Application of Sensor Fusion Techniques for Vehicle Condition and Position Analysis

Yasin Alyaprak and Gokhan Gokmen

Abstract—**Sensor fusion is a method of processing data from raw data to meaningful outputs and getting quality output. Architectures used in sensor fusion are chosen depending on the application. The sensor fusion architecture that is frequently used today was found by the directors of the United States Joint Laboratory (JDL). Sensor fusion has been realized with this architecture. Using the axial data of a car, inertial movements such as acceleration, deceleration and stationary are classified as controlled. At the classification point, low level and high-level methods are used in the sensor fusion application. By pre-processing the received data, joint high-quality data was obtained with complementary sensor modeling, and high-level sensor fusion methods were used after recording the obtained data. Artificial intelligence algorithms are preferred for high-level sensor fusion. Various algorithms such as "Decision Tree", "Gradient Boosting", "Multi-Layer Perceptron", "Regression Algorithm" have been used. Real-time acquired data is stored after preprocessing and raw data fusion. The stored data has created a high-level sensor fusion at the point of decision making with supervised learning artificial intelligence algorithms.**

Index Terms— **Sensor Fusion, IMU, Gyroscope, Accelerometer, Artificial Intelligence.**

I. INTRODUCTION

SENSOR FUSION is the combination of sensed data or data from sensed data to be better than would be possible when these sources were used individually. Data sources for a fusion operation are not expected to be exactly the same type. Sensor fusion can be created with different types of sensors [1].

It is not necessary to use different sensors for sensor fusion. It is sufficient to have different data belonging to the same sensor. Direct fusion is the merging of data from one or more sensors, while Indirect fusion is the use of environmental information sources [2]. Consequently, sensor fusion defines direct fusion systems.

Sensor fusion also involves combining data received at different times or combining multiple received data

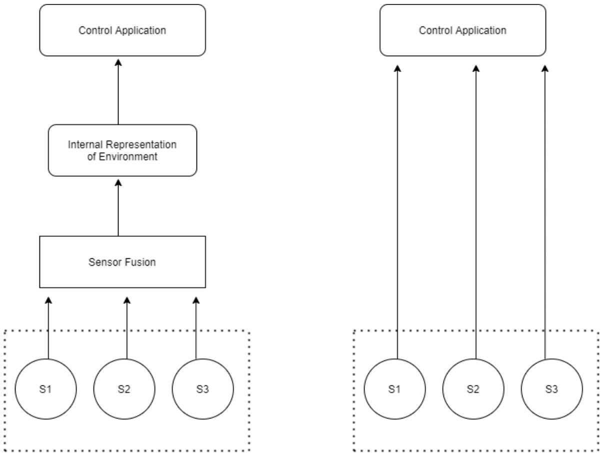

Fig.1. Sensor Fusion and Multiple Information Merging

A. *Sensor fusion types*

Fusion of sensors for C3I-oriented (Command, Control, Communication, Intelligence) applications and sensor fusion used in real-time microprocessor systems (embedded system) works on another level. C3I-based work usually deals with medium to high-level sensor fusion issues. Applications in embedded systems focus on low-level fusion [3].

Low-level aggregation in sensor fusion with three-level categorization combines raw data sources to extract more qualified data from raw data inputs. Intermediate aggregation or feature-level aggregation combines more meaningful data than raw in an entity map that may be used for significance. High level fusion (fusion of decision), unite the final decision and results. Among the decision fusion methods, there are artificial intelligence and statistical approaches [4].

II. RELATED WORKS

R. Olfati-Saber [5] provides consensus algorithms for networked dynamic systems, scalable algorithms for sensor fusion in sensor networks. This article introduces a distributed filter that checks the average of n sensor measurements of the nodes of a sensor network, called the consensus filter.

M. Kam [6] worked on the robot's self-positioning with sensor fusion techniques in robot navigation. The obstacles and routes around the robot were tried to be determined by

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means of the sensors used. Among the sensors used are rangefinder, GPS, obstacle recognition sensors.

J.K. Hackett [7], a multisensor fusion research are presented for the latest technology. He classified the fusion definition into 6 categories: scene segmentation, representation, 3D shape, sensor modeling, autonomous robots, and object recognition.

