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Enhanced Navigation System for AUV Using Mobile Application

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Abstract: Autonomies Underwater Vehicle (AUV) is a self-automated vehicle. AUV is preprogrammed to be utilized for a wide range of missions for shallow or deep survey applications.
An AUV is able to maintain sensor positioning at an ideal height above the seafloor during surveys but when it goes underwater, the Global Position System (GPS) signal is not present. This paper introduces an enhanced model for a navigation system used in AUVs using mobile-based Inertial Navigation System (INS) that integrates the reading of Differential Global Position System (DGPS) with the measurements from INS and applying Kalman filter. To achieve high accuracy apply sensor calibration to the Inertial Measurement Unit (IMU) for improving sensors performance by removing sensors'structural errors. Using the measurements from the IMU, the INS can calculate the current altitude, velocity and position of the AUV starting from some known initial point. This makes it suitable for navigation where GPS signal is lost or when the signals are being jammed in a war situation. Experiments have been conducted in different environmental conditions to show the efficiency of the enhanced model . The experimental results show good performance in terms of cost and accuracy.

Keywords: - Autonomies Underwater Vehicle(AUV); Global Position System(GPS); Differential Global Position System (DGPS); mobile-based Inertial Navigation System(INS); Kalman filter; accelerometers; gyroscope; sensor array; sensor calibration; Inertial Measurement Unit(IMU).

I. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) have demonstrated their capabilities in civilian and military applications. Civilian applications include detailed seabed mapping, environmental monitoring and research and inspection work for offshore industry. Knowledge of the ocean bottom, its characteristics and environmental conditions is a vital prerequisite for mission planning. In military applications, AUVs can reduce the exposure of personnel to dangerous environments such as mine fields or enemy-controlled ports and waterways. They also facilitate information gathering behind enemy lines. A reliable navigation system is a key factor for the success of an operational mission with an AUV in a real scenario. Navigation of AUVs has been and remains a substantial challenge [1, 2, 3].

This paper introduces a mobile-based Inertial Navigation System (INS) which is designed to provide accurate and powerful monitoring for AUVs' applications. Thus its enables AUVs to drive underwater for long-duration missions fully autonomous and without supervision from a surface ship. This research work aims at developing measurement methods for integrating GPS and INS. The INS can be used to provide a navigation solution when the GPS signals are lost, and the GPS can be used to filter and limit the long term errors which are inherent to any integrated INS [4]. This integration has used the Kalman filter to provide an optimal estimate of the INS errors over time. An INS navigation solution uses on-mobile sensors such as accelerometer and gyroscope sensors to obtain the position, velocity, and altitude of the moving AUV [5]. The INS is self-contained and independent of any external signals. One of the shortcomings of INS when operated in a stand-alone mode is the time-dependent growth of systematic errors. The time-dependent position errors will quickly exceed the accuracy specifications for many applications [5, 6]. GPS on the other hand, can deliver excellent position accuracy. The excellent positioning accuracy of DGPS can be used to provide frequent updates to the INS. Frequent updating is needed to control errors growth of INS results [7].

The main advantage of the mobile-based navigation system is the cost of using mobile sensors. Also it provides an accepted accuracy measure by integrating both INS/GPS together and applying Kalman filter to minimize the error. On the other hand, there are some limitations that should be taken into consideration when dealing with this system. First of all is the accuracy of mobile sensors. The proposed navigation solution depends on processing of data gathered from multiple sensors so the small error in one sensor will led to a larger error in the estimated location.

The rest of this paper is organized as following: Section 2 provides details about the proposed system and the problem solving methodology. Section 3 presents some experimental results obtained from using the proposed approach and assesses its performance compared to the methods currently in use. At last, Section 4 presents the conclusion of the paper by summarizing the key issues of the research study and suggests possible directions for the future research.

