robot_localization - angular drift when fusing IMU

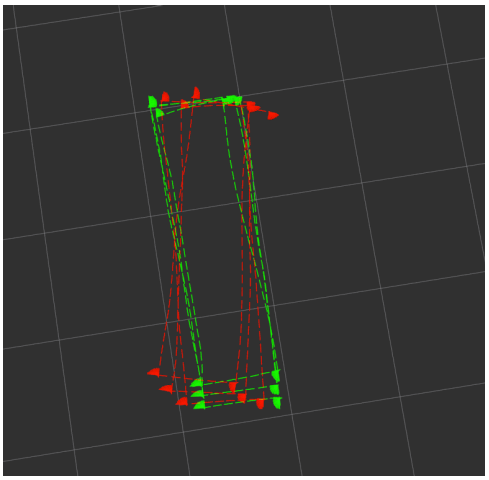
I've run into an interesting issue. It seems that when I'm fusing angular velocity it ends up adding a significant angular drift to odometry output.

My robot platform is a differential_drive robot with a caster wheel. On my robot I have two IMUs: one in the front (Realsense Tracking camera) and another one in the back (Phidgets Spatial IMU).

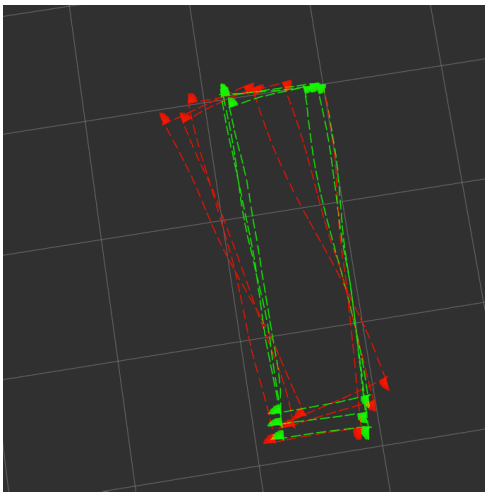
Here is my starting robot_localization config:

```
odom_frame: odom
base_link_frame: base_link
world_frame: odom
publish_tf: true
frequency: 25

two_d_mode: true

odom0: /rr_robot/mobile_base_controller/odom
odom0_config: [false, false, false,
               false, false, false,
               true, true, false,
               false, false, false,
               false, false, false]
odom0_differential: false

# imu0: /rs_t265/imu
imu0: /imu/data_raw
imu0_config: [false, false, false,
              false, false, false,
              false, false, false,
              true, true, true,
              false, false, false]

imu0_differential: false
imu0_relative: true
```

Here is the output for the /rs_t265/imu topic (mounted in front):

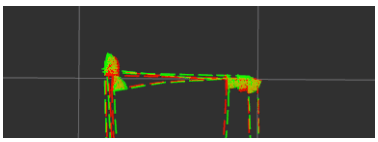


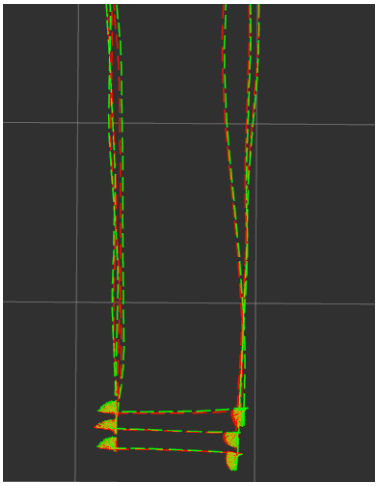
and here is the output when using Phidgets (mounted in the back of the robot):



The green odometry in the picture is the wheel odometry that is very close to the actual path traveled by the robot. The odometry marked in red is the output of robot_localization package.

Almost all sources I've seen on the internet suggest fusing x and y velocity from the odometry topic and angular velocities of the IMU (magnetometer doesn't work well enough for me due to magnetic interference). The only way I can get the fused odometry appear much closer to the wheel odometry is by fusing the yaw of odom0 message, however it seems to make the filter not take the imu into account very much:

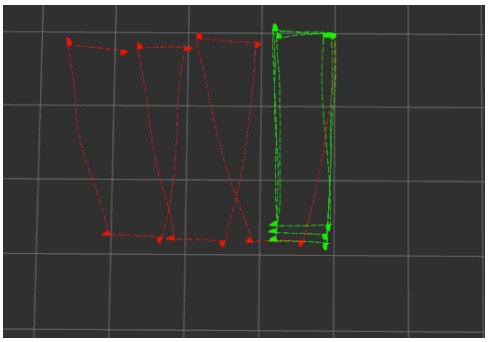




Am I'm missing something in my setup? I think I read up all the information on robot_localization that's available on the internet and didn't come to any obvious conclusions. I'd appreciate any feedback you might have!

