Kauno technologijos universitetas

Elektros ir elektronikos fakultetas

(T121M001) Skaitmeninių signalų apdorojimas realaus laiko sistemose

Kursinis darbas

GNSS ir INS navigacinė sistema

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Dėstytojas: doc. Šarūnas Kilius

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Turinys

1. Įvadas

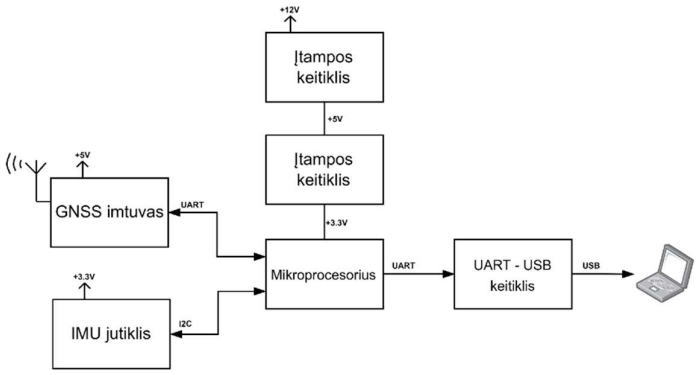
Šiuo metu prieinamiausias ir patraukliausias navigacijos metodas yra GNSS sistema, kuri yra išmaniuosiuose telefonuose. Tačiau ši sistema prastai veikia tankiai apgyvendintose vietovėse, kur yra gausu daugkartinių atspindžių. GNSS pozicijos nustatymo paklaida stipriai priklauso nuo palydovų kiekio. Kai palydovų kiekis mažas, gaunama didelė paklaida. Tačiau požeminiuose tuneliuose GNSS signalo patikimai priimti neįmanoma. Vis dažniau kartu naudojami ir INS metodai, kurie papildo GNSS sistemą. INS sistema nepriklausoma nuo išorinių radijo signalų. Tokia sistema leidžia atlikti vadinamą "dead reckoning", t.y. pozicijos aproksimavimą net ir tuneliuose. Šiame darbe bus suprojektuotas navigacijos algoritmas, sujungiantis GNSS ir INS sistemas.

2. Įranga

Kursiniame darbe pasirinkta naudoti šiuos komponentus:

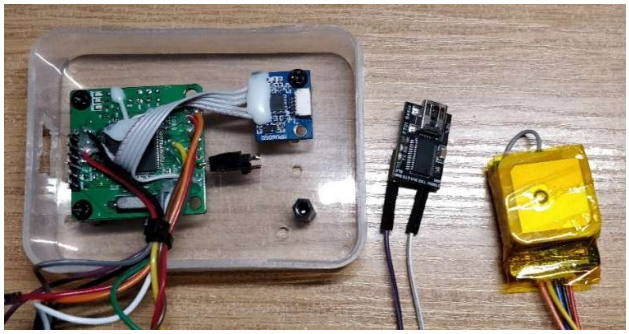
- Mikroprocesorius STM32F732
- GNSS imtuvas Waveshare LX76
- IMU jutiklis (3 ašių giroskopas ir 3 ašių akselerometras) Ivensense MPU6050
- UART – USB keitiklis Sparkfun FTDI

1 pav. pateikta GNSS/INS navigacijos sistemos struktūrinė diagrama:



1 pav. GNSS/INS sistemos struktūrinė diagrama

2 pav. pateikta surinkta GNSS/INS sistema:



2 pav. GNSS/INS sistema

Nuspręsta, kad suprojektuotą GNSS/INS sistemą patogiausia bus testuoti automobiliu. 3 pav. pateikta GNSS/INS sistemos montavimo vieta automobilyje:

3 pav. GNSS/INS sistemos montavimo vieta automobilyje

3. Algoritmas

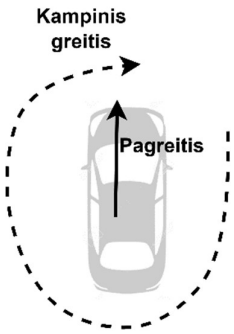
Siekiant nustatyti automobilio koordinatę GNSS sistema, reikia dekoduoti GNRMC duomenų paketus. Pavyzdinis GNRMC duomenų paketas pateiktas žemiau:

```
$GNRMC,185823.40,A,4808.7402374,N,01133.9324760,E,0.00,112.64,130117,3.00,E,A*14
```

Žinutėje:

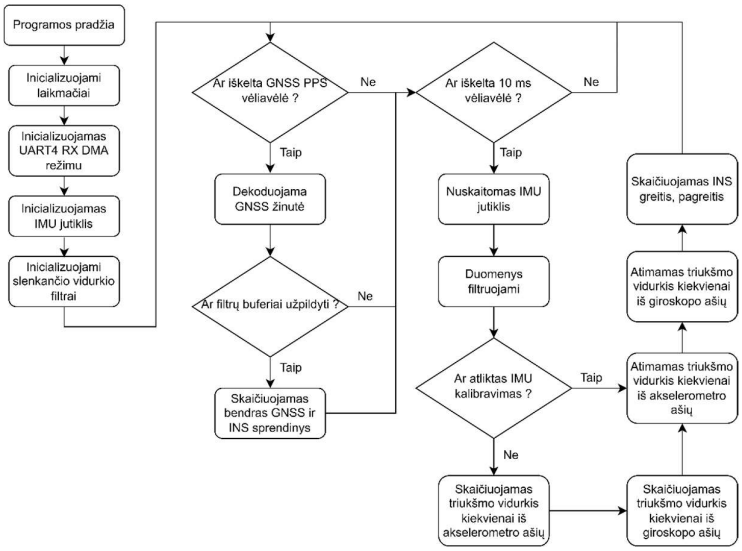
- 185823: GMT laikas: 18 val 58 min 23 s
- A: galimas koordinatės sprendinys
- 4808.7402374: 48 – sveikoji platumos laipsnių dalis; 08.7402374 trupmeninė platumos laipsnių dalis minutėmis
- N: šiaurės pusrutulis
- 01133.9324760: 011 – sveikoji ilgumos laipsnių dalis; 33.9324760 trupmeninė ilgumos laipsnių dalis minutėmis
- E: rytų pusrutulis
- 0.00: greitis jūriniais mazgais
- 112.64: bearing kampas nuo šiaurės ašigalio pagal laikrodžio rodyklę

Pasirinkta matuoti automobilio kampinį greitį giroskopo z ašimi ir linijinį pagreitį akselerometro x ašimi. 4 pav. pateikta struktūrinė diagrama, kokie automobilio paremetrai matuojami:



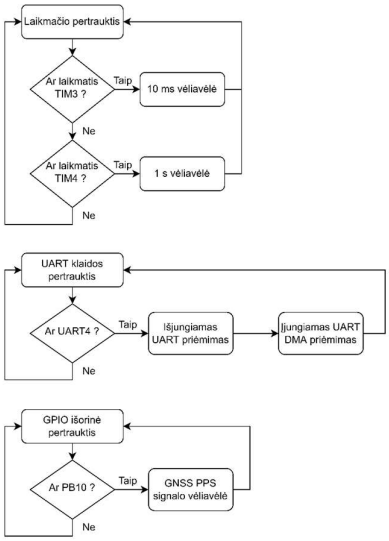
4 pav. IMU jutikliu matuojami automobilio parametrai

5 pav. pateikta pagrindinio main.c programinio algoritmo struktūrinė diagrama:



5 pav. main.c algoritmo struktūrinė diagrama

6 pav. pateikta pertraukčių programinio algoritmo struktūrinė diagrama:



6 pav. Pertraukčių algoritmo struktūrinė diagrama

Kad išbandyti algoritmą realiu laiku, buvo nuspręsta siųsti duomenis iš mikrovaldiklio į nešiojamą kompiuterį naudojant UART sąsają ir UART – USB keitiklį. Duomenys buvo rašomi į .txt failą naudojant RealTerm programinę įrangą. Žemiau pateiktas duomenų paketas:

52; -0.1006; 6.7795; 1; 0; 54.93124008; 23.93642426; 49.0780; 0.0000; 71.1800; 54.93124008; 23.93642426; 49.0780; 13.6328; 71.1800;

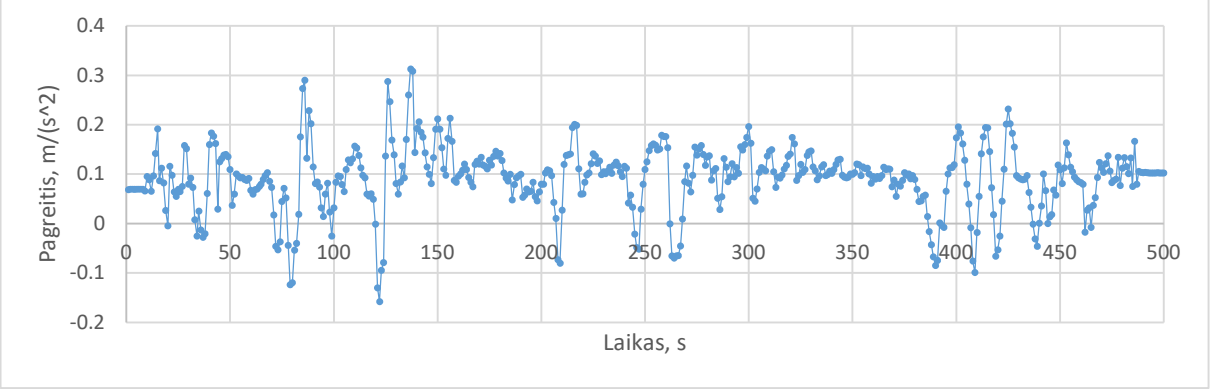
Duomenų pakete:

- 52: žinutės skaitliukas
- -0.1006: pagreitis, išmatuotas akselerometru
- 6.7795: kampinis greitis, išmatuotas giroskopu
- 1: vėliavėlė, parodanti, ar siunčiamas bendras sprendinys pagal GNSS
- 0: vėliavėlė, parodanti, ar siunčiamas bendras sprendinys pagal INS
- 54.93124008: GNSS platuma
- 23.93642426: GNSS ilguma
- 49.0780: GNSS greitis, km/h
- 0.0000: GNSS greitis, m/s
- 71.1800: GNSS bearing kampas
- 54.93124008: bendro sprendinio platuma
- 23.93642426: bendro sprendinio ilguma
- 49.0780: bendro sprendinio greitis, km/h
- 13.6328: bendro sprendinio greitis, m/s
- 71.1800: bendro sprendinio bearing kampas

4. Rezultatai

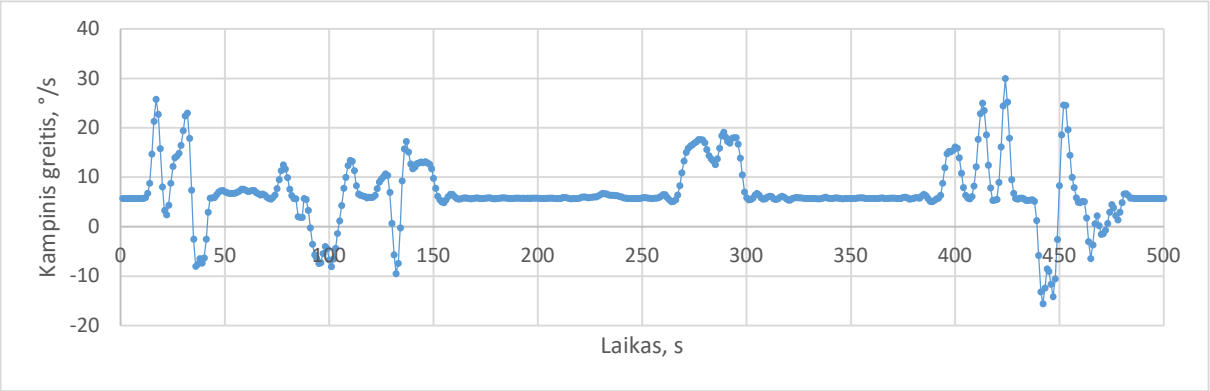
Siekiant išbandyti algoritmą realiu laiku buvo imituojamas GNSS sistemos palydovų dingimo scenarijus: penki GNSS/INS sprendiniai skaičiuojami pagal GNSS, penki pagal INS ir taip toliau.

7 pav. pateikta akselerometru išmatuoto pagreičio laikinė charakteristika. Pagreitis yra teigiamas, kai automobilis greitėja, neigiamas, kai automobilis lėtėja. Charakteristikoje matoma 0.06 m/(s^2) nuolatinė dedamoji, kuri greičiausiai atsirado dėl netinkamo akselerometro kalibravimo.



