Optimal Robot Localisation Techniques For Real World Scenarios

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***Abstract*—The following paper is a thorough review of our research based on the localisation of robots.It is an attempt to segregate the techniques, to locate the accurate position of robots in different environments and to discuss the superlative methods to localise such robots or in some cases an unmanned vehicle.The paper is divided into three real world problem statements and a thorough analysis of the best technique amongst others is made, for all the three conditions namely underwater,indoor and Space, based on a number of parameters such as the cost, accuracy, efficiency, implementation of the technique and the environmental conditions around the robot.The primary reason to select these problem statements is due to the recent trends of research in these domains.Each of the technique has been chosen after discarding several previously applied techniques and an effective approach has been put forward for localising the robots in different areas .**

Keywords—Azimuth, Doppler Velocity Log, Fish-Eye Camera, Hyperbolic navigation, IMU, Piezo-Resistive, RFID, SLAM, Transponder, UAV, Ultrasound, Visual Odometry

I. INTRODUCTION

The localisation of a robot is a mandatory factor to be considered while designing autonomous robots or UAV’s (Unmanned Autonomous Vehicles).Three major areas where localisation needs to be done are ground, space and underwater.With the advancements in the field of robotics certain areas of interests exists , of which we would focus particularly on the three prominent ones mentioned above. Locating the exact position of such robots and tracking them can help solve several problems related to mobility and reduce human efforts to a large extent. However an adjustment between the design metrics needs to be taken into consideration to ensure that all the features are maintained above an assumed threshold level. Some of the parameters which are needed to be considered while selecting such robot localising techniques are as follows:

- Sensors precision
- Robot position estimation (e.g object position calculation)
- Guidance mechanism (e.g degrees of freedom)
- Inertial navigation
- Desired speed of robot

A compromise needs to be done between these parameters to ensure that the robot works efficiently in a given environment. e.g tradeoff between the design metrics of a robot localisation techniques is shown below.

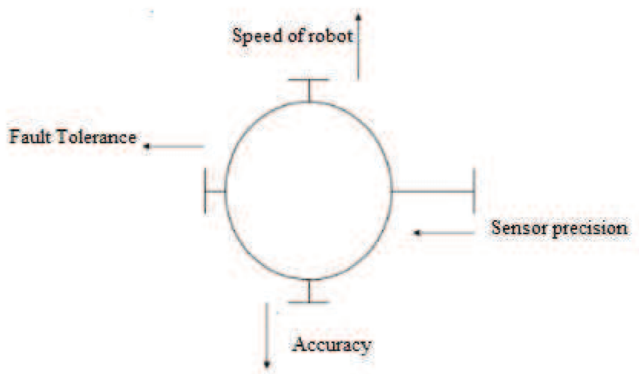

Fig 1.The diagram indicates that if we increase the speed of the robot it’s accuracy would reduce significantly because it would be difficult to track them. The same is not true with two other parameters ;fault tolerance and sensor precision.These parameters have a direct relation between them, meaning if one is increased the other would also be increased.The circle in the above figure is moved to the left due to the above mentioned reason.

By considering the above mentioned parameters , three specific problem statements have been considered as follows :

- To triangulate the position of the robot in indoor environments such as homes,offices and storage houses to accurately track its movements and behaviour.
- To enable the UUV (Unmanned Underwater Vehicle) to collect relevant underwater information and samples for the data pertaining to debris of crashed airplanes and ships and information regarding the content of the water to measure the extent of purity.
- To explore a new planet by collecting information of its terrain, water availability and gases in its atmosphere using space navigation rovers.

Attempts are being made to boost the localisation accuracy of indoor robots so that they can be used autonomously in warehouses and offices.The first problem statement can assist in selecting optimal technique for such indoor robots. Similarly the second problem statement will explore the localisation techniques which are implemented in underwater robots and will help in selecting a technique that will overcome the problems such as attenuation of electromagnetic signals in deep oceans.Finally, the third problem statement will expedite the study of techniques used in localisation of rovers to explore new planets and it's terrains.

II. FIRST PROBLEM STATEMENT

The first problem statement primarily focuses on robot position handling in indoor environments.The different techniques employed for indoor robot localisation are as follows:

A. ADOPTED TECHNOLOGIES:

1) Ultrasound technology-Here, RF frequency is sent as reference by the transmitter and dead reckoning sensors are used to detect the position of the robot. Also, linear Kalman filters are used to find out the error in positioning of the robot.However they fail to give steady bearing information[2].

2) Bluetooth modules-This wireless technology is computationally inexpensive and provides low topographical error rate of 0.427m.This error can be further reduced by applying it with trilateration method where multiple reference points with known positions are used to track unknown objects in the vicinity of robots.Also, by using Adaptive power control and BLE (Bluetooth Low Energy), it is possible to augment and decrease transmitted power. However, its disadvantage is that the RSSI (Received Signal Strength indicator) is unable to receive power above the required threshold if the obstacle is far afield and therefore travel time from transmitter to receiver crosses tolerable limit[2].

