Extended Abstract

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Calibration of multiple laser range finders for mobile robot localization in ITER

Fusion power promises itself as a clean and sustainable source of usable heat-energy, meaning almost no green-house gases emissions, recyclable radioactive waste, and abundant, safe and efficient fuel supplies. The International Thermonuclear Experimental Reactor (ITER) is a multinational in-progress experimental project of a fusion reactor. It is the next step in the demonstration of a nuclear fusion energy possibility to answer the problem of world growing energy demand without the environment impact that the actual sources of energy deliver. Among the great scientific challenges this project implies, such as controlling the plasma temperature, all nominal and maintenance operations, which includes vehicles navigation, will be handled completely remotely through the ITER hazardous and cluttered environments. To perform the previous and other tasks with minimal error margin, an accurate navigation method is needed due to the tight safety margins inside the building. A network of Laser Range Finder (LRF) sensors, installed into walls, is proposed to aid the vehicles localization. In order to ensure the localization is done with the demanding accuracy, a calibration procedure needs to be executed regularly. This procedure enables the measurements, from different LRF devices in the network, to have a meaningful and accurate correspondence between them. From time to time sensors require a recalibration due to some changing in the factors that affect the measurements.

The objective of this thesis is to develop and implement a calibration algorithm to estimate the exact poses (position and orientation) of each LRF installed in the network. The poses should be given in an absolute two dimensions frame. The resultant poses are to be used in a localization algorithm that assumes the poses of all sensors are known and accurate. The calibration algorithm assumes a map of the environment is known. When the position and orientation is completely unknown, the algorithm should be fully autonomous estimating the pose. Since it is impossible to test it in a real ITER scenario, a simulator was developed and results evaluated.

In ITER, the optimal locations where the LRF sensors should be installed are already determined. The main problem occurs when a sensor real location is different from the supposedly predefined optimal location. As a consequence of sensor misplacement, measurements from distinct LRF lose correspondence between them. Address and solving this problem is the main focus of the present work. This issue, where the exact position and orientation of the sensors are spoiled, can be caused by human error on installation procedure, erroneous map measurements or any other factor derived from sensor operation. The possible scenario where poses are completely unknown is assumed valid. In the case of erroneous pose description, the localization algorithm, which heavily relies on the sensors readings accuracy, may fail or mislead their outputs because measurements are biased, proving it is not robust to this kind of errors. These deviations compromise maneuvers of hazard material transportation vehicles on the cluttered ITER environment. Like the other operations in ITER, calibration can only be done remotely. In this case, the map presents the most important environment description and could be extremely useful. With that said, a possible solution would be to do a localization procedure of the devices using the available map. As a consequence of the proposed solution other problems arise. An important one is the presence of error in the map layout description: errors in walls dimensions and unmapped areas or features that do not have any correspondence in the physical place the map describes. How robust it needs to be to overcome such issues?

Some calibration algorithms for LRF devices have been proposed, but most of them require additional sensory systems such as cameras, fixed or moving well defined targets while others require their own motion information. Given the access restrictions in ITER in addition to other constraints regarding LRF positions and vehicles navigation, the existent solutions may not fulfill the presented requirements.

This thesis is composed by three main Chapters: the proposed solution, the simulation and the results. In the end, the conclusions present a critical view about the obtained results and the best suited algorithm for each scenario. In the proposed solution a detailed description of the algorithms used is provided including their associated advantages and drawbacks. The different scenarios which the solution will be able to handle are described in this Chapter too together with a block diagram that summarizes the proposed solution. In the simulation Chapter, the LRF principle of operation is described to identify the most relevant variables and features that affect the LRF operation, to properly simulate it. Not only the scan process but as well as the LRF model and maps implementation are also described in this Chapter. In the results Chapter, several tests were carried out, both from simulated and real-life scenarios using a simulated model and two different commercial laser sensors. Every scenario identified was approached using, at least, four different poses in all the tested maps, including ITER and real environments. Robustness tests were also carried for the algorithms and maps developed. The score and evaluation of the results is done using a function that measures the near point to point Euclidean distance.

The main focus of this work is its application in ITER environment. Nevertheless industrial environments where accurate operations take place might benefit from this work. In ITER, a robust localization method is necessary for not compromising vehicle maneuvers. The solution proposed is an algorithm to calibrate a LRF sensor network that receives three input parameters: a map description of the environment, LRF data, and an initial pose estimate for each device of the network. The first two are mandatory. After its execution, the algorithm returns an estimated pose for each device in the network in a given common reference frame. Regarding the initial pose availability, four possible scenarios were identified: initial pose estimate completely known, initial pose estimate completely unknown, only position known and only orientation known. The algorithm behaves differently according to the scenario in question. In the first phase, the algorithm processes the raw LRF readings data to eliminate differing measurements. The next phase depends on the identified scenario. Whenever an initial pose estimate is completely known, the ICP algorithm is executed. For that to happen, the map needs to be converted into points. Despite being the fastest method, it showed poor robustness to outliers. In case only the position is known, a brute force orientation version of the ICP algorithm is applied. It consists in initializing the ICP algorithm for a set of predefined initial orientation angles. It takes longer to complete, but similar results to the previous scenario were obtained. When the opposite happens, only the orientation is available, a voting method is applied. It consists in counting the votes that result from the backwards projection of each LRF measurement, assigning this way an estimate probability of the LRF position to the resultant map coordinates. It is the most time consuming method but reveled consistent results even in the presence of outliers. In case the initial estimate is not available, a global localization solution takes place. In this case, ICP alone cannot be used because of its problem of local minima thus, the vertex method takes place. This method consists in extracting geometric features from the LRF readings and in a matching method. It begins by extracting lines and vertices using clustering and Split and Merge techniques followed by a matching phase based on the geometric brute force combinations of the previous extracted features. The main problem with this method is the threshold values: it is highly reliant on threshold values in the first phase which can compromise the correct features extraction. In any case, even if there exists wrong extracted features among correct ones, the algorithm is able to achieve great results, in some cases better than ICP. As an alternative to this method, the ICP brute force experiment was conducted where the map was divided into a grid and for each point of the grid, the ICP was executed. Although much more time consuming than the vertex method, the results obtained were slightly more accurate.

Some of the problems identified were related to the limits of the algorithms. Classical ICP algorithm, for example, does not have any mechanism for outliers rejection, thus, a small deviation in the readings or the map description induced a high impact on its respective results. The voting method can be harmed by two variables: the initial orientation estimate and the resolution value of the map conversion to points. Some tests are presented to verify their influence on the results. The geometric feature extraction process is the main weakness of the vertex method. From small lines, threshold values to an unfaithful score evaluation, all can contribute to results deterioration. For future developments, some solutions are suggested to tackle these and other problems identified. Despite the problems presented, even when the initial pose is completely unknown, simulation results obtained present an uncertainty value proportional to the devices accuracy. These results are, this way, enough not to compromise the correct functioning of the localization algorithm. At last, an idea for a commercial product based on the work developed is presented.