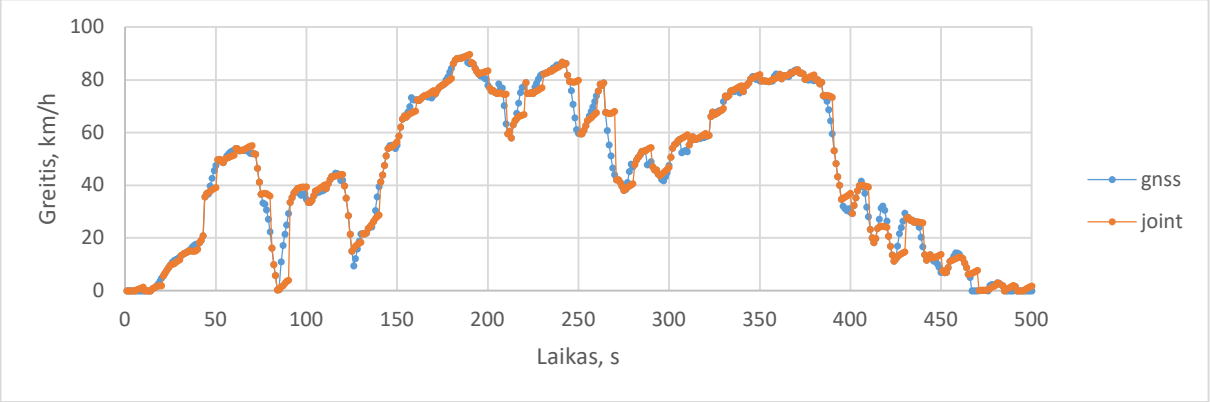
7 pav. Akselerometru išmatuoto pagreičio laikinė charakteristika

8 pav. pateikta giroskopu išmatuoto kampinio greičio laikinė charakteristika. Teigiamas greitis, kai automobilis sukasi pagal laikrodžio rodyklę, o neigiamas, kai sukasi prieš laikrodžio rodyklę. Charakteristikoje matoma 6 °/s nuolatinė dedamoji, kuri greičiausiai atsirado dėl netinkamo giroskopo kalibravimo.



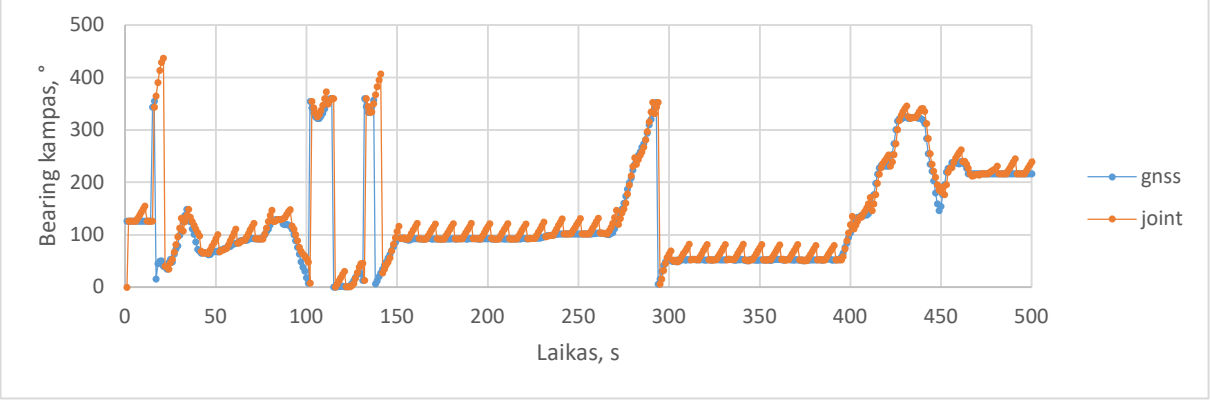
8 pav. Giroskopu išmatuoto kampinio greičio laikinė charakteristika

9 pav. pateikta GNSS ir bendro sprendinio greičio laikinė charakteristika:



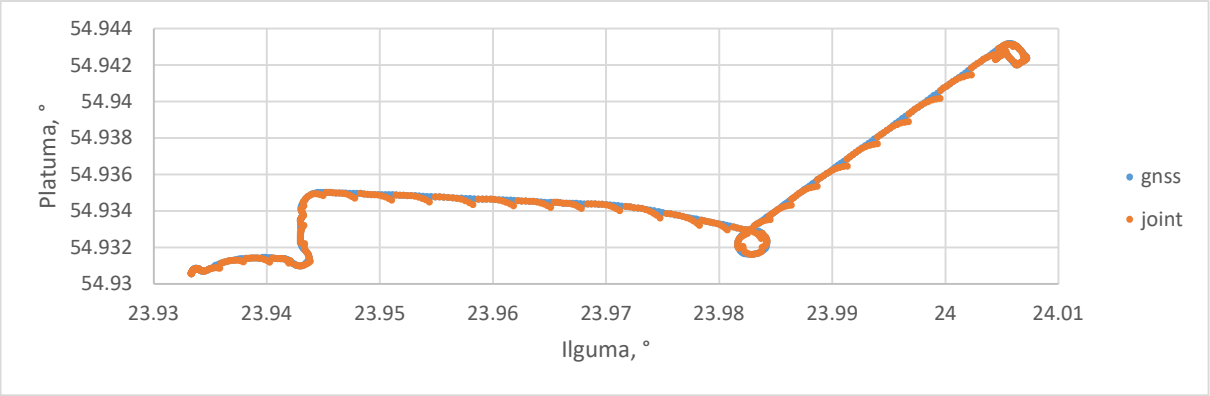
9 pav. GNSS ir bendro GNSS/INS sprendinio greičio laikinė charakteristika

10 pav. pateikta GNSS ir bendro sprendinio bearing kampo laikinė charakteristika:

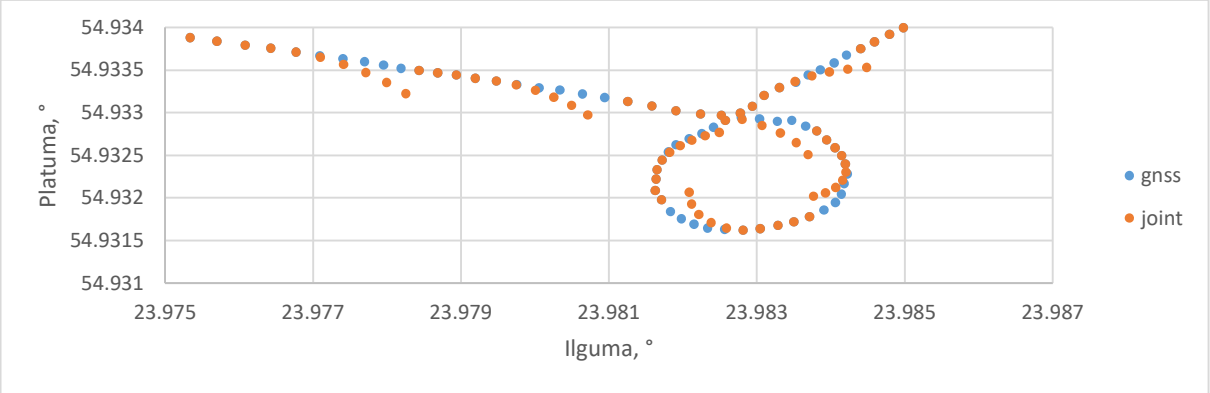


10 pav. GNSS ir bendro GNSS/INS sprendinio „bearing“ kampo laikinė charakteristika