3) WIFI module- Here, consider an example of a robot to be localised in a building. Here we can install multiple wifi access points in the building to cover entire area of building and accuracy of localisation can be improved by installing access points in weak areas[1].The major impediment to the implementation of this method is the high power consumption and the cost of installation of the wifi access points[1].

4) RFID technology- Here,Radio frequency identification tags will be fixed up at regular intervals in the indoor environment and the tag reader will be embedded in the robot.The robot will scan the tag and will be able to restore its new position in the indoor environment[3]The moving obstacles in the surroundings are a hindrance to this technology as they can block the view of the tags from the tag reader which can introduce error while localizing the robot [3]. The tags can wear out and the code on them may not be read properly by the robots.

5) GPS-Although global positioning system is widely used in outdoor terrain, it is not used for indoor robots because the precision level in GPS is in the range of meters and indoor robots need to move distances in centimeters to perform their tasks accurately.

6) Fisheye Camera Technique- In this technique a stationary fisheye camera is used for localisation of the robot in indoor environment. The fundamental element of the suggested robot localisation technique is a fisheye camera model[5]. The fish-eye model uses 3D mapping of points from one device to the other or from one frame to the other.In this ,we use two frames namely reference frame and current frame. The mapping of the current frame is done simultaneously with respect to reference frame. These points are located with the help of segmentation which is carried out from the top view.A complex model which calculates the altitude for vertical and azimuth values for horizontal plane for localising the position of the robot is used. The collected samples are loaded, recorded and then mapped using spatial mapping technique.This is a comparatively accurate and low cost approach for localisation of indoor robots.

B. RELATED WORK ON FISHEYE MODEL

The paper “Real Time Indoor Robot Localization Using a Stationary Fisheye Camera” written by Konstantinos K. Delibasis1, Vasilios P. Plagianakos and Ilias Maglogiannis [6] have done research on how to localize robot in indoor environments. Generally the main problem in robotics arises due to inaccurate localization of robot as the robot’s nature depends on its location. In the above paper they have proposed "fisheye camera technique" for localization of robot. By using this technique there is no need of interfacing sensors with the robot and so the size of overall model reduces.The fisheye camera generates video frames which are then compared with the real ground position. Thus a slight error (less than 0.1 meters) might generate in the robot's position obtained by fisheye camera with respect to the real position and this error can be calculated. Thus true position of robot can be known.We will study this technique in detail for indoor robot localisation.

C. Forward and Inverse Fisheye Camera Model

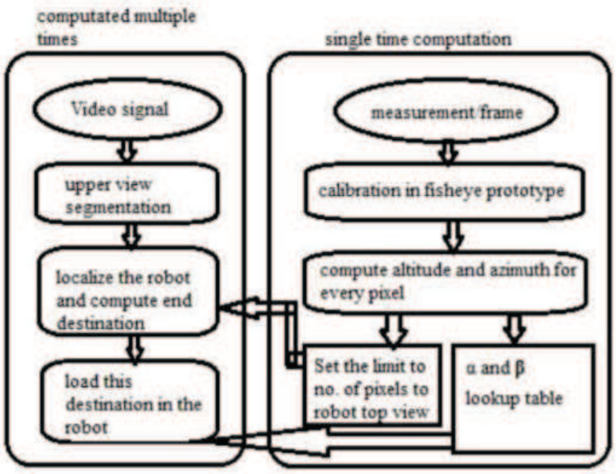

Fig.2 -Architecture of the suggested technique[6]

The block diagram consists of several blocks first one being the block for video signal, followed by upper view segmentation and finally gathering and loading of the data in the memory.This is coupled with techniques from the fisheye lens camera on the right hand side.To start with, the camera is calibrated as per the requirement.Then real time samples are taken by plotting a table for the altitude and azimuth values for every point or real time sample taken. [4].

The fisheye camera provides wide angle view because of the fact that it can provide a range of vision of 180 degrees.Instead of rectangular coordinates, spherical coordinates are used to express range of vision by its azimuth and elevation angles β and α.The modelling (N) in forward direction is described by,

$$(p, q) = N(a, b, c)$$

and in inverse direction,it is described by,

$$(\beta, \alpha) = N^{-1}(p, q)$$

The image formation decides the interpretation of camera modelling.Here we consider a rounded element of random radius R_0 and having centre at A (0,0,C1).

For any random point X having coordinates (a,b,c) we find the intersection B of line AX with the optical element. The point X is imaged at the central projection (Ain,Bin) of B on the image plane using O(0,0,0) as center of projection.This AX line is uniquely described by angles β and α respectively[6].

