Informal Project

Study and analysis of various sensors and data fusion for pose estimation, mapping and localisation

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Tasks completed:

1. Preliminary research, highlighting the merits/demerits of the following sensors:
    a. LiDAR
    b. Stereo-Vision Cameras
    c. Inertial Measurement Units
    d. GPS
    e. Wheel Encoders

2. Research on output data of some of the sensors
3. Reading through parts of the book 'Programming Robots with ROS' by Morgan Quigley, Brian Gerkley and William D. Smart

Information obtained from the above research has been combined and presented as one under the heading of 'Background Research on Sensors' categorized by sensor type.

Next few tasks:

1. Getting familiar with the different output of sensors using Gazebo with TurtleBot, for which I have been reading 'Programming Robots with ROS' as mentioned above
2. Research on pose estimation softwares
3. Getting familiar with Robot Pose EKF in ROS

Background Research on Sensors

LiDAR:

- LiDAR is the shortened form of Light Detection and Ranging/ Light Imaging, Detection and Ranging.
- It is used to give long range views for topography matching and map development.
- It involves determining ranges by targeting an object with a laser and measuring the time for the reflected light to return to the receiver (similar to radar and sonar).
- The 3-D point clouds acquired from these types of scanners can be matched with digital images taken of the scanned area from the scanner's location to create realistic looking 3-D models in a relatively short time when compared to other technologies.
- It also involves occupancy grid map generation. An array of cells is divided into grids which employ a process to store the height values when lidar data falls into the respective grid cell. After this, a binary map is created by applying a particular threshold to the cell values, after processing the radial distance and z-coordinates from each scan.
- It is often used in vehicles for which the scanners are designed to deal with the significant aerodynamic forces, vibrations, and temperature swings common to the automotive environment.

Merits:

- Easily generates 3D data, which can later be combined with data from cameras for creating realistic models, with RGB values.
- 3D data is often preferred to 2D data as the 3D shapes of objects in the environment are invariant to changes in lighting, shadows, occlusions etc.

Demerits:

- There can be considerable difficulty in reconstructing point cloud data in poor weather conditions. In heavy rain, for example, the light pulses emitted from the lidar system are partially reflected off rain droplets which adds noise to the data, called 'echoes'.
- Refraction from protective glass case can introduce further errors (protective coatings can be applied to reduce amount of refraction/reflection)
- It is a much more expensive sensor, as compared to others.

Point Cloud Data:

- It is the spatially organized LiDAR data.
- Each point represents a single laser scan measurement.
- Initial point clouds are large collections of 3D elevation points, which include x, y, and z, along with additional attributes such as GPS time stamps. The specific surface features that the laser encounters are classified after the initial lidar point cloud is post-processed.
- Each point in the point cloud is given the colour of the pixel from the image taken located at the same angle as the laser beam that created the point (RGB value) and intensity.
- Using this data, a realistic model of the environment can be formed, which involves converting the data into a polygon mesh for 3D softwares.
- .xyz is the usual file format for this (a text file that has only the coordinate information). .las incorporates more data.

Stereo-Vision Cameras:

- It includes wo cameras rigidly mounted to a mechanical structure
- It has two or more lenses with a separate image sensor or film frame for each lens. These two lenses allow it to simulate human binocular vision, and therefore gives it the ability to capture depth using stereo disparity.
- Both passive and active stereo cameras exist, where active stereocams which actively employs a light such as a laser or a structured light.
- The output data is called RGBD data, which provides information on the depth, texture, shape and colour of the objects in the surroundings.

Merits:

- Its main advantage over generic image capturing devices is that it captures depth using stereo disparity.
- Landmarks can be extracted form RGBD data using pretrained CNNs (using Earth terrain data and even Martian terrain data)
- It is less expensive as compared to LiDAR, and still provides information on depth.

Demerits:

- There are difficulties detecting depth when objects are not very textured, and are sensitive to the changes in lighting conditions throughout the day unlike LiDAR (this is one reason why data from LiDAR and stereocams is combined such that the shortcomings of both sensors can be compensated by each other).
- The quality of data here depends on the quality of the camera's mechanical design, resolution, lens type and quality, lighting, contrast between objects and their edges (a sharp contrast is preferred for easy and accurate detection).
- It has a limited FOV and multiple may be required (the optimal position for a vehicle/rover would be right in front, though multiple should be used on all 4 sides).

Inertial Measurement Units:

- An inertial measurement unit works by detecting linear acceleration using one or more accelerometers and rotational rate using one or more gyroscopes. Some also include a magnetometer which is commonly used as a heading reference (also included in GPS sometimes).
- They usually consist of a 3-axis accelerometer and a 3-axis gyroscope (giving 6 degrees of freedom), and optionally a magnetometer in addition (giving 9 degrees of freedom).
- The magnetometer readings are usually fused with the other readings using the IMU's own processor to give those readings greater accuracy.
- The output in essence consists of body frame accelerations, angular rate and magnetic field measurements.
- Accelerometer: Tests the motion acceleration of the carrier, which is then used to calculate the real-time location of the carrier (measures the vibration/acceleration/motion of a structure)
- Gyroscope: Determines an object's orientation within 3D space, measures angular velocity about three axes: pitch (x-axis), roll (y-axis), and yaw (z-axis)
- Magnetometer: Used as a heading reference (the direction it is pointing), measures the direction/strength/relative change of a magnetic field at a particular location

Merits:

- They detect both rotation and movement in 3 axes.
- They directly measure linear accelerations and rotational velocities, so their outputs are better than accelerations and velocities obtained by taking the time derivative of position data.
- IMU enabled GPS devices allow the GPS receiver to work when GPS-signals are unavailable.