II. EXPERIMENTAL METHODS

The proposed system seeks to enhance the AUVs navigation system by improving the accuracy of the calculated position in addition to minimize the number of times it is forced to float to update its location. It attempts also to minimize the processing and calculation cost by using android-based mobile processing. The proposed system calculates position, velocity and altitude and improves its accuracy by integrating it with DGPS reading data. To reach the defined target we design an AUV as shown in Fig1. 1 shows the structure of the enhanced AUV implementation of the proposed navigation system.

The scenario of AUV's mission session starting from station, sailing underwater to perform its job and finally back to station done in sequence of event to ensure the success of the operation. Fig. 2 shows the sequence diagram for the applied actions done by the system's three actors (client mobile on the station, server mobile inside the AUV and AUV) to achieve the proposed navigation accuracy.

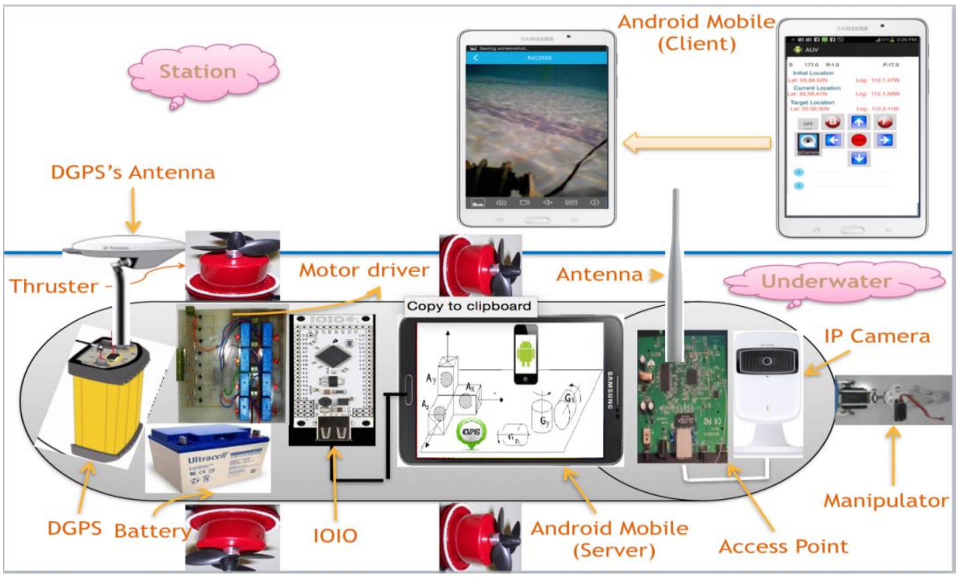
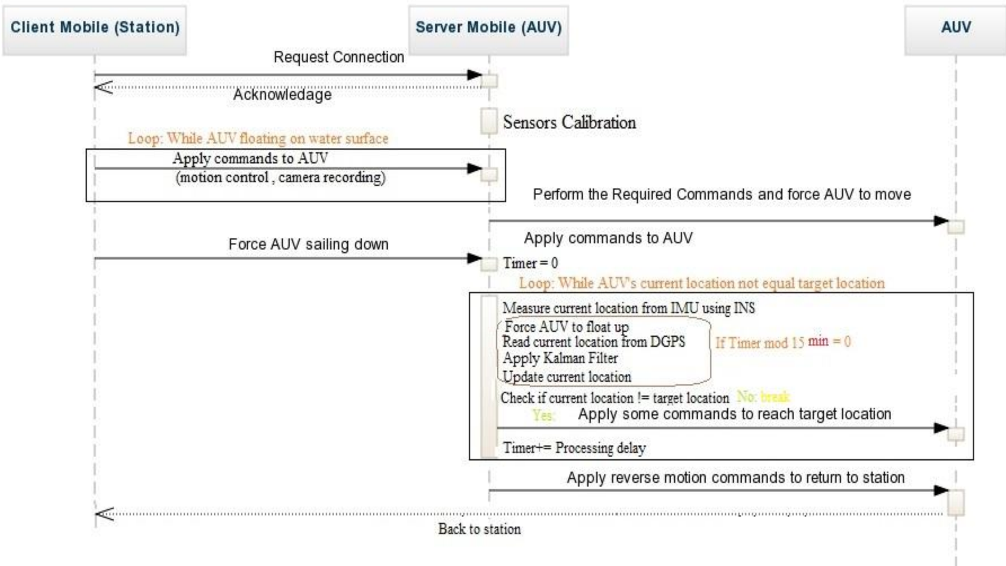