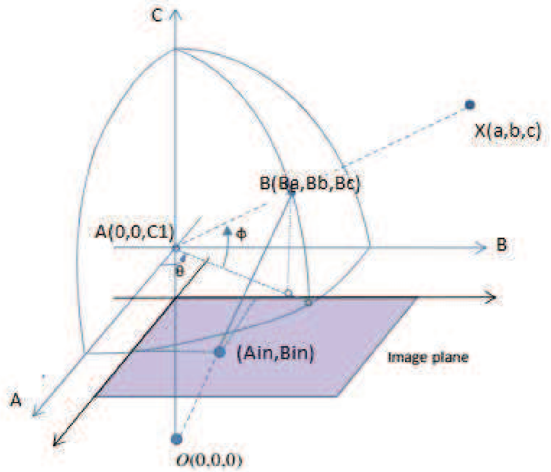

Fig.3. shows the geometry of fisheye camera model where azimuth angle β = θ and elevation angle α = ϕ [6]

The position of B is given by :

$$(B_a, B_b, B_c) = (\lambda(a - a1), \lambda(b - b1), \lambda(c - c1)) \quad ...(1)$$

The central projection (A_{in}, B_{in}) of B on the image plane is given by :

$$(A_{in}, B_{in}) = \frac{Cplane}{C1}(B_a, B_b) \quad ...(2)$$

Thus, any point X having coordinates C > C1, will be imaged on the image plane at position (A_{in}, B_{in}), which is bounded by the radius of the virtual rounded optical element.

D. Case Study- Indoor robots used in warehouses of Alibaba and Amazon:

We would be considering the case study for Amazon and Alibaba Ltd.Amazon uses barcode stickers which are not feasible because of several reasons, the quality of the stickers being one of them. The warehouse consists of moving robots and it is certain that these robots would come in the way of such stickers thus disrupting the view of such robots to the stickers and causing an error. Alibaba on the other hand works purely with Wi-Fi technology. The major hindrance for using such technology is the range and the cost of installation of several Wi-Fi hotspots together at a single place.The storage units are huge and require several hotspot devices to be placed together. Therefore we suggest a technique which uses a fisheye lens for the purpose of localisation coupled with stationary fish-eye camera.The biggest advantage of using this type of lens is that it relates the pixels within the frame with the real time geometry[4].As far as the speed is concerned the method is extremely fast and accurate and no delay occurs.Thus the robot is tracked in real time thus reducing any errors.The camera can rotate 180 degrees in 2 turns which indicates one turn for forward and backward fisheye model each[6]. However it must be understood that fisheye lens is just a replacement for the sensor that were to be used in the robots.The method to be used would still require a variant of dead reckoning, meaning particle filtering or *SLAM(Simultaneous localisation and Mapping)* .The robots in the Amazon and Alibaba warehouses do not need to use any of the above discarded ideas of Wi-Fi or barcode stickers but would only have to deal with a single stationary camera lens if employed.

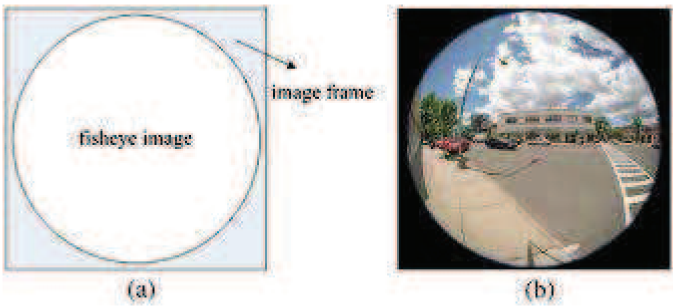

Fig 4 . The figure on the left indicates the image frame and the circular image of the fisheye image and the right hand side image indicates a real time image of the same.[28]

It must be also understood that Fisheye camera lens has to be coupled with one of the techniques of active localisation where the algorithms have direct impact on locating the position of the robots.It is purely based on vision and therefore does not require the help of any extra materials such as sensors.The focal length for a fisheye lens is generally shorter than the normal lens thus providing a wide angled view of the surrounding.The warehouses have several robots working simultaneously and therefore they can be categorised as having dynamic Environments.In such environments, it reduces the chances of error due to obstructions or in technical terms occultations.The camera is calibrated and with the help of that dead reckoning becomes easier as compared to other cases.The camera is fitted on the front of the vehicle because image matching would have been difficult with the side facing cameras .

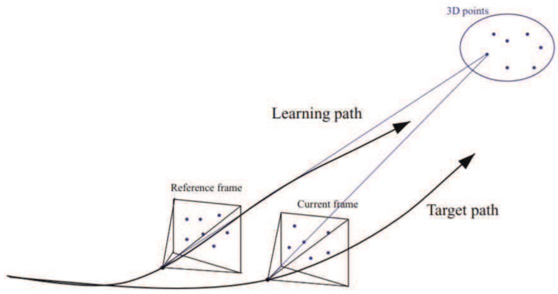

Fig 5. Indicates the mapping process of a fisheye camera lens and a 3D approach to the same

E. Calculated effects with the help of robot localisation in warehouses :

Traditionally a worker could sort 1500 products during a 7.5 hour shift.After using robots along with human labour, the company could sort 3000 products in the same time.In a factory there are several robots and therefore the closest unmanned vehicle has to be located by the system and the same is used in reducing human labour.After reaching the destination the robot picks up the material from a pod underneath and delivers it to the location as specified by the map.Every time you add a robot to the workforce; according to some studies conducted by universities across the world; the employment factor reduces by 5.6 people.If you take 1000 workers together the employment factor goes up from 0.18 to 0.34 percentage point,and the wage factor reduces from 0.5 to 0.25.The fact that the number of industrial robots is going to increase four times in the coming years, is a valid point here.As there aren't many robots till date the jobs of the people have not been adversely affected.Currently the robots in some of the major multinational companies have a speed of 1.3 metres per second and size of 2 feet by 2.5 feet and are capable of upheaving 1000 pounds.However larger robots are being manufactured which can lift upto 3000 pounds also.As a side note only 70 percent of jobs are done by the robots which within no time would reach close to 100 percent.