11 ir 12 pav. pateikta GNSS ir bendro sprendinio koordinatės plokštumoje:

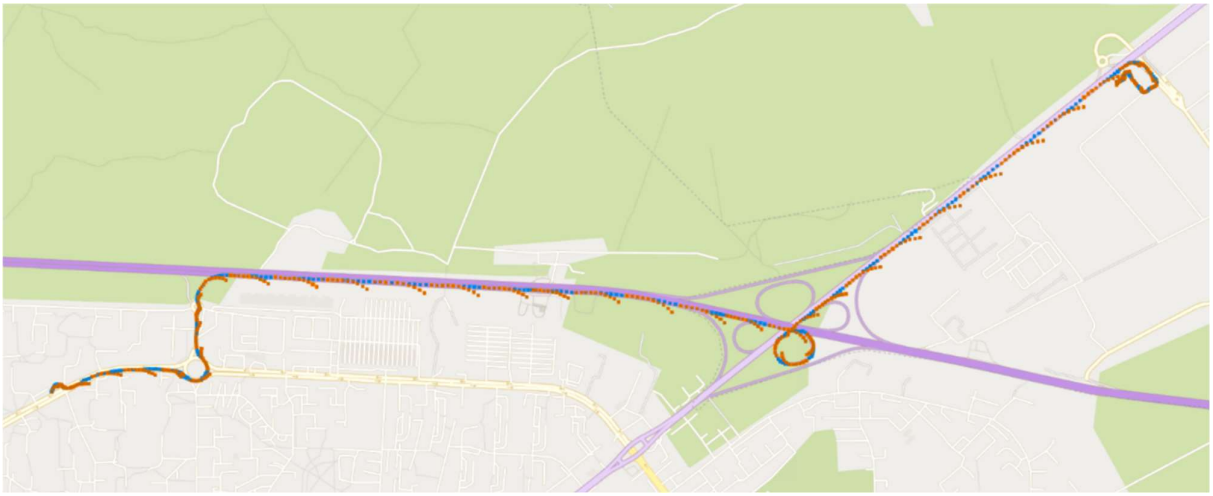


11 pav. GNSS ir bendro GNSS/INS sprendinio koordinatės plokštumoje

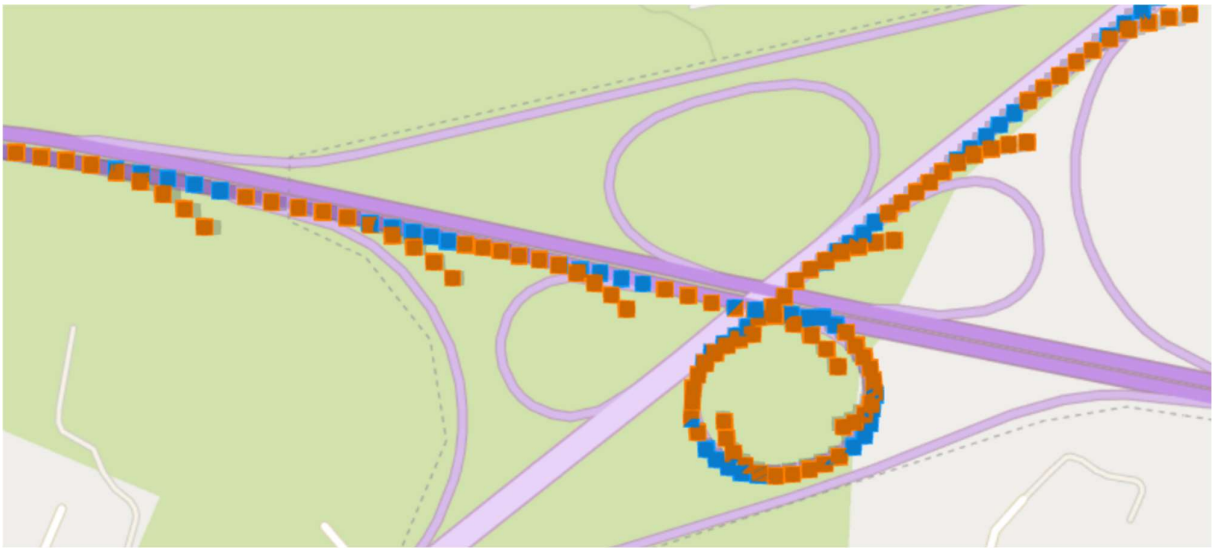


12 pav. GNSS ir bendro GNSS/INS sprendinio koordinatės plokštumoje iš arčiau

13 ir 14 pav. pateikta GNSS ir bendro sprendinio koordinatės žemėlapyje:



13 pav. GNSS ir bendro GNSS/INS sprendinio koordinatės žemėlapyje



14 pav. GNSS ir bendro GNSS/INS sprendinio koordinatės žemėlapyje iš arčiau

5. Išvados

Šiame kursiniame darbe buvo suprojektuota navigacinė sistema, kuri sujungia GNSS ir INS. Atliekamas vadinamas „dead reckoning“, kai dingus GNSS palydovų signalui navigacija atliekama pagal IMU jutikliu išmatuotą pagreitį ir kampinį greitį.

Navigacinė sistema buvo išbandyta realiu laiku, programiškai imituojant palydovų dingimą. GNSS/INS sistema dingus palydovams navigaciją atlieka efektyviai. Tačiau reikia tobulinti akselerometro ir giroskopo kalibravimą. Dėl netinkamo giroskopo kalibravimo GNSS/INS sprendinyje matomi periodiški nukrypimai.

