International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:8, No:7, 2014

Conception of a Reliable, Low Cost and Autonomous Explorative Hovercraft

S. Burgalat, L. Teilhac, A. Brand, E. Chastel, M. Jumeline

***Abstract*—**The paper presents actual benefits and drawbacks of a multidirectional autonomous hovercraft conceived with limited resources and designed for indoor exploration. Recent developments in the field have led to the apparition of very powerful automotive systems capable of very high calculation and exploration in complex unknown environments. They usually propose very complex algorithms, high precision/cost sensors and sometimes have heavy calculation consumption with complex data fusion. These systems are usually powerful but have a certain price, and the benefits may not be worth the cost, especially considering their hardware limitations and their power consumption. The present approach is to build a compromise between cost, power consumption and results preciseness.

***Keywords*—**Hovercraft, Indoor Exploration, Autonomous, Multidirectional, Wireless Control.

I. Introduction

In last few years, exponential growth of the drone industry and frequent use of such vehicles in the academic field have brought up many new applications and innovations, but with their consequences on structural and software requirements on embedded systems.

Energy efficiency, weight gain and overall cost reduction are the main challenges [1] and the most important factors affecting actual drone capacity designed for autonomous indoor exploration to complete its tasks successfully. Producing a cheap vehicle able to evolve in complex indoor environments at big scale would help activities such as building surveillance, surface estimations, or military reconnaissance in dangerous areas. Such actions are often performed in particular indoor environments, with flat floors and relatively low complexity of the surroundings, mostly walls or large plain objects. This kind of missions is adequate for autonomous drones with relatively high battery life allowing them to explore wide areas. The most important parameters involved for achieving these tasks are maneuverability, size/weight and power consumption of embedded systems as shown in Fig. 1. Commonly used drones for such uses are quadri-copters [2], robots on wheels [3], or hovercrafts [4], respectively represented in blue, red and green on Fig. 1. Hovercrafts can be an interesting alternative to flying drones since they can evolve on many types of environment while being able to navigate closely between obstacles. The model on which the prototype is based exploits this particular characteristics and allows direct movement in any given direction which can be useful in dead ends or cluttered environments. The fact that any friction is eliminated also allows great maneuverability and reduces the needs of an overly powerful propulsion system.

Weight constraint is then less significant and module size only depends on fan size producing vehicle lift. The design choices are mainly made by considering the cost reduction requirement. Onboard sensors have, therefore, a very low resolution and the main board controller chosen here is a simple Arduino board. To fulfill its mission, the robot is connected to a deported ground station. This system composition insures real time constraint, low cost hardware composition and high level computation.

Most autonomous explorative systems have to implement a solution to simultaneous localization and mapping problem (SLAM). The robot has to be capable of evolving in a complex and unknown environment and to locate itself while respecting real time constraints. The main problem in indoor exploration is the complex structures detection. Their detection with high resolution sensors is easy. In case of a low resolution detection, error avoidance and correction becomes a real problem. The use of occupancy grid is justified here; larger size landmarks insure accurate detection. A good solution proposed to static and dynamic detections using occupancy grid was published in 2005 by Wolf and Sukhatme [5]. Using a dynamic and probabilistic update of two maps (one for static objects and a second one for dynamic objects), the proposed algorithm permits to reach real time detection and high accuracy.

Based on Monte-Carlo methods, Montemerlo M., Thrun S., Koller D., et al [6] proposed a solution using a particle filter for real time localization. Their solution is very robust but presents computational problems with a high level of particle involved. However in a small population of particles, their solution suits perfectly to the low cost real time localization of present hovercraft which stays aside theirs. Another version of FastSLAM [7] has been published in 2003.

S. Burgalat, L. Teilhac, A. Brand, E. Chastel and M. Jumeline are with the ECE Engineering School, Paris, France (e-mail: burgalat@ece.fr, lteilhac@ece.fr, brand@ece.fr, chastel@ece.fr, mjumelin@ece.fr).

