A Computationally Efficient Solution to the Simultaneous Localization and Mapping (SLAM) problem in Houses of Mirrors

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Abstract

Every day people are dying because there is no method for a robot to navigate in a house of mirrors. The Simultaneous Localization and Mapping (SLAM) algorithm has been theoretically developed and optimized for computational efficiency in most environments where robots may need to navigate [1]. It provides an incredibly useful way for robots to navigate inside or outside without the aid of GPS navigation while simultaneously creating elaborate point clouds of their environments in two dimensions and for the gifted, three. However, there has yet to be a widely developed solution to navigating in a GPS denied house of mirrors. The traditional SLAM problem is already computationally taxing enough, there is no feasible way to implement it when all of the feature space is not finite or fixed. In this paper, a novel technique will be developed that will allow a robot to implement a SLAM algorithm in a house of mirrors at a local carnival in a simulated search and rescue operation. This technique is then demonstrated on the Mirror-Realm SLAM Robot (Mrs. Robot).

Keywords: Navigation, Simultaneous Localization and Mapping (SLAM), Robotics, PNT, Fun House Mirrors, Mrs. Robot

1. Introduction

In the past decade there has been a steady increase in places where robots can navigate to do useful things. SLAM has been a fast developing field in robotics which has been crucial to putting more robots in places where robots historically have not existed. You may have noticed that less and less robots each year are getting lost and stopping to ask for directions. This is all due to the SLAM algorithm and not because the 2018 Geneva conference outlawed the breeding of female robots for population control who are more likely to ask for help when lost [2].

The proliferation of these algorithms has allowed for more robots to navigate more spaces and be further integrated into our modern lives. With better sensors, processors and a demand for more robots and drones the areas in which they cannot navigate are becoming more and more rare. There are only a few things robots cannot currently navigate such as ice caves, their way out of VIM, conversations about where this relationship is going, and to be discussed in this paper, a house of mirrors.

1.1 Background

The SLAM algorithms attempt to solve the problem of navigation in an unknown area by taking in, typically visual, data and creating a map of features. With those features, the map is refined and used to solve for a better estimate on the sensor's position. This is typically implemented using factor graphs or Extended Kalman filters to update feature space and a navigation state.

Especially in indoor SLAM algorithms, a problem arises in loop closure. When a sensor returns to an original position, it must update a location with previous data. Applying these location priors creates the problem of applying information incorrectly and creating a dangerous information loop which works the exact same way as a twitter echo chamber. Traditionally in SLAM algorithm applications, features do not move and are not infinite. Because the sensor is measuring itself through mirrors and attempting to estimate its own state off of that position, every moment a SLAM is used in a house of mirrors creates a dangerous information loop.

1.2 Purpose

Every day, we lose on average two and a half Americans from getting lost in houses of mirrors. This is just the confirmed number of bodies found, some estimates are much higher. As seen in figure 1, the 2010-2020 locations for unresolved missing persons reports nearly perfectly lines up with the locations of state fairs with houses of mirrors [3].

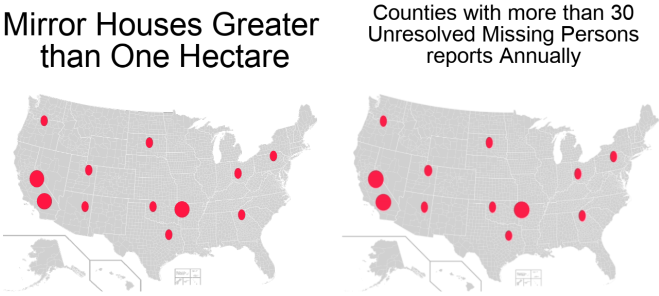

Figure 1: Large Mirror Houses Against Missing Persons Reports

The Mothers Against Houses of Mirrors (MAHM) have been lobbying for decades to have these death traps banned. While only successful in New Mexico and Washington State, they still remain legal. Though the CDC has recommended that you should always carry three days of water and food with an emergency space blanket, a flare gun, and a liter of bear mace on your person when entering a house of mirrors, this is often not enough to survive long enough to be rescued.