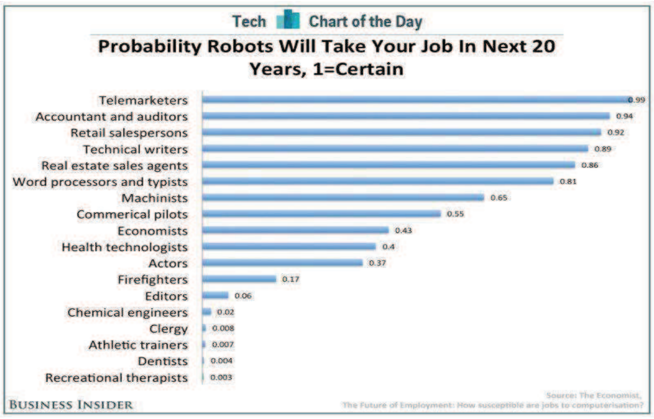

Fig 6.Shows the probability for the chances that the robots would overhaul the human labour force.[26]

III. SECOND PROBLEM STATEMENT

The second problem statement primarily focuses on underwater robot localisation.The main problem that occurs in such scenarios is the presence of an ocean current adds a velocity component to the results and thereby it will be detected by the speed sensor.In the surrounding of the sea the speeds can go up by upto 2 knots .Dead reckoning is such scenarios presents a very poor estimate of the position.Several other techniques are:

A. Adopted Technologies:

1) *GPS (Global Positioning System)*- Compared to indoor environments,GPS is more feasible in underwater environments.Because of vast area of oceans, GPS satellites such as NAVSTAR 26(US 83) and NAVSTAR 27(US 84) can cover wider periphery and localize the robot. However one drawback exists i.e GPS uses electromagnetic waves for its purpose and therefore cannot be used in deep waters because EMW cannot travel underneath[10]. As a result, it is feasible to implement this method is a surface level instead of using in deep oceans.
2) *Piezo-resistive Sensors*- Neoteric researches have shown that flow sensing technique can be exploited to trace the surrounding environments of underwater robot to localize it. Piezoresistive sensors use a pressure signal for underwater feature extraction.The features are interpreted in the form of histograms of intensity of frequency components in that signal[8]. However, if two identical objects are placed as obstacles,then the glitches would increase resulting in faulty feature extraction.
3) *Transponder geometry and Hyperbolic navigation method*- This technique places the beacons on the sea-bed before deployment of the ship so that the triangulation of the position of the ship becomes easier.These beacons causes the decrease in the power consumption.The increase in number of beacons directly leads to improvement in accuracy.
   This method has three parts namely :
   a) LBL (Long Base Line)
   b) SBL (Short Base Line)
   c) USBL (Ultra Short Base Line)
4) *Acoustic sensors*- Namely Doppler velocity logs are quotidian method of obtaining accurate information and it assists to measure the velocity of UAV with respect to bottom terrain of ocean; they use SONAR which includes a type of Acoustic Sensor. They can surpass the drawbacks of blocking of the (EM).

Though this technique assists localisation in deeper regions of ocean belts, they cannot be used because the surface beneath is not uniform and contains several holes and cracks etc.Also, SONAR system are costly to install and manage. Thus we would use hyperbolic navigation method for this problem statement.

B. Related work

The paper by the name "Autonomous Underwater Vehicle Navigation" talks about the hyperbolic navigation method in detail.The method uses well defined geometry of the beacons in order to accurately navigate the position of the ship.This method has two very distinct advantages.The first one is the low power dissipation.As the continuous pinging reduces, the power reduces by a factor equal to that consumed by each beacon.An estimation of the maximum range is also possible if the baseline method is combined with the hyperbolic approach.The geometry is decided based on the variation in the frequency which is done sequentially and in a pattern to identify a path required for defining the accurate position of the underwater robot. We will be elaborating more of this technique in detail.