He tried different strategies to derive more meaningful data from the data received from the sensors. These strategies range from simple set intersection, logical operations, heuristic generation rules, nonlinear least squares method to more complex methods that include maximum probability estimates. Sensor uncertainty is modeled by making sense with Bayesian probabilities and Dempster-Shafer algorithms.

O. Kreibich [8] presents an industrial wireless sensor network (IWSN) based machine condition monitoring (MCM) system that is capable of handling a false indication caused by temporary data loss, signal interference or invalid data. Multiple sensor fusion was used, driven by a quality parameter generated by each sensor node based on data history outliers and the actual state of the node. The fusion node also provides a quality assessment at its output. In this study, the effects of low-level sensor fusion on high-level sensor fusion were evaluated. The use of raw data in the decision-making algorithm is compared with the output of low-level sensor-fused data.

III. METHOD

In this section, sensors and artificial intelligence algorithms to which sensor fusion algorithms will be examined. The general name of the sensors to be used is the inertial measurement unit (IMU). They are units consisting of at least 2 types of sensors to measure the 3-axis acceleration and 3-axis rotational force on the moving or stationary object. Today, these devices, which have many uses, from advanced aircraft to mobile phones to simple devices, perform the analysis of the movement of the platform on which they are located. Sensor types are protractor, gyroscope, and magnetometer. These sensors alone cannot give the axial state and the inertial state [9].

A. Accelerometer

Accelerometers are microelectronic devices that measure the applied force from the reference mass. Accelerometers measure the force of gravity. When the accelerometers are under constant speed or fixed, the 3 axis angles of the object can be measured with the force created by the gravitational force on the axes. The accelerometer measures two types of forces fixed and dynamic. The constant force is the gravitational force. Dynamic forces are such as acceleration, deceleration, and friction. In many fields such as aviation, automation, product electronics, the outputs given by serial communication are evaluated. Accelerometers output in terms of gravitational acceleration. If the measuring range is low, more precise measurements can be made. (Like vibration). If the measuring range is high, the sensitivity will decrease, but it can measure high acceleration values.

While the accelerometers are stationary, they are subjected to the acceleration of gravity on the *Z*-axis of 1 g on the earth. In this case, the resultant force is 1g.

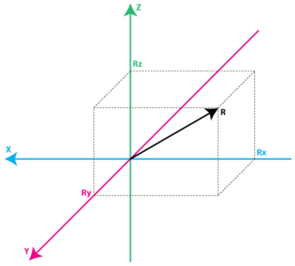

Fig.2. Acting resultant acceleration vector [9]

Thus, the tilt and roll angle can be found from the accelerometer standing still. But the roll angle cannot be found. Because rotations around the Z axis do not change the acceleration applied on the sensor [10]. Euler Angles are created for low-level sensor fusion as follows:

$$\tan\phi_{xyz} = \frac{-G_{px}}{\sqrt{G_{py}\sin\phi + G_{pz}\cos\phi}} \quad \tan\phi_{xyz} = \frac{G_{py}}{G_{pz}} \tag{1}$$

$$\tan\theta_{xyz} = \frac{-G_{px}}{\sqrt{G_{py}\sin\phi + G_{pz}\cos\phi}} \tag{2}$$

Here : G_{px} -Accelerometer Raw *X* Data
G_{py} - Accelerometer Raw *Y* Data
G_{pz} -Accelerometer Raw *Z* Data
ϕ -Pitch Raw Angle
θ -Roll Raw Angle
$\tan\phi_{xyz}$ -Euler Angle -Pitch
$\tan\theta_{xyz}$ -Euler Angle -Roll

B. Gyroscope

Gyroscopes are sensors used to measure the rotational speed at a specified reference orbit. The gyroscopes outputs are in degrees per second. Angular velocity is a measure of the speed of rotation about the axis. Gyroscopes use it to determine the axial state. For example, it can be used to balance an aircraft, to measure the angle at the equilibrium position and send it to the automatic control mechanism [11].

C. Magnetometer

Studies on the time-varying magnetic field of the earth have been carried out for years. Devices that measure this variable magnetic field are called magnetometers. Magnetometers are used extensively in industrial applications. agriculture, defense, biology, aerospace, space exploration, etc. It is also widely used in other fields such as, and currently, no electronic system is independent of magnetic field. Magnetometer is a commonly used sensor, especially in aviation.