6. Priedai

1 priedas. GNSS/INS sistema surinkti duomenys

counter	acc_x	gyro_z	gnss	ins	gnss_lat	gnss_lon	gnss_kmh	gnss_bearing	joint_lat	joint_lon	joint_kmh	joint_m_s	joint_bearing
0	0.0685	5.7586	1	0	54.93063	23.93335	0	126.11	54.93063	23.93335	0	0	126.11
1	0.0701	5.7582	1	0	54.93063	23.93335	0	126.11	54.93063	23.93335	0	0	126.11
2	0.0698	5.7546	1	0	54.93063	23.93335	0	126.11	54.93063	23.93335	0	0	126.11
3	0.0691	5.7537	1	0	54.93063	23.93335	0	126.11	54.93063	23.93335	0	0	126.11
4	0.0696	5.7569	1	0	54.93063	23.93335	0	126.11	54.93063	23.93335	0	0	126.11
5	0.0696	5.7618	0	1	54.93063	23.93335	0	126.11	54.93063	23.93335	0.2506	0.0696	131.8718
6	0.0697	5.7644	0	1	54.93063	23.93335	0	126.11	54.93063	23.93335	0.5015	0.1393	137.6362
7	0.0699	5.7682	0	1	54.93063	23.93335	0	126.11	54.93063	23.93335	0.7531	0.2092	143.4044
8	0.0664	5.7672	0	1	54.93063	23.93335	0	126.11	54.93063	23.93335	0.9922	0.2756	149.1716
9	0.0957	5.7657	0	1	54.93063	23.93335	0	126.11	54.93063	23.93335	1.3367	0.3713	154.9373
10	0.0889	5.7614	1	0	54.93063	23.93335	0	126.11	54.93063	23.93335	0	0	126.11
11	0.0657	5.9694	1	0	54.93063	23.93335	0	126.11	54.93063	23.93335	0	0	126.11
12	0.0968	6.8088	1	0	54.93063	23.93335	0	126.11	54.93063	23.93335	0	0	126.11
13	0.142	8.7744	1	0	54.93063	23.93335	0	126.11	54.93063	23.93335	0	0	126.11
14	0.1913	14.6914	1	0	54.93057	23.93332	0.8149	343.86	54.93057	23.93332	0.8149	0.2264	343.86
15	0.0868	21.3464	0	1	54.93059	23.93331	1.1112	355.21	54.93058	23.93332	1.1274	0.3132	365.2064
16	0.1124	25.8026	0	1	54.93061	23.93332	1.6298	15.84	54.93058	23.93332	1.532	0.4256	391.009
17	0.0825	22.7274	0	1	54.93063	23.93333	2.5002	45.45	54.93058	23.93333	1.829	0.5081	413.7364
18	0.0267	15.7907	0	1	54.93066	23.93335	3.5744	49.95	54.93058	23.93334	1.9251	0.5348	429.5271
19	-0.0046	8.0621	0	1	54.93069	23.93338	4.7226	50.45	54.93058	23.93335	1.9086	0.5302	437.5892
20	0.1159	3.3208	1	0	54.93071	23.93341	5.7042	40.27	54.93071	23.93341	5.7042	1.5845	40.27
21	0.098	2.4239	1	0	54.93074	23.93344	6.7598	39.05	54.93074	23.93344	6.7598	1.8777	39.05
22	0.0641	4.3531	1	0	54.93076	23.93346	7.834	35.11	54.93076	23.93346	7.834	2.1761	35.11
23	0.055	8.8287	1	0	54.93079	23.93349	8.8526	47.09	54.93079	23.93349	8.8526	2.4591	47.09
24	0.0695	12.1942	1	0	54.93081	23.93353	9.7971	53.07	54.93081	23.93353	9.7971	2.7214	53.07
25	0.0649	13.9843	0	1	54.93083	23.93356	10.7601	48.18	54.93082	23.93357	10.0307	2.7863	67.0543

