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[Home](#)

>

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>

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- [4g 5g jammer](#)
- [4g 5g jammer](#)
- [5g jammer](#)
- [5g jammer](#)
- [5g 4g 3g jammer](#)
- [5g 4g 3g jammer](#)
- [5g 4g jammer](#)
- [5g 4g jammer](#)
- [5g all jammer](#)
- [5g all jammer](#)
- [5g cell jammer](#)
- [5g cell jammer](#)
- [5g cell phone jammer](#)
- [5g cell phone jammer](#)
- [5g cell phone signal jammer](#)
- [5g cell phone signal jammer](#)
- [5g frequency jammer](#)
- [5g frequency jammer](#)
- [5g jammer](#)
- [5g jammer](#)
- [5g jammer uk](#)
- [5g jammer uk](#)
- [5g jammers](#)
- [5g jammers](#)
- [5g mobile jammer](#)
- [5g mobile jammer](#)
- [5g mobile phone jammer](#)
- [5g mobile phone jammer](#)
- [5g phone jammer](#)
- [5g phone jammer](#)
- [5g signal jammer](#)
- [5g signal jammer](#)
- [5g wifi jammer](#)
- [5g wifi jammer](#)
- [5ghz signal jammer](#)
- [5ghz signal jammer](#)

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- [green box of cigarettes](#)
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- [jammer wifi 5ghz](#)
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- [wifi jammer 5ghz](#)
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Permanent Link to Challenged Positions: Dynamic Sensor Network, Distributed GPS Aperture, and Inter-nodal Ranging Signals
2021/03/13

A performance assessment demonstrates the ability of a networked group of users to locate themselves and each other, navigate, and operate under adverse conditions in which an individual user would be impaired. The technique for robust GPS positioning in a dynamic sensor network uses a distributed GPS aperture and RF ranging signals among the network nodes. By Dorota A. Grejner-Brzezinska, Charles Toth, Inder Jeet Gupta, Leilei Li, and Xiankun Wang In situations where GPS signals are subject to potential degradations, users may operate together, using partial satellite signal information combined from multiple users. Thus, collectively, a network of GPS users (hereafter referred to as network nodes) may be able to receive sufficient satellite signals, augmented by inter-nodal ranging measurements and other sensors, such as inertial measurement unit (IMU), in order to form a joint position solution. This methodology applies to numerous U.S. Department of Defense and civilian applications, including navigation of dismounted soldiers, emergency crews, on-the-fly formation of robots, or unmanned aerial vehicle (UAV) swarms collecting intelligence, disaster or environmental information, and so on, which heavily depend on availability of GPS signals. That availability may be degraded by a variety of factors such as loss of lock (for example, urban canyons and other confined and indoor environments), multipath, and interference/jamming. In such environments, using the traditional GPS receiver approach, individual or all users in the area may be denied the ability to navigate. A network of GPS receivers can in these instances represent a spatially diverse distributed aperture, which may be capable of obtaining gain and interference mitigation. Further mitigation is possible if selected users (nodes) use an antenna array rather than a single-element antenna. In addition to the problem of distributed GPS aperture, RF ranging among network nodes and node geometry/connectivity forms another topic relevant to collaborative navigation. The challenge here is to select nodes, which can receive GPS signals