EDIT: Some additional information: For each of the IMU setups the sensor frame seems to be correctly specified in the TF tree and is correctly contained in the appropriate IMU message fields.

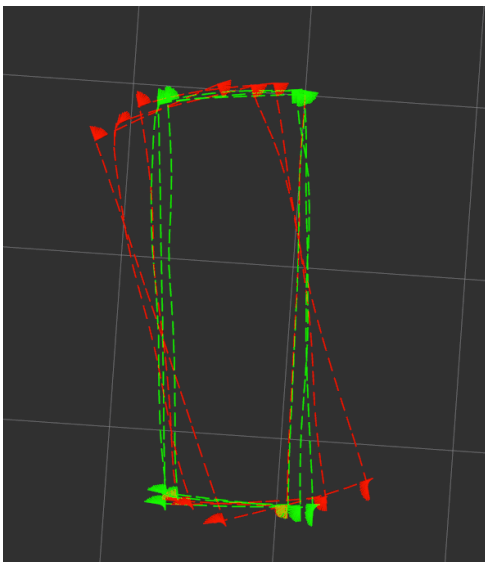
EDIT2: Output when using madgwick filter to produce an IMU message with orientation field and fusing the resultant yaw looks as follows:



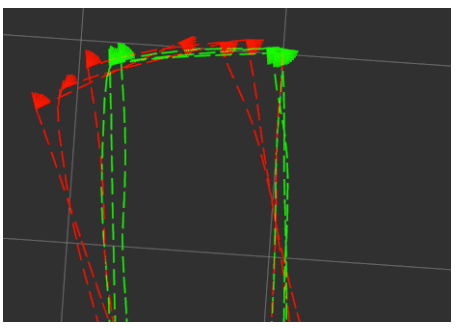
Unfortunately in 3 of the 4 corners I turn at there are huge metallic object affecting the magnetometer.

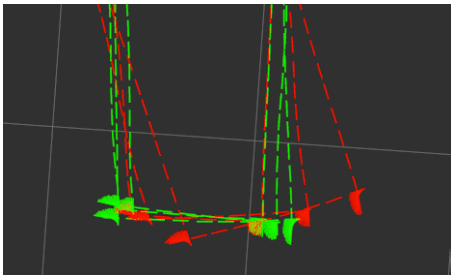
EDIT3: Trying to fuse yaw rate from wheel odom.

Before yaw rate fusion:

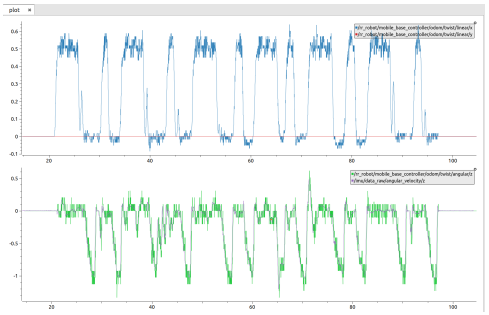


After fusing yaw rate:





When I said that my platform used encoders I lied a bit - actually I only have data from the motor's hall sensors. This makes the data quite noisy, below you can see a graph with wheel odom velocity on x and y and yaw rates (from wheel odom (green) and imu (purple). Would this noise contribute to my issue?



EDIT4: Sample sensor input:

Wheel odometry(/rr*robot/mobile*base_controller/odom):

```
header:
  seq: 2443
  stamp:
    secs: 1579080868
    nsecs: 941759306
  frame_id: "odom"
child_frame_id: "base_link"
pose:
  pose:
    position:
      x: 2.38348355885
      y: 0.0650385644131
      z: 0.0
    orientation:
      x: 0.0
      y: 0.0
      z: -0.502680731125
      w: 0.864472140994
  covariance: [0.01, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.01, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1000000.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1000000.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1000000.0, 0.0, 0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 0.03]
twist:
  twist:
    linear:
      x: 3.61499394797e-05
      y: 0.0
      z: 0.0
    angular:
      x: 0.0
      y: 0.0
      z: -1.02619873587
  covariance: [0.01, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.01, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.01, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1000000.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1000000.0, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0, 0.03]
```