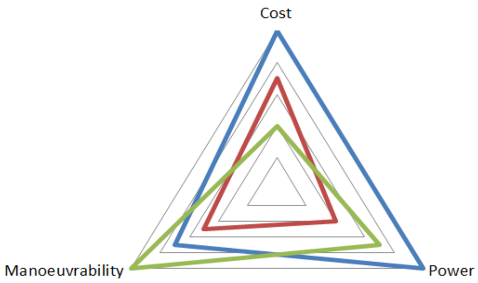

Fig. 1 Comparison of Existing Solutions According to Cost, Maneuverability and Embedded Power Parameters

II. Results

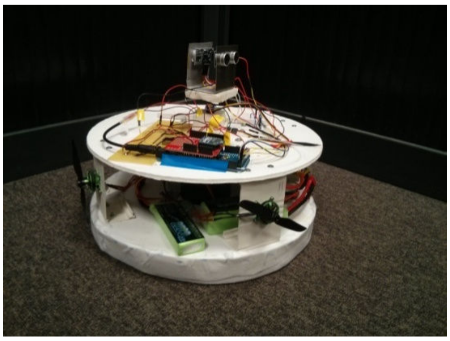

Fig. 2 Prototype of Multidirectional Hovercraft with Obstacle Detection Turret and Wireless Connection

A. Multidirectional Movement and Trajectory Control

Designing a mechanical structure allowing direct movement in all directions implies many physical constraints. The most efficient way to make the Hovercraft move directly at any given angle is to use four fans placed orthogonally. Modulating the speed of two given fans will enable a 360° available displacement. The main benefit from this kind of configuration is the ability of making 180° or 90° turns without having to follow ample trajectories and thus enhancing the possibility of reaching previously inaccessible areas.

Combined with a shortest path algorithm, the mapping or exploration of any given area can be achieved significantly quickly. This is also meaning greater energy efficiency, and so a longer autonomy which represents an important challenge for this kind of vehicle and for drones in general.

The positioning of four lateral fans in the four cardinal directions and of a larger one situated under hovercraft base, directly facing the ground, is kept here to overcome the inability of more "traditional" hovercrafts [4] to make a direct 180° or a direct turn in any given direction without having a curved trajectory.

Our prototype, shown in Fig. 2 takes advantage of produced air cushion enabling the hovercraft to be immune against floor composition and local asperities, unlike a wheeled vehicle, while avoiding its maneuverability constraints.

While this is an easy way to overcome the unidirectional aspect of current displacement for most hovercrafts, there is a strong physical constraint in the overall structure rotation generated by a powerful central fan. Since the fans are facing the module center of gravity, no rotational movement can be tolerated, unless the accumulated error impacts the mapping results without any possible counter effect.

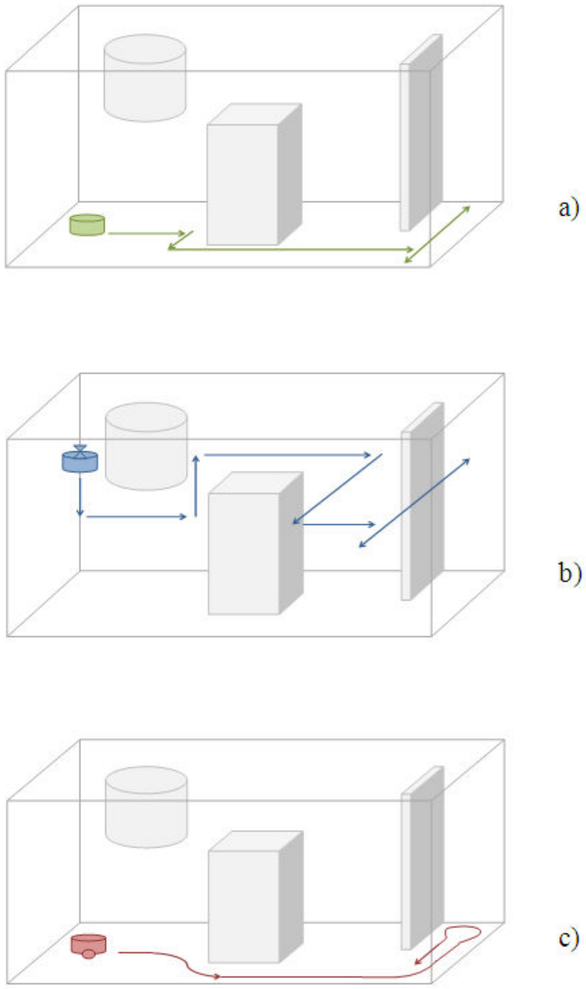

Fig. 3 Respective Paths of (a) Hovercraft, (b) Flying Drone and (c) Wheeled Robot in Given Indoor Environment

Using five fans potentially consumes more energy than only one horizontal fan in charge of both lifting and propelling, but allows faster displacement, and the lateral fans can be stopped without eliminating the air cushion.