C. Hyperbolic Navigation with Base-Line Method:

Hyperbolic navigation is a way of overcoming the shortcomings of techniques using GPS, sensors, or Wi-Fi.It uses transponder beacons which forms a unique geometry of the path where the ship or the UUV is traversing. Here the ship does not ping by itself but only receives the signal thus saving a lot of power. Our approach is based on a number of statistically fixed nodes that communicate with each other within a fixed distance thus capable of estimating the ranges to its neighbours.The mobile node and a static node are the two nodes used in this technique[11]. The static node is placed stationary at one position whereas the mobile node collects information from it by moving around it. One of the baseline nodes sends a signal to the transponder which receives that signal.It may be possible that several transponders receive the signal at the same time and thus several values for the distance would be obtained. [11].However the method is known to work based on difference between two signals which are obtained simultaneously.The Hyperbolic navigation enables us to map the location of the system on a graph in a hyperbolic geometry.This method incorporates a geometric approach, meaning the beacons are placed in such a way that the path of the ship is already known, i.e the range and the further work of receiving the signals becomes easier.It works on the concept of time-based navigation.Let us consider two base stations A and B which are several distance apart from each other .These base stations can also mean beacons or transponders.Further let us assume that one of the station has can transmit as well as receive the signals whereas the other one only has the ability to broadcast or send the signal.The distance between them is calculated based on the reference to the light speed thereby gauging the time using the well-known formula ,speed=distance/time. If for reference we place another station in the middle of the two ,which we would for now call baseline,it too would have its own field of broadcast and thereby the time for receiving and sending the signal would be reduced to half.Another important point to note is that each one of them has its own field and the intersection of the field, which is bound to be circular in many cases, would give us two intersection points, one of which is the exact location of the ship.The following diagram shows the mapping of the same.One another advantage of this method is that since the baseline is exactly half the way , the delay measured would be zero.

D. Equations and Mathematical Approach :

The equations below are described to explain the navigation system for 3 nodes.We need to assume that the reference point at one of the nodes,second node will lie on a baseline ,and the third one will form an angle of 90 degrees with the other two nodes' base lines or the node planes.Let the velocity be considered as V and difference in time be T1 and T2[12]. Let R1 and R2 be the distances from the navigation point to the node from the measured time of arrival differences.

$$\sqrt{(a^2+b^2+c^2)} - \sqrt{((a-s^2)+b^2+c^2)} = V * T_1 = R_1 \quad ...(1)$$

$$\sqrt{(a^2+b^2+c^2)} - \sqrt{((a-k^2)+(b-k)^2+c^2)} = V * T_2 = R_2 \quad …(2)$$

$$R_1^2 - s^2 + 2*s*a = 2*R_1*\sqrt{(a^2+b^2+c^2)} \quad ...(3)$$

$$R_2{}^2 - k^2 + (2*k*a) + (2*k*b) = 2*R_2*\sqrt{(a^2+b^2+c^2)} \quad …(4)$$

The above mentioned equations are basic equations for hyperbola which are rearranged as per our need.Circular Hyperboloids with A,B and A,C as foci are considered.If the measurements give the result in terms of sum of the values instead of differences then the radical signs would have positive signs instead of negative ones [12].And R1 and R2 would be interpreted as range sums rather than differences. Now, assume no loss of generality and R1 is not equal to zero : On rearranging and equating (3) and (4) we have,

$$Z = L*a + M \quad …(5)$$

where,

$$L = [\{ R_2 * (\tfrac{s}{R_1})] \quad ...(6)$$

$$\mathrm{M} = \{k^2 - R_2^2 + R_2*R_1*(1-(\mathrm{s}/R_1)^2)\}/(2*K_y) \quad …(7)$$

On putting (5) in (3) we have,

$$c = \pm\sqrt{f*a^2+g*a+r} \quad ...(8)$$

$$c^2 = f*a^2+g*a+r \quad …(9)$$

where,

$$f = -\{1-(s/R_2)^2+e^2\} \quad ...(10)$$

$$g = s*\{1-(b/R_1)^2\} - 2*e*M \quad …(11)$$

$$R = (R_1{}^2/4)*\{1-(s/R_1)^2\}^2 - M^2 \quad ...(12)$$

The navigation point must lie necessarily at the point where two hyperboloids meet.The value of **f** would determine whether its an ellipsoidal curve or a hyperboloid.If the angle subtended by the baseline is small then an ellipse would come as a result of it.[12].Finally the vector **T** which would be used to plot the position of the rover would be as follows :

$$T = a*i + (e*a+o)*j \pm \sqrt{f*a^2+g*a+rk} \quad ...(13)$$

Algorithm 1 Localization Algorithm

```
procedure LOCALIZE(A_1 ··· A_t)
    s ← max speed
    I_1 = A_1        ▷ Initialize the first intersection region
    for k = 2 to t do
        Δt ← k − (k − 1)
        I_k = Grow(I_{k−1}, sΔt) ∩ A_k    ▷ Create the new intersection region
        for j = k − 1 to 1 do              ▷ Propagate measurements back
            Δt ← j − (j − 1)
            I_j = Grow(I_{j+1}, sΔt) ∩ A_j
        end for
    end for
end procedure
```

Fig 7.The figure indicates the algorithm used for the above mentioned method.To begin with the algorithm a variable has been taken and then re-iterated as per the need.[25]

E. Problem with Hyperbolic Navigation and its Resolution :

The only problem that exists with the hyperbolic navigation system is that because there can be an overlap of several fields , it would create a confusion for the user to actually determine which of the intersection would be the best fit for the position of the ship.For eg.the zero delay from the master to the receiver station B would mean that either it is equidistant from the receiver or is at the center of the two base stations.To overcome this problem the speed of the light is taken as the reference and the time delay dependent upon it is calculated.This may also result in problems, because the delay times would match with each other.To overcome this new problem we propose a method which involves a second master in the situation. We get two delays on the chart on searching up both the delays on the chart and we can obtain the position of the ship using one of the delays.It is possible that both the delays are close to each other, in that case select any of the two or take the average of the two.The cost of setting this type of system is also pretty low because the stations consists of nothing but a transponder hooked on to the receiver or a broadcast signal.