Fig.1 Structure of AUV prototype implementation of the proposed navigation system



2 Sequence diagram for the proposed AUV's navigation system

2.1. Communication implementation (request connection):

It is the starting point where the AUV in the station and in its preparation phase to start its session. It has to establish connection between both android mobiles (Client located on station and server located inside AUV) by implementing client server architecture. This client-server architecture is implemented via Virtual Network Circuit (VNC) that enables the client mobile to perform any required operation on the server. The VNC is implemented by locating the two android mobiles in the same Wireless Local Area Network (WLAN). This WLAN provided by the Access Point (AP) and its antenna while the AUV is floating on surface as shown in Fig. 3.

Fig. 3 Client-server architecture implementation using VNC to establish connection between the two android mobiles located in the same WLAN.

2.2. Sensors Calibration:

Once a connection is established, we have to set up the sensors used in the navigation calculation process (Gyroscope, Accelerometer and GPS) as shown in Fig.1 by removing their structure errors. The process of removing the structure errors is called sensor calibration and this is a comparison of measuring equipment against a standard instrument of higher accuracy to detect, correlate, adjust, rectify and document the accuracy of the instrument being compared [7]. This definition includes the capability to adjust the instrument to zero and to set the desired span. This process is implemented in the server mobile which carries the sensors that are used in the INS calculation.

2.3. Control AUV stationary (Remotely controlled):

Once the connection is established and the AUV is still floating the client can perform any operation on the server including open camera located in the AUV, record life streaming video about the AUV's mission session underwater and applying some motion commands to the AUV. The developed android application covers all the operation can be done on the AUV in only one screen including open AUV's camera, controlling AUV' light, AUV's motion control, manipulator control, show server mobile's sensors data, the AUV’s current location reading from DGPS and its current location calculated from the INS/GPS processing done on server mobile as shown in Fig. 4.

All this data can appear to client mobile only when the AUV is floating as they be in the same WLAN and the client can apply any control command not just retrieve data. Once AUV is sailing down the connection lost and start the preprogrammed process applied in server mobile.

2.4. Preprogrammed navigation system implementation (INS/GPS):

Autonomous operation in deep water or covert military operations requires the AUV to handle submerged operation for long periods of time. Once AUV is sailing down the connection lost and no commands can be applied by the client mobile [7]. Also the GPS signal is not present as GPS is satellite-depended navigation system. So the AUV have to preprogrammed to perform it's operation without any supervision from the station. AUV start its underwater sailing by a given known target location and it has to reach it autonomously without any external control from station. There are some questions AUV have to ask and need reliable answers to perform its operation effectively. These questions includes: what is current location?, How far from target location? and which commands have to applied to reach the target location?. The issue of calculating the current location can be implemented using several ways INS, DGPS with floating intervals and integration between INS/DGPS [7,8].

Fig. 4 Android application components and it's view on server and enabling client to perform all commands while they are in the same LAN.

An INS calculates position, velocity and altitude using high frequency data from an Inertial Measurement Unit (IMU). The IMU typically consists of three-axis accelerometer measuring specific force and three-axis gyro measuring angular rate in addition to reading the initial location from GPS, all located inside the server android mobile in the AUV. The INS calculations are done by giving a known initial location from GPS when AUV is floating on the surface, using the accelerometer and applying double integration on its output acceleration to get the movement distance in all space planes (x, y, z) and finally acquiring the angler orientation angles in the 3-axis space from the 3-axis gyroscope.