26	0.0753	14.2939	0	1	54.93085	23.93361	11.4824	63.56	54.93082	23.93361	10.3018	2.8616	81.3482
27	0.1578	14.8923	0	1	54.93087	23.93365	11.8343	72.66	54.93082	23.93366	10.8699	3.0194	96.2405
28	0.1522	16.4569	0	1	54.93087	23.93371	12.1306	78.85	54.93081	23.9337	11.4178	3.1716	112.6974
29	0.0803	19.4319	0	1	54.93087	23.93378	12.7232	99.3	54.93079	23.93374	11.7069	3.2519	132.1293
30	0.0923	22.4414	1	0	54.93087	23.93385	13.39	107.37	54.93087	23.93385	13.39	3.7194	107.37
31	0.0737	22.9797	1	0	54.93085	23.93392	13.853	124.89	54.93085	23.93392	13.853	3.8481	124.89
32	0.008	17.8706	1	0	54.93084	23.93397	14.1863	137.14	54.93084	23.93397	14.1863	3.9406	137.14
33	0.0249	7.4309	1	0	54.93082	23.93401	14.6308	148.82	54.93082	23.93401	14.6308	4.0641	148.82
34	0.0252	-2.5277	1	0	54.93078	23.93405	15.1679	133.4	54.93078	23.93405	15.1679	4.2133	133.4
35	-0.013	-7.9831	0	1	54.93075	23.9341	15.6494	124.98	54.93076	23.9341	15.1211	4.2003	125.4169
36	-0.0276	-7.5436	0	1	54.93072	23.93418	16.4643	111.18	54.93075	23.93416	15.0217	4.1727	117.8733
37	-0.0205	-6.4144	0	1	54.93071	23.93426	17.168	100.81	54.93073	23.93422	14.9479	4.1522	111.4589
38	0.0612	-7.3444	0	1	54.93071	23.93434	17.631	86.71	54.93072	23.93428	15.1683	4.2134	104.1145
39	0.1602	-6.2939	0	1	54.93071	23.93442	17.7051	72.44	54.93072	23.93435	15.745	4.3736	97.8206
40	0.1836	-2.4973	1	0	54.93072	23.93451	18.1866	69.01	54.93072	23.93451	18.1866	5.0518	69.01
41	0.1769	2.9582	1	0	54.93074	23.9346	19.1682	65.08	54.93074	23.9346	19.1682	5.3245	65.08
42	0.1626	5.8394	1	0	54.93077	23.93472	20.8165	65.85	54.93077	23.93472	20.8165	5.7824	65.85
43	0.0295	5.9081	1	0	54.93081	23.93486	35.5954	65.87	54.93081	23.93486	35.5954	9.8876	65.87
44	0.1255	5.927	1	0	54.93084	23.93501	36.7807	64.8	54.93084	23.93501	36.7807	10.2169	64.8
45	0.1317	6.5139	0	1	54.93089	23.93517	36.7437	61.96	54.93087	23.93516	37.2548	10.3486	71.3139
46	0.1389	7.0496	0	1	54.93094	23.93532	39.6698	62.47	54.93089	23.93532	37.7549	10.4875	78.3635
47	0.1401	7.2558	0	1	54.93103	23.93546	42.6701	66.21	54.9309	23.93549	38.2592	10.6276	85.6193
48	0.1357	7.3543	0	1	54.93105	23.93564	45.6333	67.88	54.9309	23.93566	38.7477	10.7633	92.9736
49	0.1092	7.0951	0	1	54.9311	23.93581	47.5408	68.02	54.93088	23.93583	39.1409	10.8725	100.0687
50	0.0368	6.9426	1	0	54.93115	23.93599	49.7262	67.33	54.93115	23.93599	49.7262	13.8128	67.33
51	0.0602	6.7246	1	0	54.9312	23.93621	49.8744	70.38	54.9312	23.93621	49.8744	13.854	70.38
52	0.1006	6.7795	1	0	54.93124	23.93642	49.078	71.18	54.93124	23.93642	49.078	13.6328	71.18
53	0.096	6.8146	1	0	54.93127	23.93663	48.615	73.03	54.93127	23.93663	48.615	13.5042	73.03
54	0.0931	6.877	1	0	54.93129	23.93685	49.8929	74.57	54.93129	23.93685	49.8929	13.8591	74.57
55	0.0934	7.0207	0	1	54.93131	23.93707	51.0411	75.99	54.9313	23.93706	50.2291	13.9525	81.5907
56	0.0896	7.2438	0	1	54.93134	23.9373	51.893	77.7	54.93131	23.93728	50.5517	14.0421	88.8345
57	0.0873	7.5759	0	1	54.93137	23.93752	52.5412	78.08	54.9313	23.9375	50.866	14.1294	96.4104
58	0.0918	7.6074	0	1	54.93138	23.93773	52.9857	80.76	54.93127	23.93772	51.1965	14.2212	104.0178
59	0.0673	7.4251	0	1	54.93139	23.93795	53.3932	82.37	54.93122	23.93793	51.4387	14.2885	111.4429
60	0.0597	7.1854	1	0	54.93142	23.93818	53.9488	84.34	54.93142	23.93818	53.9488	14.9858	84.34
61	0.0686	7.2014	1	0	54.93143	23.93843	53.8562	84.75	54.93143	23.93843	53.8562	14.9601	84.75
62	0.0696	7.3151	1	0	54.93143	23.93867	53.1894	88.16	54.93143	23.93867	53.1894	14.7748	88.16
63	0.0754	7.3196	1	0	54.93143	23.9389	53.2265	88.75	54.93143	23.9389	53.2265	14.7851	88.75
64	0.0799	6.9204	1	0	54.93143	23.93914	53.4117	89.77	54.93143	23.93914	53.4117	14.8366	89.77
65	0.0894	6.6771	0	1	54.93143	23.93937	53.208	90.04	54.93142	23.93937	53.7335	14.926	96.4471
66	0.0971	6.4447	0	1	54.93147	23.93962	52.9857	89.46	54.93139	23.9396	54.0831	15.0231	102.8918
67	0.1031	6.5952	0	1	54.93146	23.93985	52.8931	91.9	54.93134	23.93982	54.4543	15.1262	109.487
68	0.0857	6.4054	0	1	54.93145	23.94008	52.0782	92.72	54.93128	23.94004	54.7628	15.2119	115.8924