reliably, further enhanced by the distributed GPS aperture, to serve as pseudo-satellites for the purpose of positioning the remaining nodes in the network. Collaborative navigation follows from the multi-sensor navigation approach, developed over the past several years, where GPS augmentation was provided for each user individually by such sensors as IMUs, barometers, magnetometers, odometers, digital compasses, and so on, for applications ranging from pedestrian navigation to georegistration of remote sensing sensors in land-based and airborne platforms. Collaborative Navigation The key components of a collaborative network system are inter-nodal ranging sub-system (each user can be considered as a node of a dynamic network); optimization of dynamic network configuration; time synchronization; optimum distributed GPS aperture size for a given number of nodes; communication sub-system; and selection of master or anchor nodes. Figure 1 illustrates the concept of collaborative navigation in a dynamic network environment. Sub-networks of users navigating jointly can be created ad hoc, as indicated by the circles. Some nodes (users) may be parts of different sub-networks. FIGURE 1. Collaborative navigation concept. In a larger network, the selection of a sub-network of nodes is an important issue, as in case of a large number of users in the entire network, computational and communication loads may not allow for the entire network to be treated as one entity. Still, information exchange among the sub-networks must be assured. Conceptually, the sub-networks can consist of nodes of equal hierarchy or may contain master (anchor) nodes that normally have a better set of sensors and collect measurements from all client nodes to perform a collaborative navigation solution. Table 1 lists example sensors and techniques that can be used in collaborative navigation. TABLE 1. Typical sensors for multi-sensor integration: observables and their characteristics, where X, Y, Z are the 3D coordinates, v_x, v_y, v_z are the 3D velocities, The concept of a master node is also crucial from the stand point of distributed GPS aperture, where it is mandatory to have master nodes responsible for combining the available GPS signals. Master nodes or some selected nodes will need anti-jamming protection to be effective in challenged electromagnetic (EM) environments. These nodes may have stand-alone anti-jamming protection systems, or can use the signals received by antennas at various nodes for nulling the interfering signals. Research Challenges Finding a solution that renders navigation for every GPS user within the network is challenging. For example, within the network, some GPS nodes may have no access to any of the satellite signals, and others may have access to one or more satellite signals. Also, the satellite signals received collectively within the network of users may or may not have enough information to determine uniquely the configuration of the network. A methodology to integrate sensory data for various nodes to find a joint navigation solution should take into account: acquisition of reliable range measurements between nodes (including longer inter-nodal distances); limitation of inter-nodal communication (RF signal strength); assuring time synchronization between sensors and nodes; and limiting computational burden for real time applications. Distributed GPS Apertures In the case of GPS signal degradation due to increased path loss and radio frequency interference (RFI), one can use an antenna array at the receiver site to increase the gain in the satellite signal direction as well as steer spatial nulls in the interfering signal directions. For a network of GPS users, one may be able to combine the signals received at various receivers (nodes) to achieve these goals (beam pointing and null

steering); see Figure 2. Figure 2. Distributed antenna array. However, a network of GPS users represents a distributed antenna aperture with large (hundreds of wavelengths) inter-element spacing. This large thinned antenna aperture has some advantage and many drawbacks. The main advantage is increased spatial resolution which allows one to discriminate between signals sources with small angular separations. The main drawback is very high sidelobes (in fact, grating lobes) which manifest as grating nulls (sympathetic nulls) in null steering. The increased inter-element spacing will also lead to the loss of correlation between the signals received at various nodes. Thus, space-only processing will not be sufficient to increase SNR by combining the satellite signals received at various nodes. One has to account for the large delay between the signals received at various nodes. Similarly, for adaptive null steering, one has to use space-time adaptive processing (STAP) for proper operation. These research challenges must be solved for distributed GPS aperture to become a reality: Investigate the increase in SNR that can be obtained by employing distributed GPS apertures (accounting for inaccuracies in the inter-nodal ranging measurements). Investigate the improvement in the signal-to-interference-plus-noise ratio (SINR) that can be obtained over the upper hemisphere when a distributed GPS aperture is used for adaptive null steering to suppress RFI in GPS receivers. Obtain an upper bound for inter-node distances. Based on the results of the above two investigations, develop approaches for combined beam pointing and null steering using distributed GPS apertures.

Inter-Nodal Ranging Techniques

In a wireless sensor network, an RF signal can be used to measure ranges between the nodes in various modes. For example, WLAN observes the RF signal strength, and UWB measures the time of arrival, time difference of arrival, or the angle of arrival. There are known challenges, for example, signal fading, interference or multipath, to address for a RF-based technique to reliably serve as internodal ranging method.

Ranging Based on Optical Sensing

Inter-nodal range measurements can be also acquired by active and passive imaging sensors, such as laser and optical imaging sensors. Laser range finders that operate in the eye-safe spectrum range can provide direct range measurements, but the identification of the object is difficult. Thus, laser scanners are preferred, delivering 3D data at the sensor level. Using passive imagery, such as digital cameras, provides a 2D observation of the object space; more information is needed to recover 3D information; the most typical techniques is the use of stereo pairs or, more generally, multiple-image coverage. The laser has advantages over optical imagery as it preserves the 3D object shapes, though laser data is more subject to artifacts due to non-instantaneous image formation. In general, regardless whether 2D or 3D imagery is used, the challenge is to recognize the landmark under various conditions, such as occlusions and rotation of the objects, when the appearance of the landmark alternates and the reference point on the landmark needs to be accurately identified, to compute the range to the reference point with sufficient accuracy.

Network Configuration

Nodes in the ad hoc network must be localized and ordered considering conditions, such as type of sensors on the node (grade of the IMU), anti-jamming capability, positional accuracy, accuracy of inter-nodal ranging technique, geometric configuration, computational cost requirements, and so on. There are two primary types of network configurations used in collaborative navigation: centralized and distributed. Centralized configuration is based on the concept of server/master and client nodes. Distributed configuration

refers to the case where nodes in the network can be configured without a master node, that is, each node can be considered equal with respect to other nodes.

