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Near Real-Time 3D Path Visualization for Navigation Systems with IMU Sensor and Kalman Filter

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Abstract

Path tracing or simulation in robotics Operating System ROS is very popular in highly dynamic research projects. The Matplotlib's 3D path tracing is a graphical 3-axis plotting tool with real- time data visualization over a very long range. The data's are generated in all 3 dimensions from accelerometer readings for visualizing the ground station navigation system. The communication between the two radio modules are established and the data's are transmitted between the two modules that are placed remotely. The data can be plotted in real-time in 3 Dimensions and then, visualized. The main goal of path tracing is to make a comparative study between 3 axis displacement as any kind of irregular plot or trace can be a sign of a dangerous situations that can occur. There are many other significances of this concept that can be used in navigation systems.

Keywords: Accelerometer, Gyroscope, Transceiver, nRF24, Kalman Filter, Path Visualization.

1. Introduction

Using the navigation systems similarly, vehicles with different velocities and acceleration can also be traced the need to trace such vehicles is to guarantee its safety. So, the research aims to develop a specific system for tracing the position of such vehicles and flights with readings calibrated using gyroscope and accelerometer in IMU sensor and the data is then, used to calculate the real time velocity and the linear acceleration in 3 Dimension.

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The navigation systems often have threats of facing unintended problems and causing unwanted fatalities. Our main goal is to get the displacement of the navigation systems with the IMU sensor data to trace it's position in 3D and visualize it in real- time. The accelerometer data is filtered out with the use of Kalman filter so that the radio module can communicate between two devices to transfer the obtained data and plot it in 3D.

The main goals of the research carried out are:

- To study the displacement in the 3-axis for a body using IMU
- To make a comparative study with the use of filters.
- To develop a system to plot the body's displacement in 3-axis in real-time and make visualization using Matplotlib.

2. Literature Review

The article by Dubey et al. (2019) presents a real-time implementation of the Kalman filter for improving the accuracy of time-of-flight measurements in an ultrasonic pulse-echo setup. The authors emphasize the importance of accurate time-of-flight measurements in ultrasonic applications, particularly in the fields of medical imaging, non-destructive testing, and distance measurement.

The real-time tilting measurements with the IMU suffer lots of errors and can yield unreliable and inaccurate sensing so, the study of Kalman and Complementary filter have been done by (Pengfei Gui et..,al 2015) concluded it is not easy to get an accurate orientations from a accelerometer because signal that has been extracted from the inverse trigonometric function is likely much sensitive to the variations.

Trucks in mountainous areas need a high level of automation to be efficient and reduce the number of workers required to transport agricultural products. Research on Adaptive Integrated Navigation Method and Path Tracking Control Strategy Combining Global Navigation Satellite System (GNSS) and Inertial Navigation System (INS) The challenge of advanced control. An indirect Kalman filter (KF) is used for GNSS/INS data aggregation and an improved KF tuning calculation method is used to avoid KF variance, and decision making is u sed to deal with GNSS measurement parameters during the burst. To realize autonomous driving a five-layer fuzzy neural network controller is proposed that takes the time difference, path difference, and road curvature as input and the angle concerning to the output to achieve high-speed traffic.

Surveys on Potential UAV and Roads in Urban Environments Using Broadband Models highlighted when the drone's position is continuously estimated using visual odometry, scene mapping is used for correct visualization of the landmark-based position drift. The drone's path is defined by a series of waypoints and landmarks near the waypoints are carefully chosen at the intersection. (Ayham Shahoud et al., 2023) The system was employed in a virtual environment that included an IRIS drone model, a ROS, and the 3D dynamic simulator Gazebo.

The following method and soil quality monitoring in the GNSS-based tractor- scraper classification system requires a new coin-based model quality control. This function generates an estimate of side slip, which is included in the kinematic model of the tractor scraper. The method has been validated by field experiments where the GNSS-based tractor-scraper soil formation system automatically follows the planned path in the wetland to achieve soil formation. (Yunpeng Jing et al., 2021) Experimental results show that the postexposure method of this method outperforms the pure control (PPC) method.