D. Artificial intelligence algorithms

In this study, classification and interpretation studies were carried out on the stored data. After the low-level sensor fusion, artificial intelligence algorithms were used at the decision-making point, that is, in the high-level sensor fusion part. Various supervised learning algorithms have been used. Decision Tree [12, 13] is a type of algorithm that aims to reduce the disorder in the system [14]. The Gradient Boosting algorithm, on the other hand, aims to create stronger algorithms by modeling the error between the results of any algorithm and the actual values. The Multi-Layer Perceptron algorithm is a method of generating output by summing the weighted percentage of the inputs and passing them through the threshold function in neuron logic [15].

IV. EXPERIMENTS

In this section, data collection, filtering, application of sensor fusion and preparation as input to artificial intelligence algorithms will be explained.

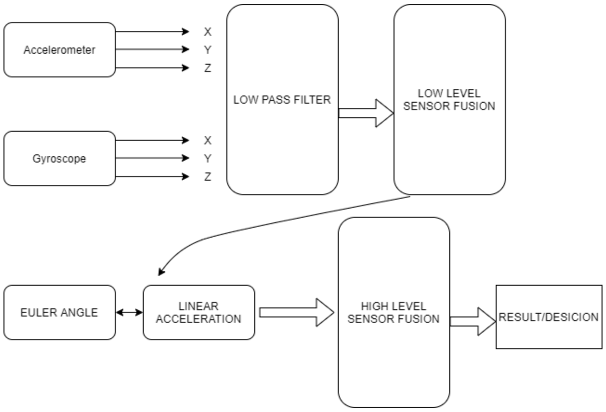

Fig.3. Flow Diagram

The sensors will be subjected to both low- and high-level fusion algorithms. Accelerometer data alone gives more meaningful data than Gyroscope data. The gyroscope sensor gives the angular velocity. It does not give information about direct axial changes. By taking its integral, the sum of the changes is reached. The sum of these changes is used to reach the desired axial angles. But there will be shifts in the gyroscope sensors. And it never outputs 0. Since the value of 0 cannot be taken, a cumulative angle change is observed from the integral calculation over time. An accelerometer is needed to compensate for this angle. Raw data were collected using the sensor kit shown in Figure 4. This development kit includes a 3-axis gyroscope, magnetometer and accelerometer sensor.

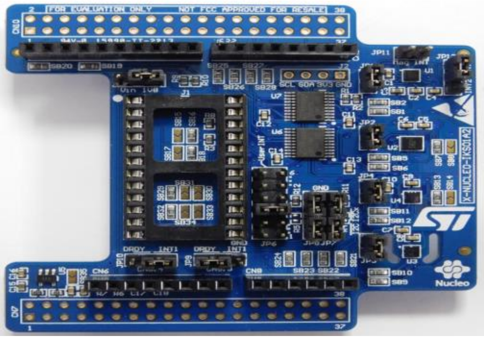

Fig.2. X-NUCLEO-IKS01A2 [16]

The collected data was first subjected to a sliding mean filter. Complementary filter is used for low level sensor fusion. Euler angles were reached after the complementary filter.

In order to use artificial intelligence algorithms, the data collection program shown in Figure 5 was written. With the written program, the data was transferred to the PC with the stm32L073 series microprocessor connected to the sensor kit. Saved in .csv format via the program.

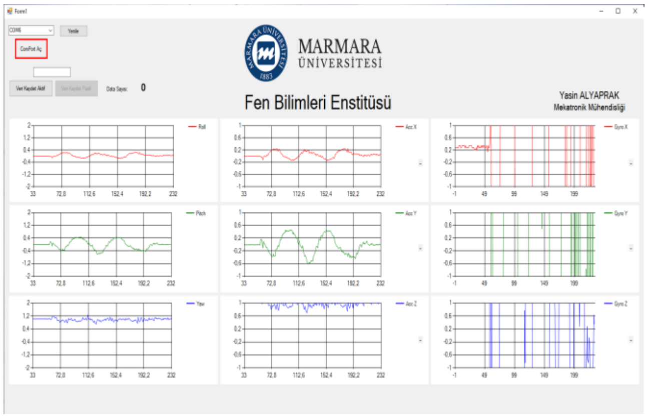

Fig.3. Data Collection Program Runtime Display

Fig.4. Real-Time Data Collection with Car

The high number of repetitions in algorithms such as artificial intelligence and machine learning will increase the percentage of classification and prediction accuracy. Within the scope of the study, this system test was carried out with a real car. Take-off acceleration in 3 repetitions, deceleration acceleration and fixed position data while traveling with a certain speed was taken. The slope factor for these 3 cases was added to the test.