Specialized rescue teams are being developed according to MAHM lobbied regulation to mitigate many of these risks but very often become victims themselves. For this reason, a more automated approach will ideally be the answer to saving lives from these horrific state fair attractions.

2. The Infinite Mirror Realm transpose SLAM Algorithm

The math and model for a traditional SLAM algorithm is outlined in [1] in a concise way. Unfortunately, that math does not work when every feature space estimation loop attempts to fit an infinite series to its own position-mirror realm gateway, and navigation state solution. Thankfully, it was proven by [4] that mirror realm gateway reflections are mathematically convergent unlike the scottish accent.

With all of the infinite series Mirror Realm space shown in Figure 2 provably convergent, we were able to add recursively infinite, infinite series summations and definitions to the mathematical models developed in [1]. Once these new definitions were solved for all of the models using wolfram alpha we gave the output to a team of unpaid Cranberry Lemon sophomore engineering summer interns and told them to write it into a Ros server node in C++.

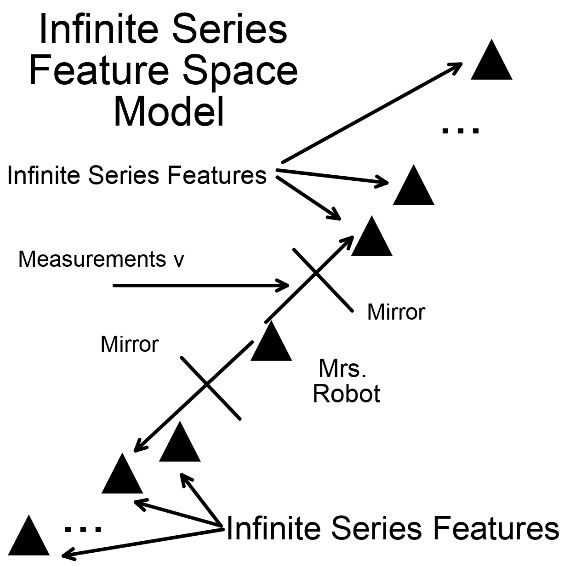

Figure 2: Infinite Series Feature Space Model

2.1 Vehicle Reflection-Landmark Model

Extrapolating the math in [1], the environmental state space begins to look like equation 1 below. Both sides of the equation became a convergent infinite series of Kalman estimates where X is the vehicle positions, u contains the corresponding ros commands the server wasn't too busy to listen to and F is all of the different transition matrices. Obviously, equation 1 creates a Tesseract state space for internal dimension realm navigation by the vehicle. Each sensor measurement feature v iterates an equally infinite v amount of states [5].

$$\sum_{v=0}^{\infty} X_v(k+1) = \sum_{v=0}^{\infty} F_v(k)x_v(k) + u_v(k+1) + v_v(k+1)$$

Equation 1: Infinite Landmark model

Next, equation 2 shows how the landmark space p can be translated to the infinite series Kalman filter space using the ∞ by ∞ matrix MR (Mirror Realm state transition matrix) which translates the landmarks from the Mirror Realm to the Tesseract-Vehicle space.

$$p_i(k+1) = MR\ p_i(k)$$

Equation 2: Mirror Realm Space transform

The Mirror Realm landmark space is defined by equation 3 below. Each vector is made up by ∞ elements where each element is another transposed vector of ∞ vectors similarly composed internally forever. Through the recursive nature of our landmark Mirror Realms space, the sensor's feature space could be adequately defined by the model.

$$p = \sum_{v=0}^{\infty} [\sum_{v=0}^{\infty} [\sum_{v=0}^{\infty} [\sum_{v=0}^{\infty} p_1^{\sum_{v=0}^{\infty} T...} ...]^{T...} ...]^{T} ...]^{T}$$

Equation 3: Landmark Space

2.2 Infinite Observation Model

The observation model then compared the mirror realm landmark space to the vehicle tesseract model with transition matrix H applied to each sensor angle measurement output. When we applied the recursively infinite vector landmark structure to our Tesseract space, the analytical math started to get a little heady and we promised ourselves we'd put it in an appendix. Thankfully for the one member of our team who knows LaTeX, the Jabde proceedings limited papers to under 100 pages and we did not have to include it in this paper. If you would like to view the full math to reproduce the results, the full set of proofs are hosted here.