The study aims to determine the accessibility and intelligibility of urban areas by asking the participants to draw the shortest route between the selected location on the map and the center. (Alice Vialard et al., 2021). Participants were asked to draw a path between two points while following a connected path, the image speeds, completion time, and accuracy were recorded to measure navigational difficulty. A study was conducted to investigate the effect of intersections on the following speed and it was confirmed that there are intersections on the road that affect the following speed.

3. Methodology

The communication is carried out across the two radio modules nRF24L01 which is working as a transceiver. The data is sent from MPU-6050 sensor-connected microcontroller to the receiver side using nRF24 and the sent data are displacement in X, displacement in Y and, displacement in Z axis. The successful range tests are carried out in order to get the accurate range of nRF24L01 communication modules and similarly, any sort of interference present over there are eradicated using a 10uf capacitor connected between 3v and gnd for the nRF24l01. The successive range tests are carried out before the plot in 3D.

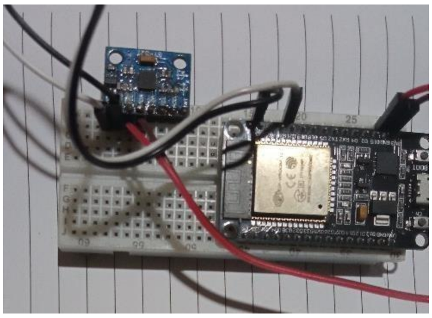

Figure 3.1. IMU Sensor with ESP32 Dev Board

The IMU sensor (Fig.3.1)_ is connected to the ESP-32 wroom module and it is processing the data accordingly as programmed. The program contains Kalman Filter that is used in removing the errors in the sensor data (Fig.3.2)

The Kalman filter is applied to grab accurate accelerometer values by reducing noise errors. The displacement is calculated by double integrating accelerometer values over time.

The data from the Mpu6050 sensor is sent to the receiver device through nRF and then, communication is made between the two.

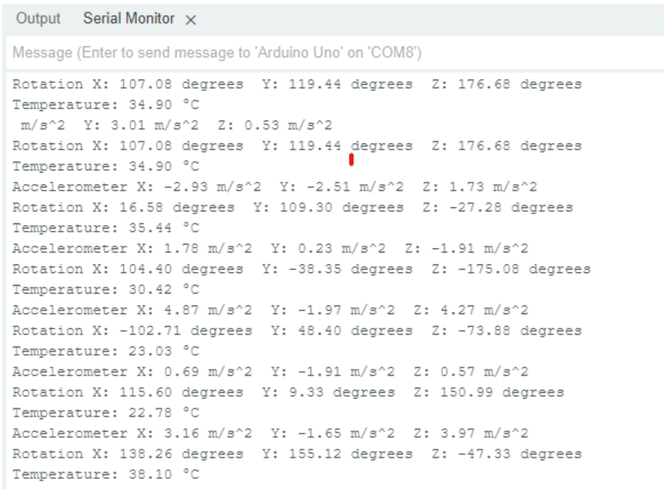

Figure 3.2. IMU Sensor Data

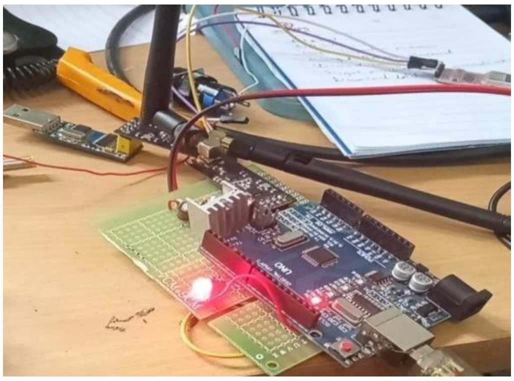

Figure 3.3. LED Blink with Radio Communication between Two Modules

The nRF24 is added to a PCB board with Arduino and LED (Fig.3.3) to determine the radio availability which is true when the transmitter address is found by the above receiver antenna and the LED glows as above. A capacitor has been used to remove the interference produced in the data transmission due to external sources.