Imu 1 input (imu/data_raw):

```
header:
  seq: 3135
  stamp:
    secs: 1579080870
    nsecs:   5166062
  frame_id: "base_imu_link"
orientation:
  x: 0.0
  y: 0.0
  z: 0.0
  w: 0.0
orientation_covariance: [0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
angular_velocity:
  x: -0.00163694430545
  y: 0.00117216312564
  z: -0.00302570279126
angular_velocity_covariance: [1.2184696791468346e-07, 0.0, 0.0, 0.0, 1.2184696791468346e-07, 0.0, 0.0, 0.0, 1.2184696791468346e-07]
linear_acceleration:
  x: 0.276053411808
  y: 0.176580007553
  z: 9.94410312535
linear_acceleration_covariance: [8.66124974095918e-06, 0.0, 0.0, 0.0, 8.66124974095918e-06, 0.0, 0.0, 0.0, 8.66124974095918e-06]
```

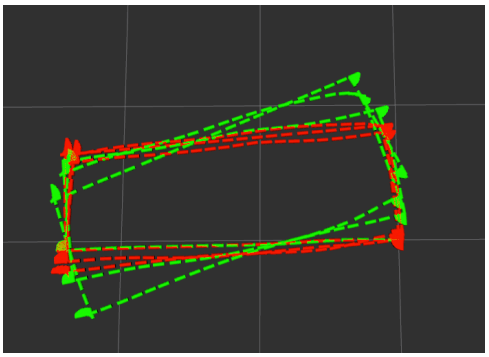
Imu 2 input (/rs_t265/imu):

```
header:
  seq: 3826
  stamp:
    secs: 1579080881
    nsecs: 461572409
  frame_id: "rs_t265_imu_optical_frame"
orientation:
  x: 0.0
  y: 0.0
  z: 0.0
  w: 0.0
orientation_covariance: [-1.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
angular_velocity:
  x: -0.0127835636958
  y: -0.885261774063
  z: -0.00958767253906
angular_velocity_covariance: [0.01, 0.0, 0.0, 0.0, 0.01, 0.0, 0.0, 0.0, 0.01]
linear_acceleration:
  x: -0.105569154024
  y: 9.05154418945
  z: 0.116197049618
linear_acceleration_covariance: [0.01, 0.0, 0.0, 0.0, 0.01, 0.0, 0.0, 0.0, 0.01]
```

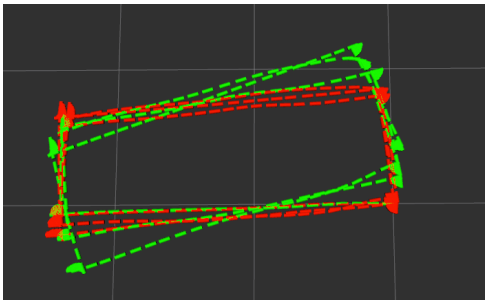
Edit 4:

Playing around with some of the values I don't see any visible change. Modifying diff drive twist covariance doesn't lead to any visible changes. Here is a result with yaw rate

twist covariance set to 0.01 (red-wheel odom, green - fused odom):

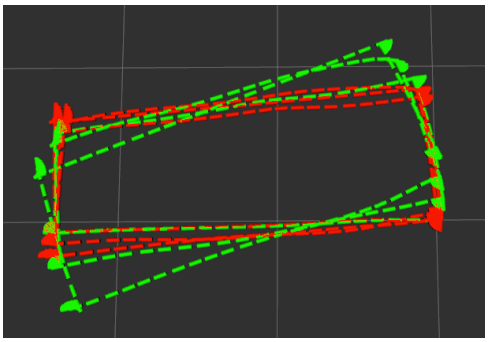


And with yaw rate covariance set to 0.00000000001:

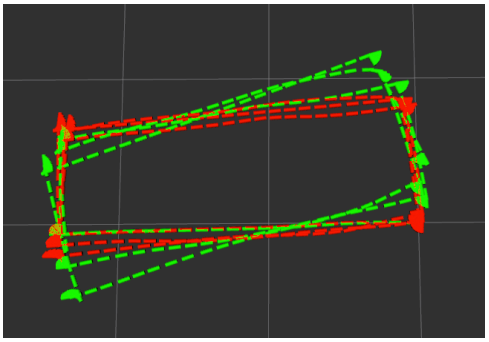


The above was done with the yaw*rate process*noise*covariance set to 0.02. I've also made sure that the modified covariance correctly appears in the message. Bringing up process*noise_covariance yaw rate results in this:

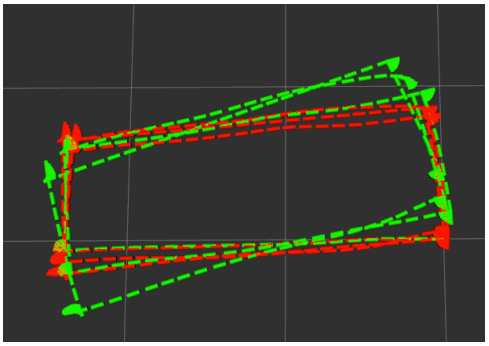
0.001:



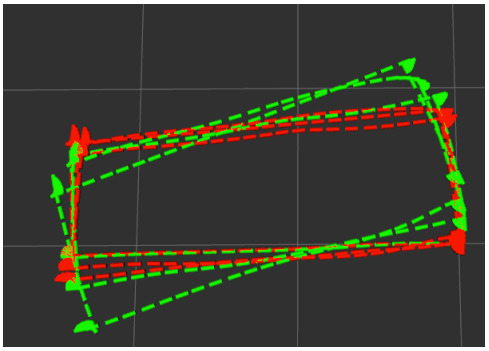
0.1:



10:



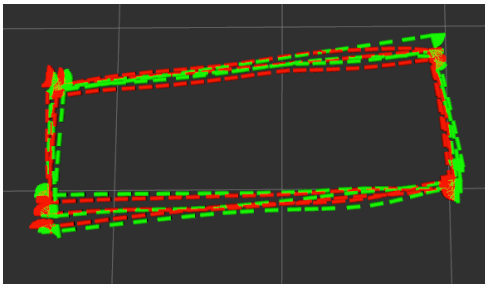
10000:



I've triple checked that the config file is correctly loaded as I find it a bit weird that my changes seemingly don't take effect. I've also checked the /diagnostic topic for any hints but I see a message `The robot_localization state estimation node appears to be functioning properly.` When I disable any yaw rate fusion in config the estimate travels in a straight line hence I'm pretty sure the config is correctly loaded. Here it is for reference:

```
frequency: 25
sensor_timeout: 0.1
two_d_mode: true
transform_time_offset: 0.0
debug: false
map_frame: map              # Defaults to "map" if unspecified
odom_frame: odom            # Defaults to "odom" if unspecified
base_link_frame: base_link # Defaults to "base_link" if unspecified
world_frame: odom           # Defaults to the value of odom_frame if unspecified

odom0: /rr_robot/mobile_base_controller/odom
# odom0: /rs_t265/odom/sample
odom0_config: [false, false, false,
               false, false, false,
               true,  true,  false,
               false, false, true,
               false, false, false]
odom0_queue_size: 10
odom0_nodelay: false
odom0_differential: false
odom0_relative: true

imu0: /imu/data_raw
# imu0: /rs_t265/imu
imu0_config: [false, false, false,
              false,  false,  false,
              false, false, false,
              false,  false,  true,
              false, false, false]
imu0_queue_size: 10
imu0_nodelay: false
imu0_differential: true
imu0_relative: false

print_diagnostics: true

#                           x     y     z     roll  pitch yaw   vel_x  vel_y  vel_z vel_r vel_p vel_y acc_x acc_y acc_z
process_noise_covariance: [0.05, 0,    0,    0,    0,    0,    0,     0,     0,    0,    0,    0,    0,    0,    0,
                           0,    0.05, 0,    0,    0,    0,    0,     0,     0,    0,    0,    0,    0,    0,    0,
                           0,    0,    0.06, 0,    0,    0,    0,     0,     0,    0,    0,    0,    0,    0,    0,
                           0,    0,    0,    0.03, 0,    0,    0,     0,     0,    0,    0,    0,    0,    0,    0,
                           0,    0,    0,    0,    0.03, 0,    0,     0,     0,    0,    0,    0,    0,    0,    0,
                           0,    0,    0,    0,    0,    0.06, 0,     0,     0,    0,    0,    0,    0,    0,    0,
                           0,    0,    0,    0,    0,    0,    0.025, 0,     0,    0,    0,    0,    0,    0,    0,
                           0,    0,    0,    0,    0,    0,    0,     0.025, 0,    0,    0,    0,    0,    0,    0,
                           0,    0,    0,    0,    0,    0,    0,     0,     0.04, 0,    0,    0,    0,    0,    0,
                           0,    0,    0,    0,    0,    0,    0,     0,     0,    0.01, 0,    0,    0,    0,    0,
                           0,    0,    0,    0,    0,    0,    0,     0,     0,    0,    0.01, 0,    0,    0,    0,
                           0,    0,    0,    0,    0,    0,    0,     0,     0,    0,    0,    10000, 0,    0,    0,
                           0,    0,    0,    0,    0,    0,    0,     0,     0,    0,    0,    0,    0.01, 0,    0,
                           0,    0,    0,    0,    0,    0,    0,     0,     0,    0,    0,    0,    0,    0.01, 0,
                           0,    0,    0,    0,    0,    0,    0,     0,     0,    0,    0,    0,    0,    0,    0.015]
```