2.3 Information Loop Estimation Process

The H matrix was then used to recursively solve for $P_{argmax}(p|X(k), p)$ then $P_{argmax}(X|X(k), p)$ and back and forth where P is the Maximum Aposteriori Probability (MAP). We chose a map estimation method because the pun about using a map to create a map got the most support from Cranberry Lemon navigation lab leadership during the Critical Design Review (CDR).

Thankfully the infinite linear system was still convergent and maximums were able to be estimated using gradient Ascent. Unfortunately, there wasn't a good cut off metric even in theory. While theoretically-theoretically possible, it was nearly impossible, theoretically possible but in practice theoretically improbable to determine a metric for when a sufficient maximum had been reached by the estimation algorithm. Therefore the Gradient Ascent algorithm was pinched off by a try-catch loop when the tower gaming computer installed in Mrs. Robot achieved a sufficiently debilitating memory buffer error.

3. Recursive Landmark and Magoo SLAM Techniques

Next the algorithm had to be implemented through an autonomy search and rescue application. Before the design could transition into a physical robot, basic sensor fusion work had to be accomplished. First the camera feature extraction system had to be fused into the map update algorithm previously discussed. Second, a Magoo-navigation protocol fail safe method was fused into the Tesseract-Kalmun update scheme and finally, a lifeline Ariadne's Thread approach was added for even further risk mitigation. The equipment used would be expensive for the required amount of resolution and teraflops per reflection estimated in the run up modelling and simulation work. The Ariadne's thread fail safe would ensure that the equipment would not be lost.

3.1 Recursive Closed Loop Landmark Management

First, a high powered standard definition family camcorder would feed in sensor measurements v into the recursive algorithm. Next a fully outfitted gaming tower would utilize parallel GPU processing to ray trace each v measurement from Tesseract space into the Mirror realm p^{∞} dimension space and back. At every processing step, the recursive MAP estimation algorithm will determine the most likely Tesseract state space X given the previous X and p^{∞} state. Once the gaming tower processing resource and family camcorder measurements v have been exhausted and/or the CPU temperature exceeds 170 degrees F, the estimation process will return the most recent result as its own recursive exit condition [6].

The information matrix will then be updated to reflect the new amount of information gained by the now closed loop calculation. This is done by applying L'Hopital's principle to divide the infinitely growing amount of new information by the infinitely growing amount of uncertainty surrounding that information. That number creates a new measurement covariance which is then used to apply the updated X Tesseract state to the navigation estimate Hyper-Extended Kalman Filter. [7]

3.2 Magoo Navigation Protocol

Multiple physical arms will reach out from the navigation robot attached to pressure sensors. These pressure sensors will then create another fail safe in runtime. In the eventuality that Mrs. Robot does not finish the recursive closed loop landmark management for a near perfect navigational state inference before driving into a mirror, pressure sensors will be added to measure the physical space. Those will create updates to the SLAM map created point cloud space while also preventing the robot from getting stuck as suggested in [8].

3.3 Ariadne's Thread

Finally an Ariadne thread scheme will be physically implemented on the robot so that if it runs out of battery it can be recovered. The Ariadne's thread technique is based on the mythology of the Cretan princess Ariadne who gave thread to Theseus so that he could find his way out of the Labyrinth after fighting the Minotaur. This is now a real and not made up technique used in maze solving. Once the thread on the Mrs. Robot has run out, or the robot needs a recharge before trying again, there are two tugs at the rope suggesting that it needs to be pulled back by the technician team. Otherwise if the lost person is found, there are three consecutive tugs on the thread and the rescue team will have a path that they can follow into and out of the mirror realm.

4. Experiment

In order to demonstrate this novel SLAM algorithm and corresponding techniques, a test rig was designed, constructed, and tested in a rigorous real life environment. The test rig named the Mirror-Realm SLAM Robot or affectionately Mrs. Robot, consists of a camera, lidar, motorized wheels, a modest processing unit and extended bump pads.