This directly affects the embedded system power parameter, as it decreases the amount of energy needed in full working mode. The weight constraint is also drastically reduced compared to any flying drone. Central fan lifting capacity allows a large choice regarding the weight of embedded sensors, and thus possible applications are endless.

Two lateral fans are set at the same speed for a linear movement; a diagonal movement is obtained by reducing the speed of one of the two fans.

The user is able to define hovercraft trajectory by directly modifying the speed value of each fan, or by sending it in a cardinal direction at a desired speed via the Xbee connection.

Implemented solution directly impacts the aforementioned maneuverability parameter, since it provides the movement efficiency of a quadri-copter to a ground-level vehicle as shown in Fig. 3.

Another side-effect of this type of four fans structure is the absence of rotation on any axis which could lead to recalculation of hovercraft position or to accumulation of misplaced elements during the mapping. The simplicity of this way of displacement impacts the complexity of embedded systems parameter. If there is no need to compute information coming from an inertial measurement unit to correct the drift or the rotational error, there is a gain in computation power and execution time.

B. Mapping

Establishing indoor environment cartography is the main objective of studied prototype. Two ultrasound sensors mounted on a 180° rotating turret are used. Turret current angle associated with the distance to the obstacle obtained during last acquisition allows locating the obstacle on a grid. The grid is made of 21x21 square tiles of 10 centimeters.

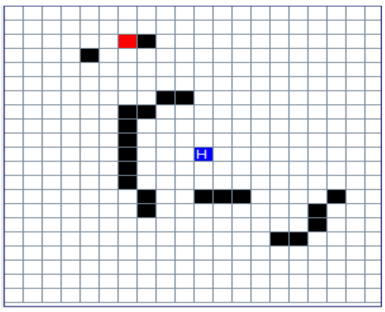

Fig. 4 Visible Map on User Interface: Plain Obstacles are shown in Black and Red

The result of mapping process is shown on Fig. 4. A relative map is presented with a dimension of 21x21 using the probabilistic system of occupancy grids.

Many constraints due to hardware limitations imposed to work on a limited set of data and to find solutions for filtering anomalies. For instance, acquisitions collected by the sensors being only accurate if the signal is sent orthogonally to the obstacle, this particular constraint makes the estimation of distance to a sideway obstacle unreliable.

Filtering the data coming from approximate detections can be done with the following method. A compromise has to be made between the number of acquisitions per given angle of the turret and the accepted delay in which the 360° map is completed. By making 3 acquisitions every 10°, the approximate time to visualize the first 360° map is under 5 seconds which is acceptable considering the relatively low speed at which the Prototype evolves.

A tolerance limit $\mathcal{T}$ at 10 centimeters between two measures taken at a same angle has been fixed. If the limit is crossed, one of the two distances is considered as an anomaly and the third acquisition will decide which one it is. The average of the two selected values gives a relatively accurate distance to the obstacle for this observation angle.

The obtained value is set in the grid by conversion of its coordinates; this quickly gives a static map of the surroundings. The dynamic map shown in Figs. 5 and 6 are obtained via a sliding window average of the last three maps, each of these maps being composed of the acquisitions made during the last 360° rotation. This gives a displayed map made of cells containing a probability of occupation [8] ranked from 0 to 3, 3 being considered a plain obstacle, 2 a high probability of a plain obstacle and therefore an inaccessible cell. One positive acquisition or less on the last three complete rotations is considered as an error and does not appear on the graphical interface.

This method allows the user to visualize a color coded map of the surrounding area (black for a plain obstacle, red for a high probability of a plain obstacle, white for an unoccupied cell, red cells correspond to a high probability of existence ($p_{L,i}$> 50 % and $p_{L,i}$ < 75%) in parallel to black cells which are considered as real ($p_{L,I}$ >75%). This dynamic map will be used to implement an autonomous movement and the automatic avoidance of obstacles.

The relatively low degree of precision of this method allows a fast mapping of an indoor environment composed of plain objects larger than a few centimeters. Map resolution can be increased, but this will affect the number of anomalies due to non-detection of obstacles placed between two acquisitions, and therefore increase the complexity of filter algorithm as well as the general data processing time.