Edit 5: Output with imu input disabled (commented out):



Edit 6: The debug file (killed shortly after the first turn): https://drive.google.com/file/d/1ZI9YlmXQe9J_0jZDcWSgNJbcVLi5BhiA/view?usp=sharing (unfortunately answer.ros.org file upload didn't work)

Asked by msadowski on 2020-01-13 08:23:15 UTC

Comments

Do any of the IMUs give you out the orientation? I'd use that over others. You may want to try putting one of the IMUs through a complementary filter and then the output orientation into R_L.

Asked by stevemacenski on 2020-01-13 15:51:13 UTC

One of the IMUs gives out orientation, however, the environment I run the robot in contains huge metallic object near 3 of the corners I turn at. I'll edit the question to add the visualisation of this one. It's actually using Madgwick and should fuse magnetometer with other sensors.

Asked by msadowski on 2020-01-14 05:54:08 UTC

Are you *sure* all the sensors are being fused? I presume you are using a bag file to get repeatable results; how are you modifying the covariance values in your bag file? Did you define static transforms for the IMU data frame_ids? And are you plotting the right output topic? The fact that *nothing* changes the output leads me to believe one of the inputs is being ignored. What happens if you turn off the IMU input?

Asked by Tom Moore on 2020-01-28 06:26:07 UTC

- I've updated the question to show the output with imu config commented out
    - I use only joint state information from the bag file and run differential_drive controller with this data, by changing the config I can modify the covariance
    - I've checked the time in all messages and it's consistent
    - All static transforms are there and the tree seems OK (checked with rqt_tf_tree and also with roswtf)
    - I checked rosnode info with ekf node and rqt_graph and can confirm that both imu and odom topics are fed into the ekf node. I also confirmed that I'm subscribed to the correct topic (odometry/filtered)

Asked by msadowski on 2020-01-28 08:09:58 UTC

So the filter is clearly trusting your IMU far more than your odom data. At this point, I would turn on debug mode (set the debug output file to an absolute path), let the robot go through a single turn, then quickly kill it. Zip that and post it here.

Asked by Tom Moore on 2020-01-29 04:40:41 UTC

Edited the question and posted a google drive link to the zipped debug file.

Asked by msadowski on 2020-01-29 04:59:34 UTC

BTW, you have `two_d_mode`, but are fusing roll and pitch data. Those are going to get ignored.

Asked by Tom Moore on 2020-01-29 05:39:26 UTC

Answers

So you're fusing only velocity data. Every velocity measurement contains error. When you integrate the velocity measurements into a pose estimate, you also integrate the errors. Drift will *always* be an issue when you have no absolute pose data included.

But note that your wheel encoder odometry yaw is *also* accumulating error, before you even send it to the EKF. The robot's odometry will just be counting encoder ticks, which is also subject to error.

In any case, the root of the issue here is that your IMU is likely noisier/more biased than your wheel odometry. Try fusing yaw velocity from your wheel odometry *and* the IMU, and see what happens.

EDIT after question update: yeah, your covariance values for angular velocity are preventing the filter from caring about the measurements from wheel odometry. Your wheel encoders have a `z` angular velocity variance of 0.03 (standard deviation of 0.173 rad/sec per measurement), whereas your `imu/data_raw` input is reporting an angular velocity variance of 1.2184696791468346e-07 (standard deviation of 0.0003491 rad/sec per measurement). That means you are telling the filter that your IMU is many orders of magnitude more trustworthy than your wheel odometry. You might as well not even be fusing wheel odometry yaw velocity in that case.

I'd also check your process noise covariance for yaw velocity, and make sure it's not too small, lest the filter ignore measurements because it trusts its own internal model too much (and the angular velocity model is literally just projecting the current velocity to the next timestep, so it shouldn't).