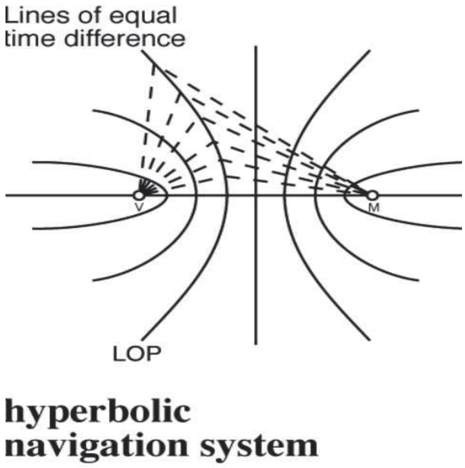

Fig 8. Indicates a typical Hyperbolic Navigation system along with the hyperbolic curves of two specified base stations V and M respectively.These are appropriately named as lines of equal time difference.[27]

F. Case Study-Robots or Unmanned Underwater Vehicle :

The robots that are used in this case have 6 DOF (degrees of freedom meaning that they can move along six different positions namely; surge, heave, sway, normal (yaw),latitudinal(pitch) and longitudinal (roll) axes. These robots either use the vision based system or use the acoustic system.We have used the vision based system but the ones using the sensors fall under the acoustic based version.The two examples of such robots are AMPUR and STARBUG and THESEUS AUV and DARPA AUV.Both of these robot were developed and tested at MIT, Boston.Lithium Polymer Battery which has a long endurance is used here. Also four thrusters are implemented each providing a maximum power of 150W and maximum thrust of 35N each. Each of them uses sensor nodes and they are self-synchronising and use TDMA(Time Division Multiple Access).The star bug is vision based and has two cameras ,one looking downward for sea-floor estimation and the other looking forward for obstacle detection.All of them have a firewire interface.Hyperbolic navigation can really prove a plus point in such situations.

IV. THIRD PROBLEM STATEMENT

The third problem statement primarily focuses on robot position handling in space. In space, the location of robot is of primary importance because of several reasons such as exploring the surface of another planet and finding the impurities in water , gases etc. or to find the possible terrain of the planet and thereby improving it if possible.

A. Adopted Technologies:

1) *Visual Odometry (VO):* This method employs the use of sensor for collecting data with respect to various features mentioned above and documenting them based on the needs. The visual odometry can be used to correct the errors caused by wheel slippage in the rover[15]. Visual odometry uses a Panoramic or a NAV camera for its purpose.
2) *Bundle Adjustment:* This method uses tie points to link images taken at different rover locations.As a result, an image network is generated and it assists in locally improving the image orientation. Topographic maps have to be made for this purpose because it works on the geometric approach of map tracing as mentioned earlier.
3) *Inertial Measurement / Navigation Unit (IMU /INU)* **:** It uses the traditional approach of navigation which is the sensor based approach for the Navigation of the Rover on the planet. Several methods can be used in combination with this method using one method alone is not sufficient. The major disadvantage of this method is that position estimation is done without using any reference frame. The measurements are basically the real time data collected from the sensors and the accelerometer .Further due to the limitations of sensors and its low precision, error is significantly more than the other techniques such as SAP (Space Activity Planner).
4) *Combination of Visual Odometry and Bundle Adjustment (VO and BA)*: Some of the methods apply a combination of Visual Odometry and Bundle Adjustment. Bundle adjustment is performed at waypoints.On the other hand, visual odometry is performed between the waypoints.The BA obtains the specified data from the VO ,tracks features ,refines image-orientation parameters as an input and first and last stereo pairs.After the BA the rover positions are updated at specified points in space.

From the above techniques we choose visual odometry approach and use Kalman filter with it since it has several advantages over other techniques. It has a far wider reach when applications are taken into account.It can be used for robotics, automotive and wearable computing. Automatic take-offs and landing also make use of this method in the UAV's (Unmanned Aerial Vehicles). Pathway of such vehicles is exactly retrieved using visual odometry. Visual Odometry provides less relative position error ranging from 0.1% to 2% and provides more exact trajectory estimate.

B. Related Work

The paper "Path Following using Visual Odometry for a Mars Rover in High-Slip Environments" written by Daniel M. Helmick, Yang Cheng,Stergios I. Roumeliotis,Daniel S. Clouse, and Larry H. Matthies have incorporated visual odometry with Kalman filter and slip compensation techniques and checked the accuracy of a system which can be used in the rover for appropriate path following. They also showed that the error using these techniques generated positioning error below 3% of the displacement of the rover. We will now focus on this technique in detail.

