]).

Although there are many algorithms for vision-based motion estimation available, they have not yet been used largely on mobile robots, and even less in autonomous cars. The major reasons for this are the complexity, the unsufficient robustness and the computational costs of these algorithms, making them unsuited for real-time applications. In recent work [10], we showed that this can be addressed by using a restrictive motion model which allows us to parameterize the motion with only one feature correspondence.

Using a single feature correspondence for motion estimation is the lowest model parameterization possible and results in the most efficient algorithms for removing outliers.

There exists some driverless vehicles products on the market equipped with the previously mentioned technologies which are more for exhibition and testing than a real product for medium-mass markets, some of this products are previous products from the same manufacturer as TAXISAT.

The VolcanBuls are three electric vehicles guided by GPS and designed by ROBOSOFT. The localization system of Volcanbul is computed by the OXTS inertial+ associated with a D-GPS; the GPS signals must be RTK to ensure a high accuracy The limitation of this system is in the constraints imposed by the GPS reception that could be blocked by high buildings or trees. The site operator has to cut trees or possible blocking elements. Moreover, the system does not ensure 100% of reliability, some issues appears when the GPS signals are not RTK due to masked constellations. The positions computed are not enough accurate to ensure the corrections of the inertial system. In this case all vehicles are stopped and driven manually

The robuRIDE28 is an electric vehicle completely autonomous, dedicated to the transportation of people. It is the second generation of Volcanbul with a new real-time control the innovation consists in computing an accurate localization using INS sensors and D-GPS system in order to avoid IMU and reduce costs. This new system only reduces the cost but the issue still the same

The PRT developed by 2getthere are small automatic vehicles running on their own guide way network. The navigation system used is the FROG system that mixes odometers and magnets in the road which implies inversions on the infrastructures. This system computes continuously longitudinal and lateral position of vehicles, ensuring that external influences are automatically corrected.The vehicles use a combination of on board digitals maps, odometry and magnets in the road for guidance, the FROG (Free Ranging On Grid) system.

The CYBERGO is a driverless 8 passengers robotized shuttle from INDUCT CYBERGO is based on two kind of technology for its localization in the environment: laser range finders (LIDAR) and several cameras and sensors. With all data sent by the sensors, the system produces a mapping of the immediate environment which allows driving the vehicle in its path).

All these commercial products have a mayor limitation in market acceptability which is the price of the vehicle sensorization. Googlecar is another example of the unmanned vehicle development which has been successfully tested, nevertheless the sensoring of the vehicle elevates the vehicles car in 300.000 $.

Major Benefit Brought by TAXISAT

The navigation system presented in this paper attempts to improve the inadequacies of GPS vehicle navigation through augmentation with dead-reckoning sensors and GNSS. GPS suffers from signal masking and multipath errors in areas such as urban canyons, densely treed streets, tunnels, and parkades. A variety of sensors are available for augmenting GPS the main problem is combining the most appropriate sensors in terms of accuracy and price. For vehicle location and navigation, sensors must be chosen to add minimal cost to the production or modification of a vehicle, while delivering continuous position availability with accuracy better than 2 meters and less than 10 centimeters in terms of lane departure-

The objective of the TAXISAT project is different from other research initiatives and projects in the sense that TAXISAT does not aim at realizing a universal localization system but aims at building an operational localization and adaptive navigation system that will allow providing a cost□effective and reliable automated transport solution.

Thus, the TAXISAT approach is not only based on the definition of a new localization solution but also on the implementation of an integrated solution where localization, navigation and information on the environment context are closely coupled to generate a generic method allowing to deploy such a solution on any site.

Some components of the TAXISAT solution can be found in the solution proposed by other initiatives; for instance, low cost sensors like 2D laser scanners will be used as inputs system for localization and navigation but information about the environment (3D reconstruction), low cost 6FoD visual sensors and advance path matching dead reckoning plus GIS and 3D reconstructed information also be integrated in the TAXISAT solution which will bring into market the first cost competitive product in the sector of automatic driverless market.

We propose a novel visual odometry algorithm for estimating the 6-DoF egomotion of a mobile robot using visual input from an on-board stereo head. The proposed approach is based on the detection and tracking of scale invariant features and employs an iterative scheme for effective outlier removal using 3D stereo data.