Thus, a total of 6 different status data were recorded from 3 tests on the slope exit direction and on the non-slope road. While the data was included in the artificial intelligence algorithm, it was processed in certain groups. A 2-stage learning table was used. In the first group, the data was generated with raw data without low-level sensor fusion.

That is tilt and roll values are not included. In the second group, learning data was created without including the gyroscope data.

After the learning data was created, learning was carried out with 60% of the data. The test was also carried out with 40%

of the data. The writing and evaluation of artificial intelligence algorithms were carried out in Python language and Jupyter environment.

V. EXPERIMENTAL RESULTS

While applying the sensor fusion experiment, the low-level sensor fusion process was applied first. Accelerometer and gyroscope data were filtered and then Euler angles were created and 2 data, inclination and roll angle, were obtained from 6 sensor data. In this way, high quality easily understandable data was obtained. Accelerometer data collected from the vehicle traveling at constant speed are shown in Figure 7, gyroscope data in Figure 8 and Euler angles obtained after low-level sensor fusion output are shown in Figure 9. Data were recorded for approximately 30 seconds.

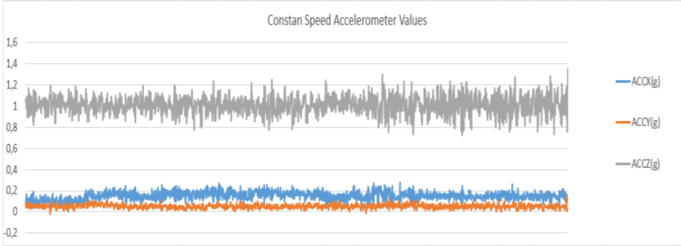

Fig.5. Accelerometer Raw Data

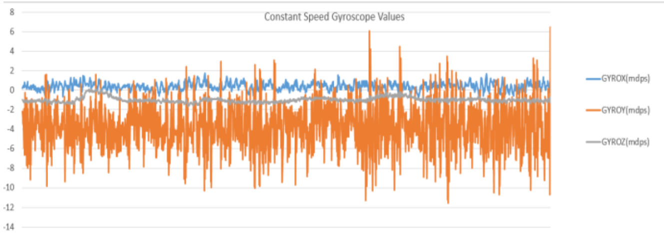

Fig.8. Gyroscope Raw Data

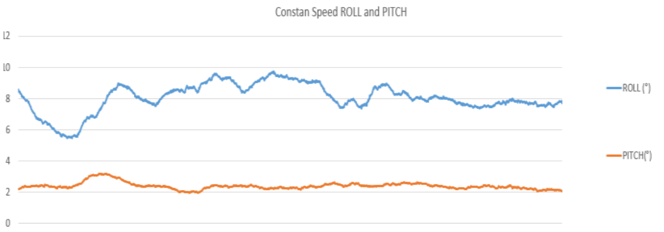

Fig.6. Low Level Fusion Output: Euler Angles

Low-level sensor fusion is planned on acceleration, deceleration and stop. Flat ground and sloping ground were used for these 3 movements. Each movement is numbered and classified.

TABLE 1
RESULTS INCLUDING LOW LEVEL FUSION

Algorithm Type	Success Rate
Decision Tree	%92.9479
Gradient Boost Regressor	%93.1992
Multi-Layer Perceptron	%87.3880
Classifier Accuracy	%83.440

After all, data were taken, the artificial intelligence algorithm was run with 2 different table data. The data collected for the artificial intelligence algorithm is divided into 60% training and 40% testing. As a result of comparing each numbered movement with any test data, the success percentages were compared. Table 1 and Table 2 were obtained by using the table with low level sensor fusion and the table without sensor fusion, respectively.