The current location can be obtained as illustrated in Fig. 5. It shows the implementation for the INS. Due to inherent errors in the gyro and accelerometer, the solution of the navigation equations embedded in the INS will have an unbounded drift unless counteracted. A performance measure for an INS is given by its pure inertial drift in position, where the divergence rate depends on the IMU quality. Since an INS is a diverging system, an aiding framework is needed to limit or reduce the error growth [7]. For autonomous missions it may be important to retain good navigation accuracy between position updates, which will usually be sparse. The use of bottom-track data from a DGPS is today the most common approach. INS/DGPS is implemented by updating the calculated location from INS by the DGPS very reliable system by forcing AUV to float in equivalent time interval. In order to fuse the data from the INS and the aiding sensor (DGPS), some form of filtering must be implemented. This is typically accomplished using a Kalman filter (KF) as shown in Fig. 6. The KF input is taken as the difference between the output from the appropriate DGPS and the INS. A proposed method is used in this paper for minimizing the INS error states and enhancing the AUV's navigation system [7, 8, 9, 10].

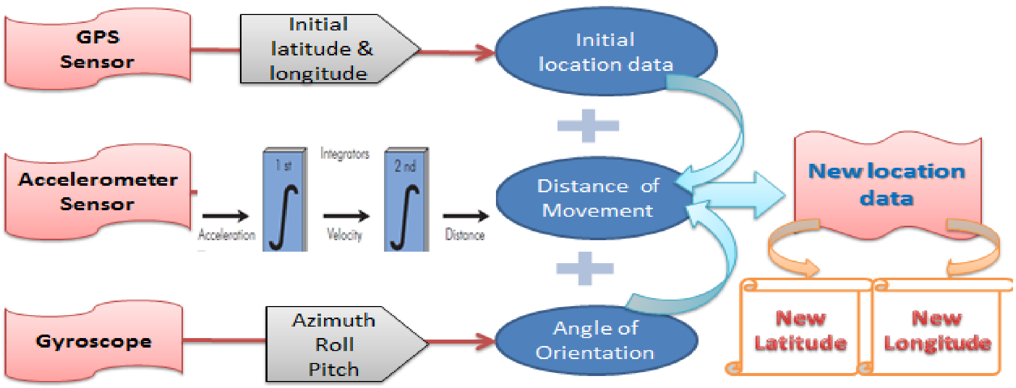


Fig. 5: Block diagram for INS navigation system implementation.