3.1. Block Diagram of the System

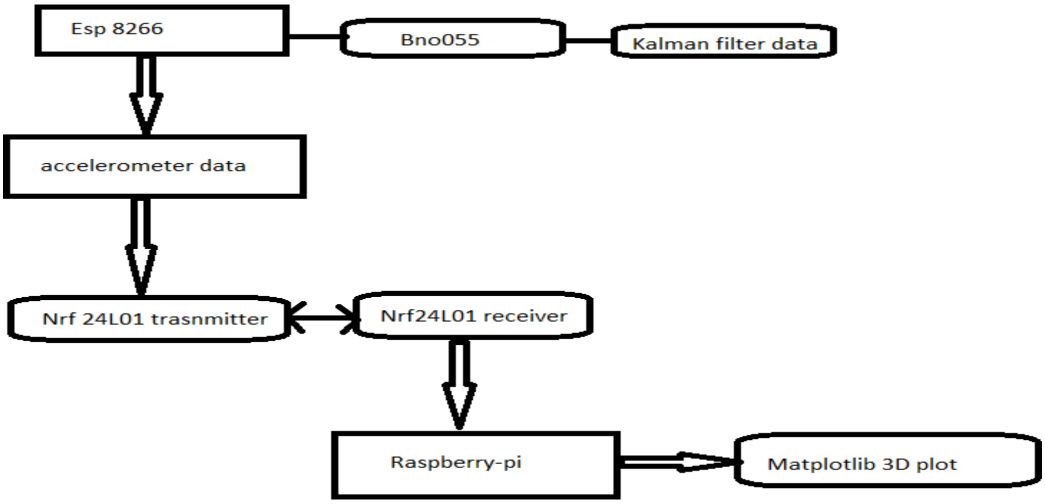

Figure 3.1.1. System Block Diagram

The accelerometer data is the key behind the overall system functioning as the data generated from the accelerometer processed by microcontroller nodeMCU gets transmitted to receiver side and then transmitted over a wide distance using nRF24L01 transmitter and similarly, received on the opposite side connected raspberry pi that is processed accordingly. The Matplotlib is a visualization library that supports 3-Dimensional visualization that arduino and other serial plotting features won't support. So, we can plot a data from loop in 3D and we have followed the same concept here, that is creating a loop of data received by nRF24L01 and then processing the data accordingly, and plotting in 3-axis.

As, shown in the above block diagram (Fig.3.1.1). a Raspberry Pi is used as a microcontroller as well as a computer to plot the obtained accelerometer data. The transmitter side sends the data and the receiver obtains using nRF24 module with a wireless communication method. The Raspberry Pi is used as a receiver which is receiving data sent by the navigation system attached microcontroller which is processing IMU sensor data and sending it using nRF24 module that is acting as a transmitter.

IMU Sensor MPU-6050

The MPU-6050 is a popular 6-axis motion processing unit (MPU) that combines a 3-axis gyroscope and 3-axis accelerometer in one package. It is often used as a sensor module in various electronics projects, especially those related to motion detection or direction detection.

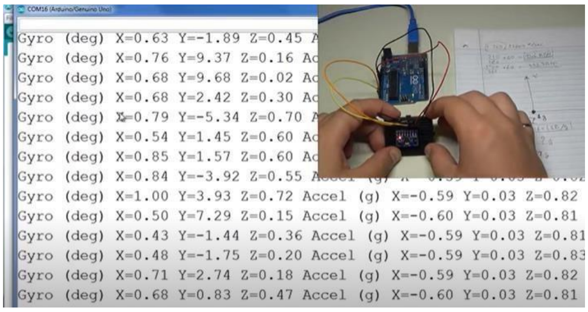

Figure 3.4. MPU6050 Values Calibration

The MPU-6050(Fig.3.4) uses a digital interface to communicate with microcontrollers or other digital systems, and it provides raw sensor data in the form of acceleration and angular velocity values. These values can be used to calculate the orientation of the module relative to a reference frame or to track the motion of the module over time.