4.1 AUTO CAD Design

Using generously donated Public domain and Creative Commons License images, our initial design for Mrs. Robot can be seen in Figure 3. The design incorporates a tower computer connected, by a neatly tucked away series of wires to a tripod mounted camera, six touchpad sensitive pool noodles and a motorized hand dolly. The CAD Mrs. Robot was designed to withstand the most dangerous of houses of mirrors.

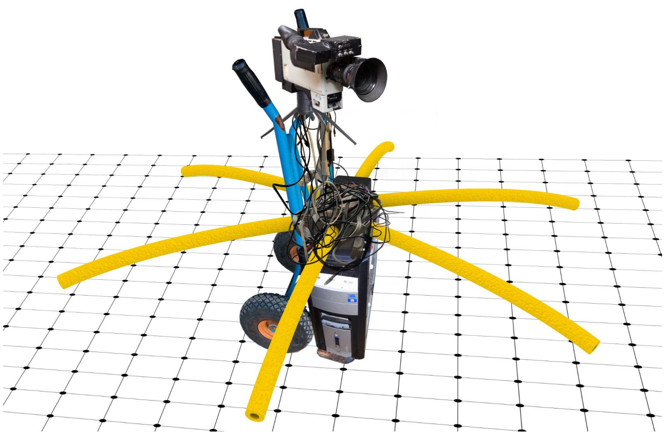

Figure 3: CAD rendering of the Mrs. Robot Photographer Markus Hagenlocher Creative Commons Attribution-Share Alike 3.0 Unported via Wikimedia Commons, Dmitry Makeev, CC BY-SA 4.0, via Wikimedia Commons

4.2 Physical Implementation

Unfortunately, not only did Todd forget to return my hand dolly, but the kids tore up the pool noodles this last Saturday and we had to improvise. Below in figure 4 is the physical implementation of Mrs. Robot we used to test the new SLAM algorithm/techniques. Instead of pool noodles a nine iron was used to sense bumping into walls due to its length, durability, and availability. Next a long board and power drill for motion was connected to a ROS server run by a small and modest processing unit. Finally, the rig was outfitted with some twine to implement Ariadne's thread technique.

Figure 4: Mrs. Robot physical implementation

4.3 Test Environment

Cranberry Lemon is setting up for its' back to school fun fair and an MAHM regulations compliant house of mirrors has been constructed with nearly a hectare of mirror maze. Five international students who thought Pennsylvania mirror mazes were similar to Austrian ones, sued the school last year for emotional damage and frostbite due to the massive scale and trickery of the Cranberry Lemon mirror maze. It would be against tradition to make this year's maze any smaller or with fewer portals so the school is required by a United Nations treaty to maintain a search and rescue team for students. The Cranberry Lemon robotics team (i.e. us) have been tasked with building a search and rescue robot (i.e. Mrs. Robot).

The early constructed maze will be Mrs. Robot's test track and its intended environment. A trained house of mirror team has been tasked to wander into the maze and camp with a weeks worth of supplies to see if our own Mrs. Robot can find them before they run out of supplies and come back.

5. Results

It didn't work. We were hoping to have an elaborately rendered image of a point cloud of the Cranberry Lemon Hectare large house of mirrors but we weren't even able to recover Mrs. Robot to process the image.

As we expected in some of the Modeling and Simulation work, Mrs. Robot made several trips into the maze before we felt the two tugs on Ariadne's thread and pulled her back. This maze is massive and even a seasoned human search and rescue team at least takes a day to find most missing persons. At the start of the second day we felt three tugs on the thread and started pulling Mrs. Robot back. At the other end of the tether was a half digested nine iron covered in some yellow tinted ooz.

We called back the team living in the maze and made a search for Mrs. Robot because there was a bitcoin wallet saved on the processing unit and could not find any of the missing components. We aren't sure what created the ooze or what happened to Mrs. Robot, but it doesn't look like we'll be able to automate the Mirror maze search and rescue process this year. We'll have to do that with trained volunteers of seniors like we do every year.

6. Future Work

We must try again next year and come up with a better Mrs. Robot design. Figure out where this goo came from. We believe that the amount of images was too much for Mrs. Robot's processor and we're going to try again next year with a bigger computer because the algorithm is flawless. If anything we have to at least find that bitcoin wallet.

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