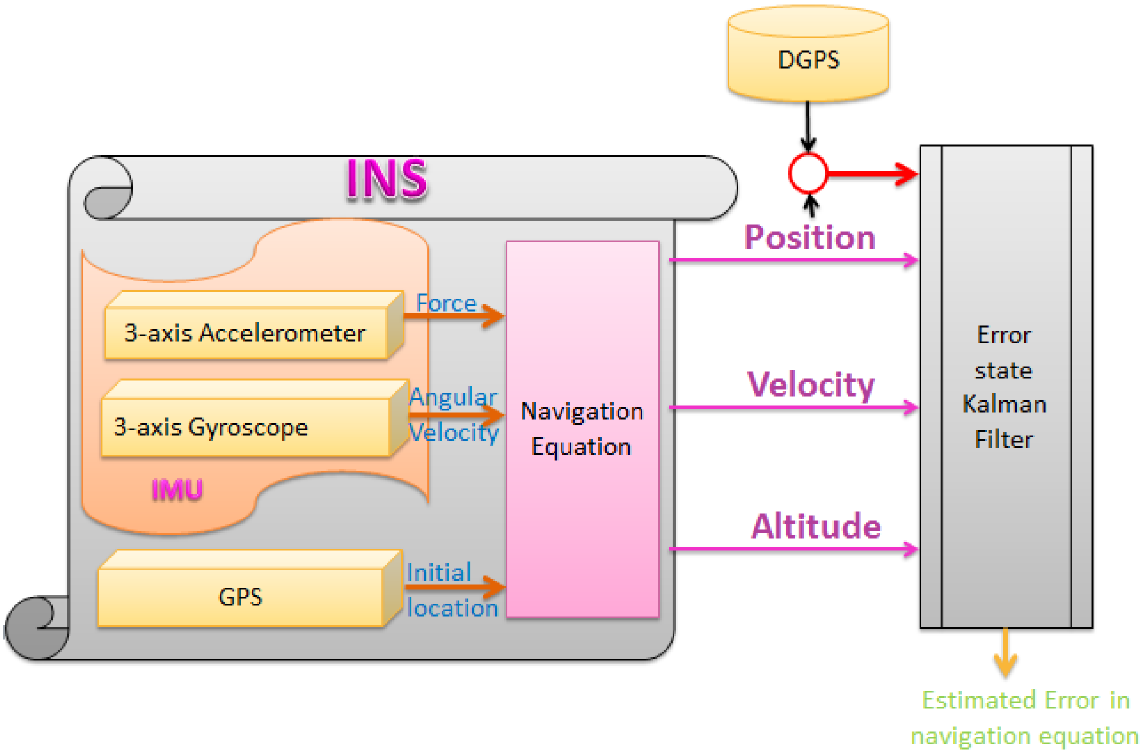


Fig. 6: INS/DGPS integrated navigation system structure.

III. EXPERMENTAL RESULTS:

To evaluate the performance of the proposed system, we applied the experimental process in different environmental conditions including ports, lakes and seas. Accuracy is the most common performance measures used in navigation system calculations. Accuracy is defined as the ratio of the error to the full scale output or the ratio of the error to the output, expressed in percent span or percent reading, respectively [8].

Table 1 shows the results of comparison of accuracy between the proposed navigation method and other standard navigation methods.

	Floating DGPS	DGPS with floating intervals	INS	INS/GPS Proposed method
Mariana Lake Depth: 10 m Coverage Area: 800 m Testing time: 25 Min	Accuracy = 98%	Interval = 5 Min, Accuracy = 90% Interval = 10 Min, Accuracy = 82 % Interval = 15 Min, Accuracy = 76 %	Accuracy = 66%	Accuracy = 84%
Abo Qir port Depth: 15 m Coverage Area: 5 Km Testing time: 3 Hour	Accuracy = 96%	Interval = 5 Min, Accuracy = 88 % Interval = 10 Min, Accuracy = 81 % Interval = 15 Min, Accuracy = 73 %	Accuracy = 51%	Accuracy = 79%

The experimental results shown in Table 1 indicate that the proposed system has better performance than the floating DGPS for military applications as it reduces the possibility of viewing the AUV by the enemy. It also minimizes the accuracy but with accepted range in most applications. The proposed system enhances the overall accuracy better than the other two systems when applying DGPF with floating interval as the accuracy depend on the interval. Minimizing the interval will move it to floating DGPS which not suitable for most military application in addition to cable length limitations. A free inertial INS will, after a short period of time, have unacceptable position errors and decrease the accuracy to be unaccepted in many applications.

IV. CONCULSION

This paper proposes an enhanced and efficient mobile-based navigation system for AUVs. The proposed system can be used in many applications such as detailed seabed mapping, research and inspection work for offshore industry and underwater mines detection .The proposed system utilizes a combination of DGPS and INS navigation systems. It integrates these two systems to calculate accurate location. Increasing the system efficiency comes from improving accuracy and minimizing the implementation cost. The results of extensive experimental trials revealed that the proposed method produced a significant improvement of around 7% in retrieval effectiveness compared to the best of the other systems tested. For future work, this integrated navigation system can be implemented using more accurate sensors. Integrating an underwater image processing unit for underwater object detection will make it more effective.

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