Extended Kalman Filter

In forecasting, the Extended Kalman Filter (EKF) is a nonlinear Kalman filter that linearizes the current mean and variance of the forecast. To replace the effective model, EKFs are used as a model in nonlinear state prediction, routing, and GPS theory.

When you track an object with a filter, you can use Check or Measure to determine the object's state based on motion patterns. In the model, a state is a collection of objects that represent the state of an object, such as its position, velocity, and acceleration. Using the Extended Kalman Filter (extended EKF) when the object is in at out-of-balance state or the error in measurement in this state.

For example, consider using the Extended Kalman Filter when the measurement target is expressed in linear coordinates such as azimuth, elevation, and distance, but the state of the target is expressed in Cartesian coordinates. The extended Kalman formulation is based on the linearization of the equation of state and the measurement equation. Linearization lets you report states and state variables in a linear approximation and requires the Jacobians of the states to be equal and the equation to be measured.

We have:

$$\boldsymbol{AccErrorX} = \boldsymbol{AccErrorX} + ((\boldsymbol{atan}((\boldsymbol{AccY}) / \boldsymbol{sqrt}(\boldsymbol{pow}((\boldsymbol{AccX}), \mathbf{2}) + \boldsymbol{pow}((\boldsymbol{AccZ}), \mathbf{2}))) * \mathbf{180} / \boldsymbol{PI}));$$

$$\boldsymbol{AccErrorY} = \boldsymbol{AccErrorY} + ((\boldsymbol{atan}(-\mathbf{1} * (\boldsymbol{AccX}) / \boldsymbol{sqrt}(\boldsymbol{pow}((\boldsymbol{AccY}), \mathbf{2}) + \boldsymbol{pow}((\boldsymbol{AccZ}), \mathbf{2}))) * \mathbf{180} / \boldsymbol{PI}));$$

$$\boldsymbol{AccErrorX} = \boldsymbol{AccErrorX} / \mathbf{200};$$

$$\boldsymbol{AccErrorY} = \boldsymbol{AccErrorY} / \mathbf{200};$$

nRF24L01 Range Test

The range experimentally determines an accurate range of nRF24l01 radio module which uses 125 different channels and each channel may provide a maximum of 6 addresses. It was found that it gives an accurate range up to 500m very well in spite of any sorts of interference present and similarly, gives up to 1 kilometer’s area where any kind of interference sources aren’t present at all.

Matplotlib

Matplotlib is a visualization tool or a standard python library that is used to plot data points as similar as in MATLAB with more features. In this research, The data from the sensor and nRF24 to python program is imported through serial port read and then, plotting in 3D simultaneously. Finally, an executable version of the Python programme was created in the research to be used with other Linux devices that support the nRF24 USB communication module.nRF.

Radio Module nRF24 Trans-Receiver

nRF24 is a transceiver module that comes in pair. That is used for communication and sending and receiving data. When there are no interference problems or a wi-fi signal of 2.4 hz frequency, that doesn't interfere with the nRF24 transceiver, communication can be made up to a distance of one kilometre.nRF.

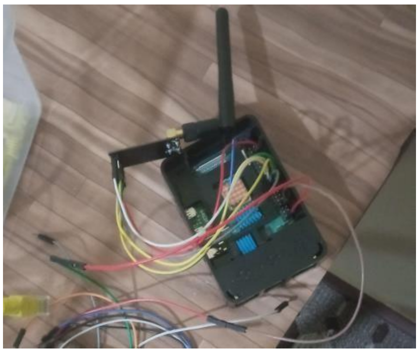

Figure 3.5. nRF24L01 Transceiver and Raspberry Pi Connection.