Architecture

The high-level overall architecture of the TAXISAT prototype is composed of the two systems with the following subsystems:

- Positioning system:
    - The positioning sensors, which purpose is to deliver low-cost sensor data (based positioning information composed by classical ones e.g gyroscopes and odomteres and new ones such as cameras where an added value for motion estimation and localization is added) to the positioning module that will perform the data hybridisation; The sensors included a GNSS receiver with access to raw data
    - The EDAS connection module, which purpose is to provide EDAS data to the positioning module;
    - The positioning module, which is in charge of the positioning data hybridisation in order to provide to position of the TAXISAT prototype to the Navigation module with a high accuracy and reliability;
- Navigation system:
    - The navigation module, which host the vehicle control law and ensure that the prototype follow the defined trajectory;
    - The Safety module, which purpose is to ensure the safety (for passengers, for surrounding people, …).

SLAM and Follow the Lane Sensors

One of the main contributions of TAXISAT is the use of video based positioning systems. The input of the video positioning module aims at enhancing its performance level compared to usual INS/GNSS hybrid system. The accuracy as well as the reliability, the robustness and the continuity of the TAXISAT hybrid-positioning module is increased thanks to the use of video analysis.

Video based positioning constitutes an additional source of data which, in itself, is already an improvement of the hybridisation process performances. In addition, thanks to an expected precision of about 10 cm and a rate of about 25 Hz, video will increase the efficiency of the INSs drift adjustment and correction which will increase the system accuracy.

TAXISAT video based positioning provides information about transversal displacements and estimations of velocity and orientation from a low-cost stereo pair camera system, and the associated video-based analysis algorithms. Novel trends on video positioning like Simultaneous Localization and mapping (SLAM) have been included in order to obtain more robust and reliable positioning information through the application of inference probabilistic methods.

Visual SLAM techniques implies the simultaneous computation of the pose of the cameras and therefore of the vehicle itself and the structure of the scene. Special efforts have been made to obtain dense landmarks reconstruction such that texture mapping can be applied from images to 3D meshes. This information also is valuable for hybridising with GIS information and computing and accurate map of the scene that enhances the accuracy when computing the trajectory of the vehicle.

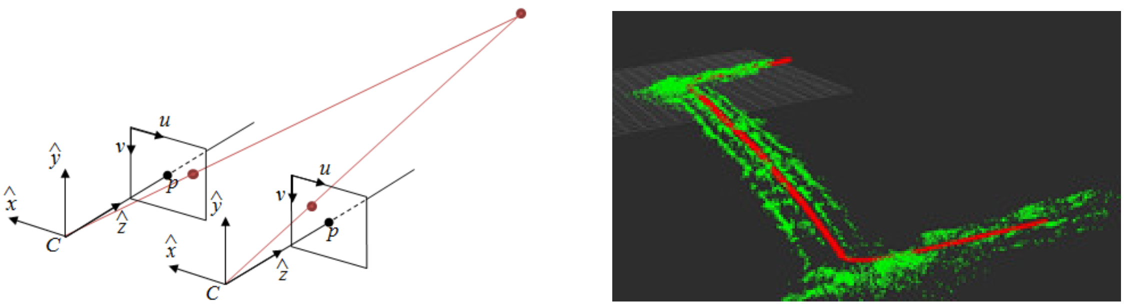


Figure1: Visual SLAM comutation and 3D Map generation

The use of a stereo pair provides much more information about the motion and structure of the scene than a single camera set-up. In comparison, a stereo pair can provide a point-wise correspondence between points of the same 3D elements seen from the two available views.

The accumulation of the obtained rotation and translation information can be used to reconstruct the 3D trajectory of the vehicle

The strategy followed in this work is based on the computation of matches using a **keypoint detector**, a **keypoint descriptor**, and a **keypoint matcher**. These steps can be described as follows:

- **Keypoint detector**: this is a module that analyzes an image and determines the position of points that seems to be significant in a local or global manner.
- **Keypoint descriptor**: this is a module that generates a "description" of a keypoint in terms of a vector or numbers according to properties of the keypoint in a local or global manner.
- **Keypoint matcher**: this module compares descriptions of keypoints in different images in order to find pairs of keypoints that have similar descriptions and thus seem to correspond to the same point of the 3D reality in different views.

The appropriate combination of such three modules is critical, and for that reason many effort has been devoted in the scientific community to provide triplets of methods that work well in several situations.

The stereo visual odometry system has been implemented following a multi-thread approach. The reason is that capturing and processing are asynchronous events that must be handled carefully. The use of multi-threads allows us to synchronize such events. Moreover, the designed approach makes that the SW system can be run in CPUs with different computational power

In our experiments we have reached output frame rates up to 25 fps (40 ms) in an Intel(R) Core(TM)2 Quad CPU Q8300 @ 2.5 GHz.