C. Method for third problem statement: Visual Odometry and the Kalman Filter approach

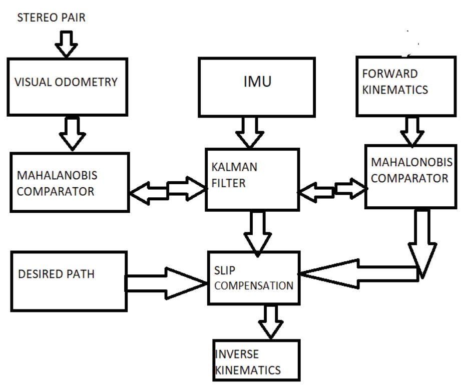

Fig 9. The figure indicates a general flow of the Localisation of the Mars Rover in space.

The technologies that are used in this case are visual odometry, full vehicle kinematics, a Kalman Filter and a slip compensation follower.The concept of Stereo imaging is used in this case. This concept can be implemented to find the source of sound. This technique uses two stereo imagery pairs one of which hands over the contents to the other ,thus incorporating the maximum likelihood algorithm.The IMU data and VO data are combined with the help of Kalman filter. The difference between the merged estimate and the kinematic estimate provides us data about the extent to which slip has occurred.The slippage of wheels in curiosity rover is shown below :

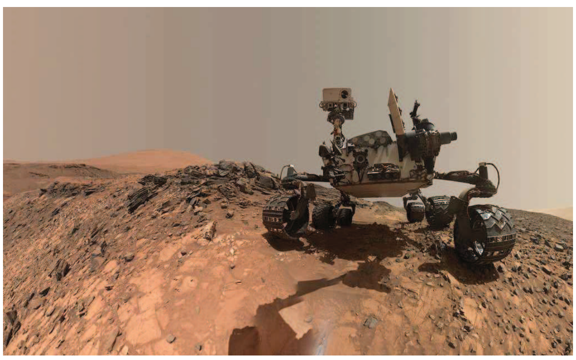

Fig 10:Shows slippage of wheels in Curiosity rover[29]

If a vector difference is present between the two then it is calculated. While locating the position of the rover,we need to study the following factors based on the terrain such as: slope,soil quality of terrain. Visual odometry works independent of the environment making it a biggest advantage as far as the contents of terrain land and gases are concerned. Correlation is established between local terrain surrounding the spacecraft and the stereo images that are obtained from the vehicles. These images give an accurate location of the robot. One must note that the error in the localisation increases as the vehicle travels more and more on the surface.A certain combination of frames such as site frame, a land frame, robot frame can be used to reduce error and also as a reference in such imagery . Another important point to be considered is the obstacle avoidance.In this case, target imaging plays a major role. This can be done by putting appropriate sensors on the vehicle as and when need arises.The exact image of the rover is in the rover frame rather than local frame. However if an error occurs after a drive then it must be taken into account.The same point must be available after and before tracking for it to be without error.To remove this error multiple point pairs must be placed on the ground.Currently many studies are going on which focus on the correlation of one set of images with the other ,in this case stereo images.One more method to accurately track the devices in this scenario is the method of SAP (Space Activity Planner). The tool allows the pixel to select any number of named targets by first selecting a pixel from the frame and then assigning it an appropriate name in the XYZ coordinate system.These are stored in a database of the SAP which can be seen by all the users of those areas simultaneously. Thus the payload and the specific scientific instruments are tracked appropriately. The target uses information from the previous SOL (one day on Mars as compared to Earth) .The information from the previous SOL is used to find the exact location or rather approximate location of the device till that time and then the data is used to plot the next location of the device using this information .

D. Equations and Mathematical Approach for Visual Odometry and Kalman Filter:

1) Mathematical Approach for Visual Odometry :

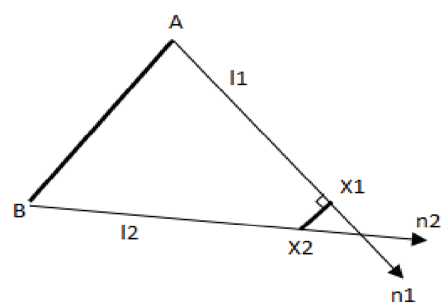

Fig.11. Feature Gap[23]

Let the stereo cameras be located at A(x1,y1,z1) and

B(x2,y2,z2) (refer fig.11). Here n1 and n2 are two unit rays from the same feature in both images. Due to noise n1 and n2 do not always meet in space. The stereo point is assumed to be at halfway between the nearest points of the two rays. Let the closest points between the two rays be X1 and X2, thus, we have

$$X1 = A + (n1 * l1) \quad \ldots(1)$$

$$X2 = B + (n2 * l2) \quad \ldots(2)$$

where l1 and l2 are lengths of X_1A and X_2B . Thus we have,

$$(X_2 - X_1) * n_1 = (B - A + n_2 l_2 - n_1 l_1) * n_1 = 0 \quad \ldots(3)$$

$$(X_2 - X_1) * n_2 = (B - A + n_2 l_2 - n_1 l_1) * n_2 = 0 \quad \ldots(4)$$

Then we have,

$$l_1 = \frac{(D*n_1) - ((D*n_2)*(n_1*n_2))}{1-(n_1*n_2)^2} \quad \ldots(5)$$

$$l_2 = (n_1 * n_2) * l_1 - (D * n_2) \quad \ldots(6)$$

where,

$$X = \frac{(X_1+X_2)}{2} \quad \ldots(7)$$

and $D = C_2 - C_1$, l_1 and l_2 are functions of feature locations on both images. By taking the partial derivatives we get,