A range test for nRF24l01 from kharipati nagarkot road to kamalbinayak was carried out with the help of the blink program that blinks led when radio defined address is available.

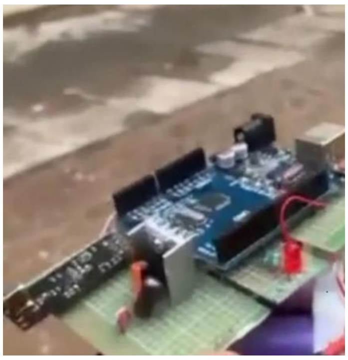

Figure 3.6. Range Test Using Radio Available Led Blink Test.

The range test (Fig.3.6) using the Arduino-based receiver with LED blink is done as shown in fig.3.7 where LED blinks every time the receiver receives a message and the both transmitter and receiver are communicating message in each second interval. So, the LED glows on and off continuously when the radio communication is perfect. This helps the receiver body to be displaced and find the range to where radio is still available and the displacement is calibrated. The radio available test is carried out by sending a message signal from the transmitter as shown in PCB (Fig.3.7) the ATmega328 chip is used and programmed to transfer certain payload data and when the data gets detected the LED blinks as in the receiver side PCB.

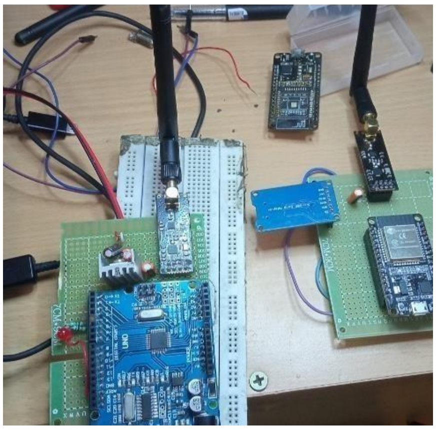

Figure 3.7. Radio Communication Data Saving in SD Module

The messages are saved in the SD card module and can later be used for generating the calculated values as well as messages communicated with the receiver. This helps to save the data in the SD card which helps us to transmit and receive the information's on time.

4. Results and Discussion

The 3-Dimensional data is plotted in Matplotlib. the error is removed using the filter the nRF model is used to communicate the data using SPI channels. The Serial Peripheral Interface(SPI) helps in serial interfacing and data communication. The SPI is mostly used for communication between the central processing unit (CPU) and peripheral devices.

The obtained 3 axis data gives displacement plot for:

Table 1. Maximum & Minimum Displacement for the Body

x-axis	max- 1000m	min-0m
y-axis	max- 1000m	min-0m
z-axis	max- 1000m	min-0m

The maximum displacement possible in each axis is 1000m as tabulated in table 1. as the nRF24 has range of nearly1km by default. So, the targeted range is to obtain approximately 1000m and that can be obtained by displacing the receiver body and calibrating the displacement checking if the radio is still available or not within the displaced area. The range test was carried out in 3-phase from Kharipati Nepal EME military school to Kamalbinayak road and the value was found to be nearly 500m in the second range test and in 3rd test it was nearly 800m to khwopa college.

Table 2. Test Results for Displacement of The System

Test no	Range in m
1.	500m
2.	800m
3.	1000m

The first range test showed 500m distance and the LED blinking when the holding human body moves. So, when a body moves, certain displacement occurs and it can be used to visualize in Matplotlib by transmitting the obtained displacement simultaneously, with nRF24 radio communication. The tests were carried out simultaneously for 3 times for finding a better displacement value as in table 2.