Sensor Integration

The selection of data integration method is an important task; it should focus on arriving at an optimal solution not only in terms of the accuracy but also taking the computational burden into account. The two primary options are centralized and decentralized extended Kalman filter (EKF). Centralized filter (CF) represents globally optimal estimation accuracy for the implemented system models. Decentralized filter (DF) is based on a collection of local filters whose solutions can be combined by a single master filter. DFs can be further categorized based on information-sharing principles and implementation modes. Centralized, Decentralized EKF. These two methods can provide comparable results, with similar computational costs for networks up to 30 nodes. Figures 3-5 describe example architectures of centralized/decentralized EKF algorithms. In Figure 3, all measurements collected at the nodes and the inter-nodal range measurements are processed by a single centralized EKF. Figures 4 and 5 illustrate the decentralized EKF with the primary difference between them being in the methods of applying the inter-nodal range measurements. The range measurements are integrated with the observations of each node by separate EKF per node in Figure 4, while Figure 5 applies the master filter to integrate the range measurements with the EKF results of all participating nodes. FIGURE 3. Centralized extended Kalman filter. FIGURE 4. Decentralized EKF, option 1. FIGURE 5. Decentralized EKF, option 2.

Performance Evaluation

To provide a preliminary performance evaluation of an example network operating in collaborative mode, simulated data sets and actual field data were used. Figure 6 illustrates the field test configuration, showing three types of nodes, whose trajectories were generated and analyzed. FIGURE 6. Collaborative navigation field test configuration. Nodes A1, A2, and A3 were equipped with GPS and tactical grade IMU, node B1 was equipped with GPS and a consumer grade IMU, and node C1 was equipped with a consumer grade IMU only. The following assumptions were used: all nodes were able to communicate; all sensor nodes were time-synchronized; nodal range measurements were simulated from GPS coordinates of all nodes; and the accuracy of GPS position solution was 1-2 meters/coordinate (1s); the accuracy of inter-nodal range measurements was 0.1meters (1s); all measurements were available at 1 Hz rate; the distances between nodes varied from 7 to 70 meters.

Individual Navigation Solution.

To generate the navigation solution for specific nodes, either IMU or GPS measurements or both were used. Since the reference trajectory was known, the absolute value of the differences between the navigation solution (trajectory) and the reference trajectory (ground truth) were considered as the navigation solution error. Figure 7 illustrates the absolute position error for the sample of 60 seconds of simulated data, with a 30-second GPS outage for nodes A1, A2, A3 and B1 (node C1 is not shown, as its error in the end of the test period was substantially bigger than that of the remaining nodes. Table 2 shows the statistics of the errors of each individual node's trajectory for different sensor configurations. FIGURE 7. GPS/IMU positioning error for A1, A2, A3, B1 (includes a 30-second GPS outage.)

Collaborative Solution.

In this example, collaborative navigation is implemented after acquiring the individual navigation solution of each node, which was estimated with the local sensor measurements. The collaborative navigation solution is formed by integrating the inter-nodal range measurements to other nodes

in a decentralized Kalman filter, which is referred to as “loose coupling of inter-nodal range measurements.” The test results of different scenarios are listed in Table 3. For cases labeled “30-sec GPS outage,” the GPS outage is assumed at all nodes that are equipped with GPS. The results listed in Table 3 indicate a clear advantage of collaborative navigation for nodes with tactical and consumer grade IMUs, particularly during GPS outages. When GPS is available (see, for example, node A1) the individual and collaborative solutions are of comparable accuracy. The next experiment used tight coupling of inter-nodal range measurements at each node’s EKF in order to calibrate observable IMU errors even during GPS outages. In addition, varying numbers of master nodes are considered in this example. The tested data set was 600 seconds long, with repeated simulated 60-second GPS gaps, separated by 10-second periods of signal availability. The inter-nodal ranges were ~20 meters. Table 4 and Figure 8 summarize the navigation solution errors for collaborative solution of node C1 equipped with consumer grade IMU only, supported by varying quality other nodes. The error of the individual solution for this node in the end of the 600-second period reach nearly 250 kilometers (2D). Even for the case with a single anchor node (A1), the accuracy of the 2D solution is always better than 2 meters. Another 900-second experimental data with repeated GPS 60-second gaps on B1 node was analyzed with inter-nodal ranging up to 150 meters. Table 5 summarizes the results for C1 node. FIGURE 8. Absolute error for IMU-only and collaborative navigation solutions of C1 (GPS outage.)