69	0.0732	6.0205	0	1	54.93146	23.94031	52.0412	93.45	54.93121	23.94024	55.0263	15.2851	121.9129
70	0.0176	5.7167	1	0	54.93144	23.94052	52.0042	92.89	54.93144	23.94052	52.0042	14.4456	92.89
71	-0.0458	5.5766	1	0	54.93142	23.94075	51.7264	92.66	54.93142	23.94075	51.7264	14.3684	92.66
72	-0.0533	5.9644	1	0	54.93141	23.94096	46.4296	92.43	54.93141	23.94096	46.4296	12.8971	92.43
73	-0.0369	6.4464	1	0	54.93141	23.94116	41.207	92.61	54.93141	23.94116	41.207	11.4464	92.61
74	0.0451	7.7298	1	0	54.9314	23.94131	36.54	92.08	54.9314	23.94131	36.54	10.15	92.08
75	0.0719	9.5067	0	1	54.9314	23.94145	33.336	96.38	54.93139	23.94147	36.7988	10.2219	101.5867
76	0.0522	11.3356	0	1	54.93139	23.94159	32.836	100.51	54.93135	23.94162	36.9868	10.2741	112.9223
77	-0.044	12.5211	0	1	54.93136	23.94172	30.7062	105.8	54.9313	23.94175	36.8284	10.2301	125.4434
78	-0.1236	11.643	0	1	54.93134	23.94184	27.1503	110.51	54.93123	23.94185	36.3834	10.1065	137.0864
79	-0.1195	9.9305	0	1	54.93131	23.94192	22.3722	118.85	54.93116	23.94194	35.9532	9.987	147.0169
80	-0.0539	7.6054	1	0	54.93128	23.94199	16.1865	125.57	54.93128	23.94199	16.1865	4.4963	125.57
81	-0.0395	6.3057	1	0	54.93127	23.94203	9.9267	126.42	54.93127	23.94203	9.9267	2.7574	126.42
82	0.0188	5.7204	1	0	54.93126	23.94205	5.7968	129.26	54.93126	23.94205	5.7968	1.6102	129.26
83	0.1756	5.6655	1	0	54.93125	23.94205	0.2778	129.26	54.93125	23.94205	0.2778	0.0772	129.26
84	0.2737	2.0325	1	0	54.93124	23.94206	0.4445	129.26	54.93124	23.94206	0.4445	0.1235	129.26
85	0.2902	1.937	0	1	54.93122	23.94209	10.9638	128.19	54.93124	23.94207	1.4892	0.4137	131.197
86	0.1323	1.9551	0	1	54.9312	23.94213	17.2606	120.38	54.93123	23.94208	1.9655	0.546	133.1521
87	0.2288	5.6936	0	1	54.93118	23.9422	21.4647	119.12	54.93122	23.94209	2.7892	0.7748	138.8457
88	0.2023	5.5449	0	1	54.93114	23.94229	24.9835	119.88	54.93122	23.94209	3.5175	0.9771	144.3906
89	0.1149	3.3236	0	1	54.9311	23.94238	29.2986	118.96	54.93121	23.9421	3.9311	1.092	147.7142
90	0.0813	-0.193	1	0	54.93106	23.9425	33.5212	117.14	54.93106	23.9425	33.5212	9.3114	117.14
91	0.0842	-3.5623	1	0	54.93102	23.94264	35.3547	110.51	54.93102	23.94264	35.3547	9.8207	110.51
92	0.0743	-5.7041	1	0	54.931	23.9428	37.04	100.16	54.931	23.9428	37.04	10.2889	100.16
93	0.0323	-6.4285	1	0	54.93099	23.94296	37.8919	88.91	54.93099	23.94296	37.8919	10.5255	88.91
94	0.0146	-7.3926	1	0	54.931	23.94313	38.7438	76.08	54.931	23.94313	38.7438	10.7622	76.08
95	0.0599	-7.2418	0	1	54.93106	23.9433	36.9289	63.42	54.93104	23.94329	38.9594	10.8221	68.8382
96	0.082	-5.406	0	1	54.93111	23.94339	36.2992	48.82	54.93108	23.94345	39.2546	10.9041	63.4322
97	0.0235	-3.972	0	1	54.93119	23.94352	36.3733	38.56	54.93114	23.94359	39.3392	10.9276	59.4602
98	-0.0249	-4.4828	0	1	54.93128	23.94363	36.8178	30.69	54.93119	23.94373	39.2496	10.9027	54.9774
99	0.0324	-6.7389	0	1	54.93136	23.94371	34.7065	18.28	54.93126	23.94386	39.3662	10.9351	48.2385
100	0.0837	-8.0322	1	0	54.93145	23.94374	33.5212	7.82	54.93145	23.94374	33.5212	9.3114	7.82
101	0.0968	-6.5157	1	0	54.93153	23.9437	33.4656	354.5	54.93153	23.9437	33.4656	9.296	354.5
102	0.0956	-4.3252	1	0	54.93162	23.94366	34.262	342.52	54.93162	23.94366	34.262	9.5172	342.52
103	0.079	-1.3475	1	0	54.9317	23.94359	36.0029	332.78	54.9317	23.94359	36.0029	10.0008	332.78
104	0.0649	1.1819	1	0	54.93178	23.94347	37.8364	325.15	54.93178	23.94347	37.8364	10.5101	325.15
105	0.1096	4.3081	0	1	54.93186	23.94334	37.2993	322.24	54.93186	23.94339	38.231	10.6197	329.4581
106	0.1291	7.7496	0	1	54.93194	23.94325	37.3734	321.85	54.93195	23.94333	38.6957	10.7488	337.2077
107	0.1235	10.0382	0	1	54.932	23.94315	37.9475	326.77	54.93204	23.94329	39.1403	10.8723	347.2459
108	0.1311	12.3852	0	1	54.93209	23.94307	38.0216	332.5	54.93214	23.94328	39.6123	11.0034	359.6311
109	0.157	13.4276	0	1	54.93219	23.94303	38.466	340.3	54.93223	23.94333	40.1775	11.1604	373.0587
110	0.153	13.2751	1	0	54.93227	23.94299	38.8179	349.78	54.93227	23.94299	38.8179	10.7828	349.78