$$l_1^{/} = \frac{[(D*n_1^{/}) - ((D*n_2^{/})*R) - ((D*n_2)*S)*[1-R^2]}{[1-G^2]^2} \quad \ldots(8)$$

$$l_2^{/} = R * l_1^{/} + S * l_1 - D * n_2 \quad \ldots(9)$$

$$X^{/} = \frac{(n_1^{/}*l_1 + n_1*l_1^{/} + n_2^{/}*l_2 + n_2*l_2^{/})}{2} \quad \ldots(10)$$

where $S = n_1^{/} * n_2 + n_1 * n_2^{/}$ and $R = n_1 * n_2$
The covariance of X is:

$$\sum_x = X^{/} * \left[\sum_m \quad 0\ ;\ 0 \sum_n\right]$$

where X′is the Jacobian matrix, or the matrix of first partial derivatives of P with respect to A and B.[23]

2) *Mathematical Approach for Kalman Filter :*
The Kalman filter technique comprises of two steps:

- Prediction step: In this the next step of the system is determined from the previous measurements
- Update step: In this the current state of the system is predicted provided the measurement at that time step.

The steps are as follows:

- Prediction:

$$A_n^- = P_{n-1} * A_{n-1} + Q_n * R_n$$

$$B_n^- = P_{n-1} * B_{n-1} * P_{n-1}^T + C_{n-1}$$

- Update

$$D_n = E_n - F_n * A_n^-$$

$$G_n = F_n * B_n^- * F_n^T + H_n$$

$$J_n = B_n^- * F_n^T * G_n^-$$

$$A_n = A_n^- + J_n * K_n$$

$$B_n = B_n^- - J_n * G_n * J_n^T$$

where,

- A_n^- and B_n^- are the predicted mean and covariance of the state, respectively, on the time step n before seeing the measurement.
- A_n and B_n are the estimated mean and covariance of the state, respectively, on time step n after seeing the measurement.
- E_n is mean of the measurement on time step n .
- K_n is the innovation or the measurement residual on time step n.
- G_n is the measurement prediction covariance on the time step n.
- J_n is the filter gain, which tells how much the predictions should be corrected on time step n.[24]

E. Case study- Curiosity Rover launched in 2011

NASA's Mars Science Laboratory designed Curiosity rover to search and identify the variety of rocks on the Gale Crater. It also has objectives of finding history of water content on martian soil and studying the processes such as sedimentation, formation of craters and frequency of wind erosion on martian topography.

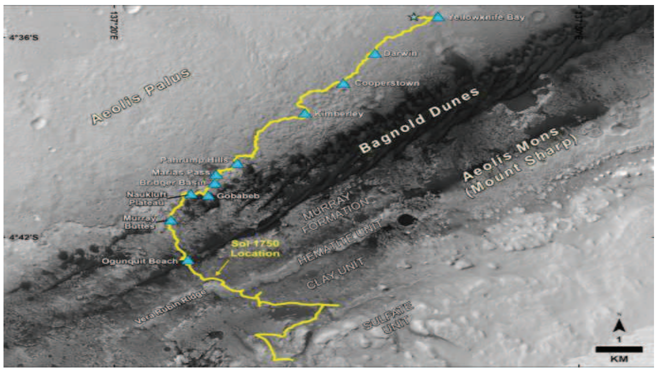

Fig 12. Actual path of Curiosity rover till July 2017.[21]
Shown above was the path followed by Curiosity Rover from

August 2012 to July 2017[20].However this wasn't the expected route by Mars lab of NASA. The complications arose recently in curiosity rover are the fissures and punctures formed in the wheels of the rover. Initially,holes were purposely punctured to provide grip to the wheels for precise localisation of robot.But this led to aggravation in spoilage of tyres[21].This spoilage is shown below

Fig 13. The perforation in wheels of Curiosity rover[22]

But using Kalman filter ,visual odometry data is assimilated with inertial measurement unit and thus localisation error is reduced. In this way,the purpose of puncturing the wheels to reduce error is fulfilled using Kalman filter.

V. CONCLUSION

Each of the problem statement presents a different perspective for the localisation of the robots.A different method was suggested for every one of them which would remove the barriers that the other methods were facing and provide with a better solution.The indoor robot localisation ,should be done with the help of the fisheye camera lens because it removes the complexities that the other methods face ranging from the GPS and the WiFi issues or the drawbacks associated with the RFID tags with tag scanner.In the underwater localisation we used a combination of several baseline techniques and transponder beacon methods for the full proof solution of the problem after considering all the complexities equally and trying to remove them.The major advantage of this is the low cost associated with it and the geometric approach it takes.Finally for the space localisation situation we used a very unique method for the localisation of robots traveling in the outer space on several planet especially on Mars.The method was visual odometry with hyperbolic navigation..Each of the problem statement was ended with a case study that explained how the robots used in today's industries would incorporate our method and thereby show calculated effects and improvements in their efficiency and thus provide the basis for further research to study localisation in the domains related to the problem statements.

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