TABLE 2
RESULTS WITHOUT LOW LEVEL FUSION

Algorithm Type	Success Rate
Decision Tree	%65.483
Gradient Boost Regressor	%72.4950
Multi-Layer Perceptron	%73.0385
Classifier Accuracy	%63.24

VI. CONCLUSION

For more than 30 years, sensor fusion techniques continue to be developed. With the renewed and newly produced sensors, the detection can be converted from very low to high levels. Self-driving vehicles, one of the most prominent examples today, use sensor fusion techniques at the point of detection and decision making.

In this study, pre-processing, processing and improvement were made by using the sensor fusion algorithm according to the JDL architecture. As a result of the experiments, high quality data that is easier to understand were obtained from the data obtained when sensor fusion algorithms are used. (Euler Angle and Linear Velocity).

High-level sensor fusion with supervised learning algorithms has been applied. At this point, it was observed that the error increased as a result of storing the data received from the sensors without processing and without being subjected to low-level sensor fusion.

All these processes are based on recording the data and then analysing the data. It has been observed that the accuracy percentage increases as the recorded data and the number of algorithm iterations increase.

REFERENCES

[1] S.Birogul, Y. Sonmez, U.guvenc,” Veri Füzyonuna Genel Bir Bakış”, Politeknik Dergisi Vol.10, No.3, pp. 235-240, 2007.
[2] W. Elmenreich,” An Introduction to Sensor Fusion”, Research Report 47/2001.
[3] Weisstein W., E., “Eric Weissten’s world of science”, www.scienceworld. wolfram.com/physic (2003).
[4] Llinas, J.,Waltz, E., “Multisensor data fusion”, Boston, MA: Artech House, (1999).
[5] O.Saber, R., J.S Shamma. “Consensus Filters for Sensor Networks and Distributed Sensor Fusion.” Seville, Spain: IEEE, Dec. 2005.
[6] M. Kam, X. Zhu, P. Kalata, “Sensor fusion for mobile robot navigation,” 1997, Proceedings of the IEEE(Volume: 85, Issue: 1, Jan. 1997).
[7] J.K. Hackett, M. Shah, “Multi-sensor fusion: a perspective,” 1990 IEEE International Conference on Robotics and Automation, Cincinnati, OH, USA.
[8] O. Kreibich, J. Neuzil, “Quality-Based Multiple-Sensor Fusion in an Industrial Wireless Sensor Network for MCM,” IEEE Transactions on Industrial Electronics,. 09.2014.

[9] Samancı.B, “Accelerometer, Gyroscope, IMU nedir?”, “http://www.barissamanci.net/Makale/26/accelerometer-gyroscope-imu-nedir/”,(05.2020).

[10] https://learn.sparkfun.com/tutorials/accelerometer-basics/how-to-select-an-accelerometer,(06.05.2021).

[11] https://learn.sparkfun.com/tutorials/gyroscope/all , (06.05.2021).

[12] T.C. Akinci. "Applications of big data and AI in electric power systems engineering." *AI and Big Data’s Potential for Disruptive Innovation*. IGI Global, 2020. 240-260.

[13] H.S. Nogay, T.C. Akinci, and M. Yilmaz. "Comparative experimental investigation and application of five classic pre-trained deep convolutional neural networks via transfer learning for diagnosis of breast cancer." *Advances in Science and Technology. Research Journal, vol.* 15, no. 3, 2021, pp.1-8. https://doi.org/10.12913/22998624/137964

[14] O. Akgun, A. Akan, H. Demir, T.C. Akinci, "Analysis of Gait Dynamics of ALS Disease and Classification of Artificial Neural Networks." *Tehnički vjesnik* 25.Supplement 1 (2018), pp.183-187. https://doi.org/10.17559/TV-20160914144554

[15] O. Turk, D. Ozhan, E. Acar, T.C. Akinci, and M. Yilmaz. "Automatic detection of brain tumors with the aid of ensemble deep learning architectures and class activation map indicators by employing magnetic resonance images." *Zeitschrift für Medizinische Physik* (2022). https://doi.org/10.1016/j.zemedi.2022.11.010

[16] https://www.st.com/en/ecosystems/x-nucleo-iks01a2.html, (04.04.2021).

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