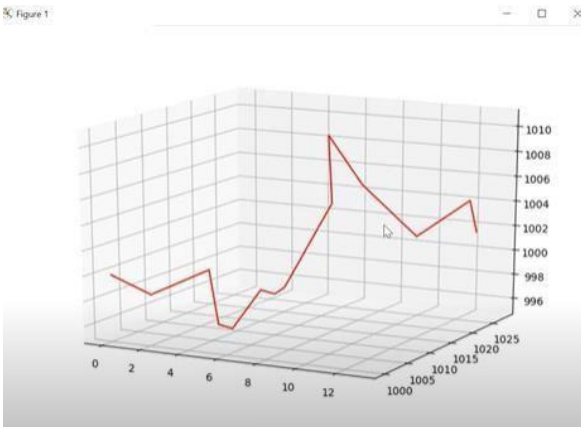

Figure 4.1. Linear Displacement in A Single Axis

The displacement increases linearly over time as the sensor moves in any direction. In 1 second the displacement is 1 meter then accordingly displacement is obtained by the above process. The displaced value for displacement in X, Y and Z directions are plotted and this enables the user to generate the obtained 3-axis displacement values thus, 3-axis data is plotted successfully. This trace helps us to get the orientation of the navigation system at a specific time. The displacement in X axis, Y axis and Z axis are plotted in figure 4.1. where, the red mark gets increased over time and plots the actual displacement in 3 Dimension for the system in which the body is attached.

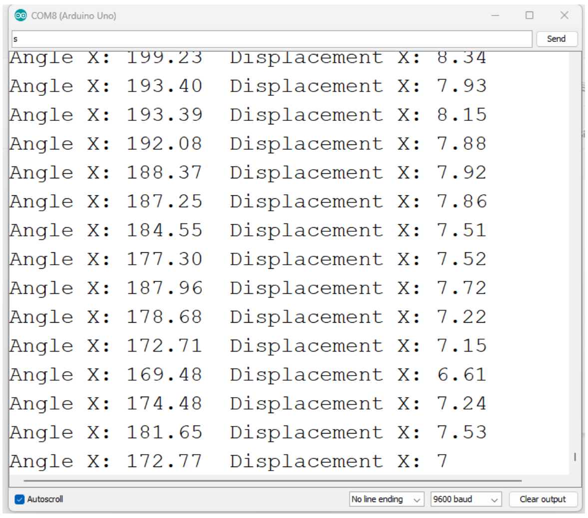

Figure 4.2. Accelerometer Displacement Data

As, we see in fig.4.2. the acceleration values in X, Y and Z directions are obtained in the arduino IDE serial port. microcontroller at transmitter side is programmed to get the IMU data for the accelerometer:

linear acceleration for the system is calculated as:

T is initially zero….

Here:

$$v += u + (a * t)$$

$$s = (u * t) + (½) * a * (t * t)$$

Then, the errors are minimized using the rejection technique in program that rejects any sorts of errors if detected. The Kalman filter produces an accurate result with error of about 0.01% and very stable values that is errorless and output isn't affected by noise so, that a highly accurate yaw, pitch and roll & accelerometer values is obtained that is tested using processing IDE tool for Arduino with mpu6050 teapot. The displacement values are sent from accelerometer to the receiver side Raspberry Pi using nRF24L01 radio module. The data is received in the receiver side so that it is plotted in 3Dimension using Matplotlib. The main objectives of using a Raspberry Pi for visualization are:

Raspberry Pi supports python and many other highly dynamic programs and languages.

The Raspberry Pi supports standard MATLAB library by MathWorks.

The python supports 3D path visualization and different kinds of plots in Matplotlib.

We view the data in the Matplotlib and make the program executable so that it can be viewed in the HDMI screen and support many other Linux devices OS too.

Path Visualization in 3D

The 3D path (fig 4.4.) visualization involves receives 3-Dimensional sensor data and then, the data is plotted in real time. The X axis is X displacement, Y axis gives displacement in Y and Z-axis gives displacement in Z direction. Finally, this method yields an output that makes comparative study of the trajectory and motion of the navigation system in which sensor is placed. The Matplotlib visualization gives:

3 axis path trace

The position of the navigation system.