- Some stereo-cameras come with pre-installed IMUs like Intel RealSense D435i as well.

Demerits:

- Dead Reckoning: It is the process of calculating the current position of some moving object by using a previously determined position and then incorporating estimations of speed, heading direction, and course over elapsed time. This is an important concept in IMUs, which often leads to errors.
- Because the guidance system is continually integrating acceleration with respect to time to calculate velocity and position, any measurement errors, however small, are accumulated over time. This leads to drift: an ever-increasing difference between where the system thinks it is located and the actual location.
- Due to integration a constant error in acceleration results in a linear error in velocity and a quadratic error growth in position. A constant error in attitude rate (gyro) results in a quadratic error in velocity and a cubic error growth in position.
- For IMUs that are a part of RGBD cameras, there is often a greater tendency to drift, a more precise main IMU may be required to rectify other readings.
- The possible errors in IMU readings are: offset, scale factor, misalignment, cross-axis sensitivity, noise, environment sensitivity.

GPS:

- GPS or Global Positioning system is a necessity for any vehicle/rover to know its current coordinates (possibly using radio frequency emitting beacons that act as small scale global positioning systems) The options here involve either using standard GPS or using Real Time Kinematic GPS.
- RTK uses measurements of the phase of the signal's carrier wave in addition to the information content of the signal and relies on a single reference station or interpolated virtual station to provide real-time corrections, providing up to centimetre-level accuracy (Carrier Phase Enhancement GPS: CPGPS).

Merits:

- Differential GPS has greater accuracy.
- GPS data can be used to correct encoder readings.
- GPS readings are often incorporated into point cloud data itself, to give an integrated output with all possible data from the surroundings.

Demerits:

- Bad satellite connection can introduce great inaccuracies.
- The GPS signal may be lost in tunnels/buildings etc. causing further issues and hence GPS alone cannot be relied upon for positioning.
- Using RTK requires RTK subscription and internet connection, or setting up your own base station to provide atmospheric corrections (valid for 20-30km).
- In addition to this, the cost of RTK is much greater.

(Further research into the merits of using RTK GPS as opposed to standard GPS is a future task, scheduled for one of the coming months, and hence much work was not required on this topic for the time being).

Wheel Encoders:

- Wheel encoders provide information about momentary position changes.
- They are used to count the number of times the motor (left or right) has rotated. This can be used to calculate the distance that the robot has driven or turned
- The wheel or shaft encoders function by rotation, and include a Hall effect sensor and a ring magnet. As each motor shaft rotates, it also rotates its attached ring magnet at the same rate. As the ring magnet completes one full rotation, the Hall effect sensor detects 4 changes (or "ticks") in the magnetic field as each magnetic pole passes by the sensor. Here the angular position of a marker on a shaft is measured relative to an adjacent frame of reference.

Merits:

- It can be used for controlling speed.
- It helps in making sure that the rover drives straight by making small adjustments in the left and right motor powers to make sure both motors rotate at the same average speed (pivot on both wheels by a specific angle by calculating how far the wheels have traveled while pivoting in a circle, turn on one wheel by a specific angle by calculating how far the driving wheel has traveled while turning in a circle).
- It can be used to drive for a specific distance by calculating how far the wheels have traveled. This is combined with adjusting the motor powers to drive straight.
- It complements GPS data, correcting errors in GPS readings (using Kalman filters)
- It is easier to implement than visual odometry (though with lower accuracy)

Demerits:

- Error accumulation: It is sensitive to errors due to the integration of velocity measurements over time to give position estimates. Rapid and accurate data collection, instrument calibration, and processing are required in most cases for odometry to be used effectively.
- There may be drift due to slippage (mitigated by using additional sensors)

Bibliography

- https://www.researchgate.net/publication/228809785_Data_Fusion_of_wheel_encoders_and_magnetic_sensors_for_autonomous_vehicles_navigation
- https://robotics.stackexchange.com/questions/18964/how-does-3d-lidar-work
- https://vision.in.tum.de/data/datasets/rgbd-dataset
- https://robotics.stackexchange.com/questions/22259/imu-gravity-sensing
- https://robotics.stackexchange.com/questions/22115/how-to-actually-fuse-sensor-using-extended-kalman-filter
- https://robotics.stackexchange.com/questions/4960/stereo-vision-on-a-moving-vehicle/4971#4971
- https://docs.idew.org/code-robotics/references/physical-inputs/wheel-encoders#:~:text=Located%20directly%20behind%20each%20motor,robot%20has%20driven%20or%20turned.
- https://info.vercator.com/blog/what-are-point-clouds-5-easy-facts-that-explain-point-clouds