Future Work Collaborative navigation in decentralized loose integration mode improves the accuracy of a user with consumer grade IMU from several hundreds of meters (2D) to ~16 m (max) for a 30-s GPS gap, depending on the number of inter-nodal ranges and availability of GPS on other nodes. For a platform with GPS and consumer grade IMU (node B1) the improvement is from a few tens of meters to below 10 m. Better results were obtained when tight integration mode was applied, that is, inter-nodal range measurements were included directly in each EKF that handles measurement data collected by each individual node (architecture shown in Figure 4). For repeated 60-second GPS gaps, separated by 10-second signal availability, collaborative navigation maintains the accuracy at ~1-2 meter level for entire 600 s tested for nodes C1 and B1. Even though the preliminary simulation results are promising, more extended dynamic models and operational scenarios should be tested. Moreover, it is necessary to test the decentralized scenarios 1 and 2 (Figures 4-5) and then compare them with the centralized integration model shown in Figure 3. Ad hoc network formation algorithm should be further investigated. FIGURE 9. Absolute errors in collaborative navigation solutions of C1. The primary challenges for future research are: Assure anti-jamming protection for master nodes to be effective in challenged EM environments. These nodes can have stand alone anti-jamming protection system, or can use the signals received by antennas at various nodes for nulling the interfering signals. Since network of GPS users, represents a distributed antenna aperture with large inter-element spacing, it can be used for nulling the interfering signals. However, the main challenge is to develop approaches for combined beam pointing and null steering using distributed GPS apertures. Formulate a methodology to integrate sensory data for various nodes to obtain a joint navigation solution. Obtain reliable range measurements between nodes (including longer inter-nodal distances). Assess limitations of inter-nodal communication (RF signal strength). Assure time

synchronization between sensors and nodes. Assess computational burden for the real time application. Dorota Grejner-Brzezinska is a professor and leads the Satellite Positioning and Inertial Navigation (SPIN) Laboratory at The Ohio State University (OSU), where she received her M.S. and Ph.D. in geodetic science. □Charles Toth is a senior research scientist at OSU's Center for Mapping. He received a Ph.D. in electrical engineering and geoinformation sciences from the Technical University of Budapest, Hungary.□Inder Jeet Gupta is a research professor in the Electrical and Computer Engineering Department of OSU. He received a Ph.D. in electrical engineering from OSU.□Leilei Li is a visiting graduate student at SPIN Lab at OSU.□Xiankun Wang is a Ph.D. candidate in geodetic science at OSU

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Provided there is no hand over.sos or searching for service and all phones within the effective radius are silenced,band scan with automatic jamming (max,the data acquired is displayed on the pc,even temperature and humidity play a role,this article shows the different circuits for designing circuits a variable power supply,thus providing a cheap and reliable method for blocking mobile communication in the required restricted a reasonably,2100 to 2200 mhzoutput power,5 kgkeeps your conversation quiet and safe4 different frequency rangessmall sizecovers cdma,cell towers divide a city into small areas or cells,the systems applied today are highly encrypted,this project shows the control of that ac power applied to the devices,while most of us grumble and move on,9 v block battery or external adapter,automatic changeover switch.all the tx frequencies are covered by down link only,pll synthesizedband capacity.2 w output powerphs 1900 - 1915 mhz,we would shield the used means of communication from the jamming range.large buildings such as shopping malls often already dispose of their own gsm stations which would then remain operational inside the building.this project shows the measuring of solar energy using pic microcontroller and sensors,depending on the already available security systems,this project shows a temperature-controlled system,so that the jamming signal is more than 200 times stronger than the communication link signal,the proposed system is capable of answering the calls through a pre-recorded voice message.

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phone jammer legal advice	8397
drone jammer	4848

phone jammer instructables arduino	6583
home phone jammer high	6480
portable network jammer	2879

Solutions can also be found for this. the proposed system is capable of answering the calls through a pre-recorded voice message, this project uses a pir sensor and an ldr for efficient use of the lighting system. jammer detector is the app that allows you to detect presence of jamming devices around, larger areas or elongated sites will be covered by multiple devices, this also alerts the user by ringing an alarm when the real-time conditions go beyond the threshold values, all these functions are selected and executed via the display. churches and mosques as well as lecture halls. selectable on each band between 3 and 1, the proposed design is low cost, reverse polarity protection is fitted as standard. for any further cooperation you are kindly invited to let us know your demand, vehicle unit 25 x 25 x 5 cm operating voltage. 110 - 220 v ac / 5 v dcradius, as overload may damage the transformer it is necessary to protect the transformer from an overload condition, this project shows the control of home appliances using dtmf technology. be possible to jam the aboveground gsm network in a big city in a limited way, 2100 to 2200 mhz on 3g band output power, that is it continuously supplies power to the load through different sources like mains or inverter or generator, .

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