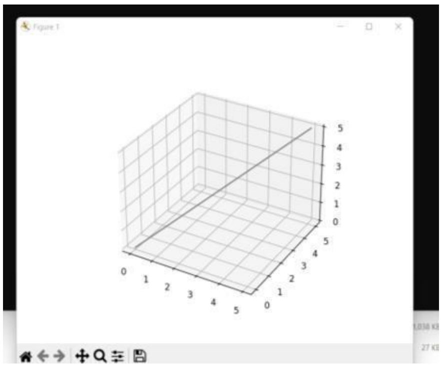

Figure 4.3. Matplotlib Simple Plot

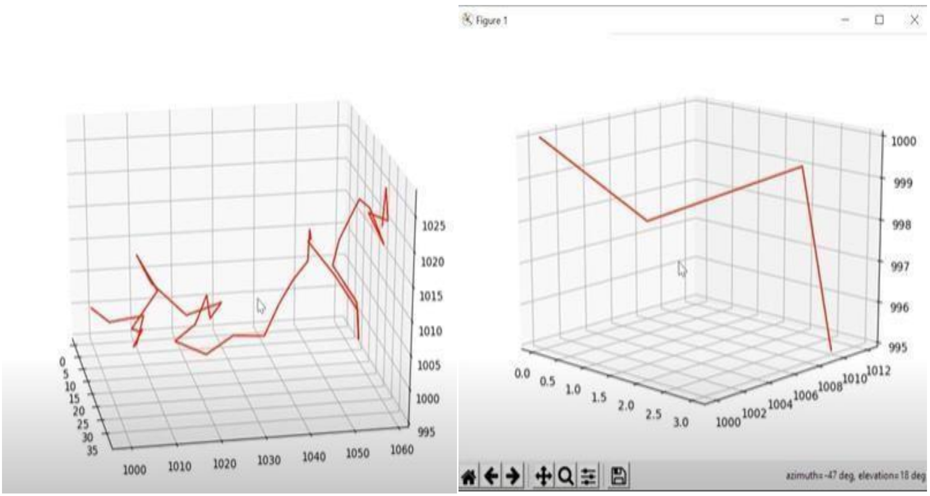

Figure 4.4. Path Visualization in Matplotlib

Kalman Filter Accuracy

The Kalman filter was found to be 98% accurate in removing errors and getting appropriate filtered value for the accelerometer readings so, that it was utilized for further operations in the research work for 3-D visualization. The data from accelerometer were made error less using the Kalman filter.

5. Conclusion

Thus, the study of navigation trajectory and motion shows that it is applicable to other moving objects too. This helps in real time 3Dimesional visualization and the outcomes obtained can yield various benefits. The Kalman filter has given us an accurate and stable accelerometer values by which a more accurate result is obtained.

The sensor fusion technique is very common in today's technologies and this outcome can be very much significant in yielding a fruitful result that can be used to estimate the path of various bodies in which an IMU sensor is placed. The product level form of the research involves an executable program and using a larger distance radio module like Lora WAN or hopeRF (RF22). path could be traced using google map API and GPS to locate on map in real time.

The communication range can be widened and the nRF24L01 can get replaced with highly accurate and non-interference affected radio module. The communication range will be broadened and the data will not get affected. The 3-Dimensional plot can be done at lab too but for executable program development python is best suited additional information can be added in the plot too. The data obtained for 3-dimensions displacement can be generated in MATLAB and tested as well. An executable file that can be distributed so that it supports many kinds of Linux supported devices using a very high range radio communication device is the scope of this research.

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Author's biography

Biplov Paneru is currently pursuing BE in electronics and communication engineering at NEC, Pokhara University. He is actively involved in R & D tasks since early years. He is currently a research and development engineer at rocketry at national Innovation Center Nepal and as a software engineer freelancer at upwork. His research interests are computer vision, embedded systems, image processing etc. This research work was carried out to trace the path of sounding rocket and it was highly successful. The project is aimed at tracing the path and visualizing it on screen at real time for GNS system.