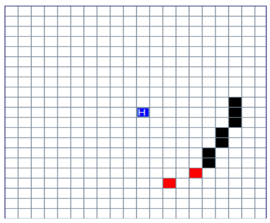

Fig. 5 Detection Map at Time t = 1sec. Obstacle at 0.8 meters. Occupancy Cells: 0.10m

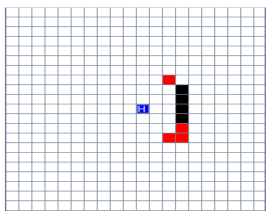

Fig. 6 Detection Map at Time t= 4sec. Obstacle at 0.3 meters. Occupancy Cells: 0.10m

The necessary time for a complete revolution of detection turret limits the speed of the module. Considering the size $\mathcal{S}$= 0.3m of tested hovercraft prototype, optimal explored distance $\mathcal{L}$ imposed by tolerance limit $\mathcal{T}$ and computation and acquisition times T_{comp} and T_{acq}, limit cruise speed for obtaining a reliable map is $\mathcal{V} = \mathcal{L}/T_{comp}$ m/s ~ .2m/s. Figs. 5 and 6 display the evolution of a static object detection while the prototype is moving towards it. As expected the relative map update is correctly done, the object is moving at correct speed and presents enough probability of existence to allow a decision to be taken in robot embedded IA.

The remote computer can take decisions according to this map concerning the trajectory of the module and direct it towards the least explored area or the clearest path.

This shows how the mapping and localization of the module can be made with very few resources and with low cost sensors since there is no need to suppress any kind of error on the trajectory. The localization can be enhanced greatly by adding an inertial central to the solution and a higher hardware budget therefore enabling the remote computer to calculate the Hovercraft speed and direction. This current implementation will lead to application where a global map is memorized by the vehicle and where the position of the Hovercraft will be displayed according to this map and its speed and direction.

This simple method of displacement combined to a vehicle that allows the elimination of many environmental constraints can be a very accurate way to determine the best trajectory to quickly build the cartography of an indoor area.

III. Conclusion

Designing a hovercraft using 4 lateral fans and a central fan assigned to lifting is an efficient way to allow multidirectional movement which can be useful in an indoor environment. The mapping of a designated area can be done in shorter time and hardly accessible areas can be explored without trapping the hovercraft in a dead end. However these interesting properties come with new structural constraints concerning mass distribution and sensors location which can be overcome with the appropriate configuration. The benefits of this new way of moving combined with the very low cost of the structure and the lightness of employed algorithms along with their deportation on a remote computer, should allow quick realization of reliable mapping of an indoor area for a relatively low cost.

Acknowledgment

The authors are very much indebted to ONERA for having provided the environment where the work has been developed, to Drs J. Marzat, B. Herissé, and S. Bertrand for guidance and to Pr; M. Cotsaftis for help in preparing the manuscript.

References

[1] Guowei C., Jorge D., Lakmal S., 2014. "A Survey of Small-Scale Unmanned Aerial Vehicles: Recent Advances and Future Development Trends". *Unmanned Systems,* Vol.2, pp.175-199.
[2] Jiinec T. 2011. "Stabilization and Control of Unmanned Quadcopter", Master's Thesis, Lulea University of Technology
[3] Saha S., Angeles J, Darkovich J., 1995. "The Design of Kinematically Isotropic Rolling Robots with Omni-directional Wheels". *Mechanism and Machine Theory,*Vol.30, pp.1127-1137.
[4] F.L. Roubieu, J.Serres, N. Franceschini, et al.: "A Fully-autonomous Hovercraft Inspired by Bees: Wall Following and Speed Control in Straight and Tapered Corridors". *IEEE International Conference on Robotics and Biomimetics (ROBIO 2012),* Guangzhou: China (2012)
[5] Wolf D., Sukhatme G., 2005. "Mobile Robot Simultaneous Localization and Mapping in Dynamic Environments". *Autonomous Robots*, Vol.19, pp.53 – 65
[6] Montemerlo M., Thrun S., Koller D., et al, 2003. "FastSLAM: A Factored solution to the Simultaneous Localization and Mapping Problem", *Proceeding IJCAI'03 Proceedings of the 18thinternational joint conference on Artificial Intelligence*, pp.593-598.5.
[7] Montemerlo M., Thrun S., Koller D., et al, 2003. "FastSLAM 2.0: An improved Particle Filtering Algorithm for Simultaneous Localization and Mapping that Provably Converges", *Proceeding IJCAI'03 Proceedings of the 18Th international joint conference on Artificial Intelligence*, pp.1151-115
[8] A. Baba, "Cartographie de l'Environnement et Suivi Simultané de Cibles Dynamiques par Un Robot Mobile". *PhD Thesis, LAAS-CNR, Univ. Toulouse III – P. Sabatier.*