EDIT after second question update: OK, so odom fusion works by itself. My money is on sensor frequency now. What is your odometry message frequency vs. the IMU frequency? Even with equivalent covariance values, if you have 10 IMU messages for every odometry message, your odometry data will be effectively lost.

EDIT after debug file

OK, you have two problems.

First, your IMU is *really* off. As an example, at one of your time steps, your wheel odometry is showing an angular velocity of -0.4103, but in that same moment, the IMU is reading -0.61551. If you *just* include IMU rotational data (turn off the angular velocity for wheel odom), I'm guessing the output would be a bit uglier.

Your process noise covariance is too high, given the noise in your sensors. What's happening is that you get an odom velocity with a tiny covariance, on the order of e-11. The filter does a predict, which adds the process noise to that quantity in its internal covariance estimate. It ends up with a covariance of something e-5. So when we do the correct step, the wheel odometry data is trusted completely, and the filter effectively jumps to the velocity in the wheel odom data. Then you get an IMU message. Again, the filter predicts across that time delta, and its internal covariance estimate moves to something on the order of e-5. The IMU data has a covariance on the order of e-7, so the filter again just trusts the IMU data completely, and jumps to that velocity. So in this case, the more frequent sensor will always "win."

My recommendation is that you stop trying to force the filter to behave a certain way, and start by giving your sensors realistic covariance values. Drive the robot in a square and measure the integrated wheel odometry yaw error after that square. Divide that total error by the number of measurements, convert to variance, and use that as your angular velocity covariance. Repeat for the IMU. You'll need some way to ground truth it.

Once you are satisfied that your sensors have accurate covariance values, then get the filter's process noise to a point where the prediction step doesn't make the filter's internal covariance huge w.r.t. the measurements.

But be warned: the IMU is clearly off. The filter will always include *some* of its measurement in the output, so if it's over-estimating your turns by a lot, it's going to drag the estimate in that direction.

Asked by Tom Moore on 2020-01-22 05:12:50 UTC

Comments

Many thanks for your suggestion Tom. I've updated the question with some further screenshots. Fusing heading rate from the wheel odom didn't change anything and I'm wondering if it is due to the noise in my data (my platform currently is using hall sensors in the motor instead of encoders).

Asked by msadowski on 2020-01-22 07:49:59 UTC

My guess is that this a covariance issues. Please post sample input messages from every sensor input. It sounds like your IMU is under-estimating its error, or that the wheel odometry is over-estimating its error.

Asked by Tom Moore on 2020-01-24 05:04:26 UTC

Many thanks for your help! I've just edited the question and pasted the sample input of every topic I've tested my setup with. At one point I was playing with the covariance values of the wheel odometry but without too much success unfortunately.

Asked by msadowski on 2020-01-24 05:27:52 UTC

Many thanks for your continued support! Weirdly none of the changes I make seem to have any effect, I've updated the original questions with some more screenshots in case you would have time to take a look at it once more.

Asked by msadowski on 2020-01-28 06:29:30 UTC

The wheel odom frequency is around 50Hz, while the IMU is 62.5Hz (checked with rostopic hz while the bag was playing).

Asked by msadowski on 2020-01-29 04:16:10 UTC

Many thanks for your pointers Tom, that really helps! Could the "IMU being way off" the result of high noise of my wheel odom angular twist? In my edit 3 I've posted a graph of heading rate from both wheel odom and IMU and although you can clearly see the noise in one of them it seems to follow the 'trend' quite well.

What I find odd is that I see similar behaviour (but the effects are flipped) on two different sensors (Realsense T265 and Phidgets IMU). I'll try to apply all of your recommendations and see where that gets me.

Do you think that getting proper wheel encoders could also help in this case?

Asked by msadowski on 2020-01-29 07:14:47 UTC

Looking closer at the data it looks like my wheel odom angular twist has a resolution of 0.1, which doesn't sound nowhere near usable. Will try to sanitize the data before I get on with anything else.

Asked by msadowski on 2020-01-29 07:15:58 UTC

The problem is that your raw wheel encoder data, as you reported, looks right: you said the robot actually traversed a rectangle (and came back to the same starting point), and when you just use wheel odometry, that's what you see. So while I agree that something is afoot, I don't know that I believe it's your encoders. Maybe try driving in a rectangle, and write a small script that integrates all the angular velocities from one IMU. When the robot returns to the start position, make it rotate to the initial heading. The summed IMU data should agree.

Asked by Tom Moore on 2020-02-11 04:22:13 UTC