Additionally and to limit the horizontal error a Follow the lane module has been included to assure that the vehicle is not going to left the lane under any circumstances. In that sense, this module is both an additional source of information about the lateral position of the vehicle for the positioning module as well as a safety net providing lateral position boundaries (in case the other positioning module fails).A multiple-lane model composed of the center lane and the adjacent left and right lanes is proposed. This moduleprovides: Tx: (lateral) translation in x, Vx: linear velocity in x, Wx: width of the lane, dWx: linear velocity of the change of width, Self Assesment values and Active Control of Light Conditions. An specific light control module has been developed a specific adapted control mode for the camera, which adapts the parameters of shutter, gain and exposure of the camera according to the perceived conditions of the environment.

Figure 2: Follow the Lane Module's Output

Sensor Data Hybridization Module

The hybridisation module is represented inFigureX. It relies on an inertial navigation system

(INS) that integrates the flow of data provided by the odometer and gyrometer of the vehicle. Then, GNSS and Video measurements are added to the navigation filter to estimate and compensate the drift of the inertial sensors

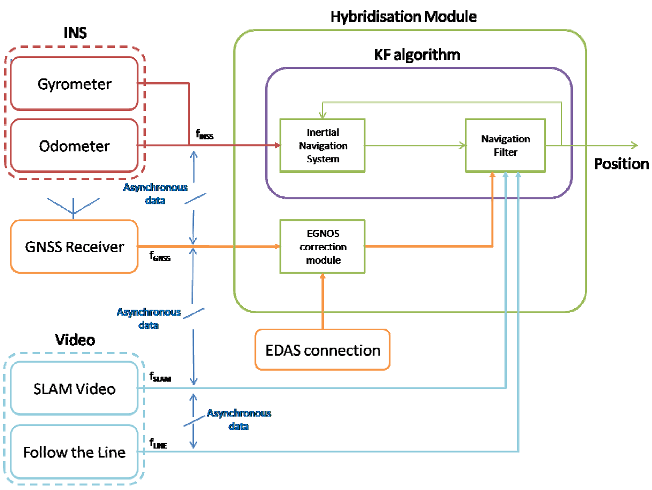
The adjustment of the inertial sensor drift will be performed by the navigation filter fed by the GNSS and Video system measurements. The navigation filter will be also useful in order to compare the incoming data with the current system state, to assess and verify the measurement consistency with it and to update once the measurements have been validated.

. A tight hybridisation solution has been chosen data of interest are the pseudoranges and the Doppler measurements. If some of them are identified as potentially affected by some errors, these faulty measurements can be rejected whereas the healthy measurements can be still taken into account by the hybridisation process.

Finally, it is worth noting that the GNSS sub-system is based on a GNSS receiver (GPS/SBAS) and a connection to EDAS (landline connection to EGNOS data). The use of EDAS to provide EGNOS correction aims at increasing as much as possible the system reliability. Indeed, EGNOS, as every single satellite-based system, implies that its satellites be visible for the receiver.

EGNOS messages will be forwarded to the TAXISAT vehicles and used in the following ways:

- Correction of the pseudoranges to improve the accuracy of the measurements provided to the Positioning module
- Computation of the standard deviations which gives the real time accuracy of the pseudorange measurements after correction



Figure·3: Flow Diagram of the Hibridization Algorithm

Simulation

First complete system simulations have been carried out for the Assessment of nominal performances or with perturbations on GNSS (Multipath, mask), and for Robustness assessment according latency on measurement time stamping, sensor quality.

Additionally Monte Carlo simulation has been used to assess the statistical performances over a large test data

TAXISAT Vehicle

The vehicle control laws have been developed and widely simulated with a promising result result of 2cm positioning repeatability and maximum lateral error of 25 cm.

Length	2.1 m
Width	1.2m
Weight	500kg
Power	4 x 900 W DC
Drive	4 wheel-drive, 4 wheel-steer
Maximum speed	15 km/h
Autonomy	+/- 6hours
Capacity	4 adults

Figure 4: Taxisat Vehicle

Tests, Demostrations and Results

During the period of April-May 2013, TAXISAT will be tested during three weeks in the city of San Sebastian (results to be included in the final version of the paper). The second demonstration will take place end of July at the Spa Francorpchamps in Belgium during the total 24 hours event. Last demonstration will take place in the attraction park of Vulcania, France. As Vulcania is already equipped with three automated guided vehicles, the main interest is to demonstrate an evolution of the existing navigation system.

Acknowledgements

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