111	0.1383	11.3878	1	0	54.93237	23.94297	40.5403	356.77	54.93237	23.94297	40.5403	11.2612	356.77
112	0.1131	8.3209	1	0	54.93248	23.94295	42.2071	359.77	54.93248	23.94295	42.2071	11.7242	359.77
113	0.0977	6.5928	1	0	54.93259	23.94296	43.3553	359.86	54.93259	23.94296	43.3553	12.0431	359.86
114	0.0929	6.369	1	0	54.93271	23.94296	43.2998	0.15	54.93271	23.94296	43.2998	12.0277	0.15
115	0.0599	6.2575	0	1	54.9328	23.94301	44.6147	0.54	54.93282	23.94298	43.5154	12.0876	6.4075
116	0.0556	6.128	0	1	54.93291	23.94302	44.485	1.2	54.93293	23.94303	43.7156	12.1432	12.5355
117	0.0606	5.8708	0	1	54.93303	23.943	43.6516	1.35	54.93303	23.94309	43.9338	12.2038	18.4063
118	0.0493	5.9886	0	1	54.93314	23.943	41.8367	1.52	54.93313	23.94316	44.1112	12.2531	24.3949
119	-0.0005	5.9184	0	1	54.93324	23.943	41.9293	1.89	54.93322	23.94326	44.1094	12.2526	30.3133
120	-0.1299	6.0221	1	0	54.93333	23.94301	39.7995	1.05	54.93333	23.94301	39.7995	11.0554	1.05
121	-0.1576	6.343	1	0	54.93342	23.94299	35.0954	0.81	54.93342	23.94299	35.0954	9.7487	0.81
122	-0.0946	7.7161	1	0	54.93349	23.94298	28.5393	0.94	54.93349	23.94298	28.5393	7.9276	0.94
123	-0.0786	9.0232	1	0	54.93355	23.94298	21.3906	3.18	54.93355	23.94298	21.3906	5.9418	3.18
124	0.1365	9.641	1	0	54.93359	23.94303	15.0012	7.03	54.93359	23.94303	15.0012	4.167	7.03
125	0.2878	10.1156	0	1	54.93361	23.94305	9.5008	12.91	54.93363	23.94305	16.0373	4.4548	17.1456
126	0.2468	10.6655	0	1	54.93363	23.94306	12.2047	18.93	54.93367	23.94308	16.9258	4.7016	27.8111
127	0.1689	10.4157	0	1	54.93366	23.94309	15.8716	26.45	54.9337	23.94313	17.5338	4.8705	38.2268
128	0.1394	6.9967	0	1	54.9337	23.94312	18.8348	28.04	54.93373	23.94319	18.0356	5.0099	45.2235
129	0.0817	0.7055	0	1	54.93374	23.94315	21.5758	25.19	54.93376	23.94324	18.3298	5.0916	45.929
130	0.0601	-5.6769	1	0	54.93379	23.94317	21.6128	13.12	54.93379	23.94317	21.6128	6.0036	13.12
131	0.0846	-9.4703	1	0	54.93384	23.94318	21.5573	359.71	54.93384	23.94318	21.5573	5.9881	359.71
132	0.1168	-7.3777	1	0	54.9339	23.94316	21.8906	344.77	54.9339	23.94316	21.8906	6.0807	344.77
133	0.0929	-0.2174	1	0	54.93395	23.94312	23.613	334.27	54.93395	23.94312	23.613	6.5592	334.27
134	0.1702	9.273	1	0	54.93401	23.94308	24.2982	334.44	54.93401	23.94308	24.2982	6.7495	334.44
135	0.2602	15.7484	0	1	54.93407	23.94304	24.1686	344.53	54.93406	23.94306	25.2349	7.0097	350.1884
136	0.3125	17.2631	0	1	54.93413	23.94303	26.2428	356.9	54.93413	23.94307	26.3599	7.3222	367.4515
137	0.3086	15.1395	0	1	54.93421	23.94304	30.4839	6.81	54.93419	23.94312	27.4709	7.6308	382.591
138	0.144	12.6748	0	1	54.9343	23.94307	35.5399	12.62	54.93425	23.94319	27.9893	7.7748	395.2658
139	0.1926	11.7261	0	1	54.93439	23.94313	39.4846	20.47	54.9343	23.94328	28.6826	7.9674	406.9919
140	0.2064	12.1037	1	0	54.93451	23.94322	41.2626	27.47	54.93451	23.94322	41.2626	11.4618	27.47
141	0.1847	12.7492	1	0	54.9346	23.94334	43.8554	34.69	54.9346	23.94334	43.8554	12.1821	34.69
142	0.1751	12.9344	1	0	54.9347	23.94345	47.5408	42.05	54.9347	23.94345	47.5408	13.2058	42.05
143	0.1432	13.1053	1	0	54.9348	23.94361	51.2448	48.16	54.9348	23.94361	51.2448	14.2347	48.16
144	0.115	13.016	1	0	54.93488	23.94382	53.9117	55.88	54.93488	23.94382	53.9117	14.9755	55.88
145	0.0994	13.1617	0	1	54.93495	23.94404	55.0785	62.44	54.93493	23.94404	54.2695	15.0749	69.0417
146	0.0813	12.9322	0	1	54.93499	23.94427	55.134	69.66	54.93495	23.94428	54.5622	15.1562	81.9739
147	0.1337	12.6605	0	1	54.93503	23.9445	55.0044	77.1	54.93494	23.94452	55.0435	15.2899	94.6344
148	0.191	11.749	0	1	54.93504	23.94472	53.9488	85.58	54.93491	23.94475	55.7311	15.4809	106.3834
149	0.2118	9.8532	0	1	54.93504	23.94501	55.2266	91.14	54.93484	23.94497	56.4936	15.6927	116.2366
150	0.1908	7.7486	1	0	54.93504	23.94527	58.6343	93.5	54.93504	23.94527	58.6343	16.2873	93.5
151	0.154	6.1882	1	0	54.93503	23.94554	62.005	93.4	54.93503	23.94554	62.005	17.2236	93.4
152	0.1106	5.4671	1	0	54.93502	23.94581	65.1534	94.43	54.93502	23.94581	65.1534	18.0982	94.43
153	0.0976	5.0575	1	0	54.93501	23.94612	66.209	92.53	54.93501	23.94612	66.209	18.3914	92.53
154	0.1729	4.9238	1	0	54.935	23.9464	65.7645	91.5	54.935	23.9464	65.7645	18.2679	91.5
155	0.2135	5.4659	0	1	54.93501	23.94669	67.7832	89.99	54.93498	23.94669	66.5331	18.4814	96.9659
156	0.1665	6.1345	0	1	54.935	23.94698	69.7834	89.83	54.93494	23.94697	67.1325	18.6479	103.1004
157	0.0874	6.5778	0	1	54.93499	23.9473	73.2281	91.97	54.93489	23.94725	67.4471	18.7353	109.6782
158	0.0839	6.5394	0	1	54.93497	23.94763	72.4317	92.67	54.93481	23.94752	67.7492	18.8192	116.2176
159	0.096	6.1424	0	1	54.93497	23.94795	72.3947	93.1	54.93472	23.94777	68.0948	18.9152	122.36
160	0.1006	5.7307	1	0	54.93497	23.94827	72.4688	93.11	54.93497	23.94827	72.4688	20.1302	93.11
161	0.1084	5.5903	1	0	54.93494	23.94858	72.1724	93.07	54.93494	23.94858	72.1724	20.0479	93.07
162	0.1203	5.6218	1	0	54.93492	23.9489	72.728	92.43	54.93492	23.9489	72.728	20.2022	92.43
163	0.1093	5.8212	1	0	54.93491	23.94921	73.4133	92.33	54.93491	23.94921	73.4133	20.3926	92.33
164	0.0933	5.8782	1	0	54.93491	23.94952	73.9133	92.41	54.93491	23.94952	73.9133	20.5315	92.41
165	0.0841	5.8259	0	1	54.93491	23.94984	73.8392	92.99	54.93488	23.94984	74.2161	20.6156	98.2359
166	0.0745	5.7078	0	1	54.93491	23.95016	73.4874	93.3	54.93484	23.95016	74.4843	20.6901	103.9437
167	0.1195	5.6278	0	1	54.93491	23.95048	73.9133	93.44	54.93478	23.95046	74.9145	20.8096	109.5715
168	0.1263	5.7808	0	1	54.93489	23.95079	73.154	92.19	54.9347	23.95076	75.3691	20.9359	115.3523
169	0.121	5.8051	0	1	54.93489	23.95112	74.1356	92.06	54.9346	23.95104	75.8047	21.0569	121.1574
170	0.1344	5.8574	1	0	54.93488	23.95144	74.6541	92.82	54.93488	23.95144	74.6541	20.7372	92.82
171	0.1183	5.7369	1	0	54.93487	23.95176	75.8764	92.28	54.93487	23.95176	75.8764	21.0768	92.28
172	0.1162	5.7394	1	0	54.93486	23.95209	76.9691	92.19	54.93486	23.95209	76.9691	21.3803	92.19
173	0.1104	5.7782	1	0	54.93486	23.95242	77.5062	92.46	54.93486	23.95242	77.5062	21.5295	92.46
174	0.1284	5.8274	1	0	54.93485	23.95276	78.0433	92.55	54.93485	23.95276	78.0433	21.6787	92.55
175	0.1184	5.8732	0	1	54.93485	23.95311	78.3396	92.92	54.93482	23.9531	78.4695	21.7971	98.4232
176	0.1359	5.8581	0	1	54.93483	23.95346	79.9694	92.56	54.93477	23.95343	78.9588	21.933	104.2813
177	0.1465	5.7621	0	1	54.93482	23.9538	81.062	92.77	54.9347	23.95375	79.4862	22.0795	110.0434
178	0.1367	5.6499	0	1	54.9348	23.95416	82.9511	92.34	54.93462	23.95407	79.9783	22.2162	115.6933
179	0.1424	5.6844	0	1	54.9348	23.95453	84.3771	92.9	54.93451	23.95437	80.4909	22.3586	121.3777
180	0.1278	5.7148	1	0	54.93479	23.9549	86.0624	92.61	54.93479	23.9549	86.0624	23.9062	92.61
181	0.103	5.8443	1	0	54.93478	23.95527	87.5255	92.31	54.93478	23.95527	87.5255	24.3126	92.31
182	0.0922	5.8701	1	0	54.93476	23.95564	88.0811	92.6	54.93476	23.95564	88.0811	24.467	92.6
183	0.0865	5.871	1	0	54.93475	23.95604	88.1182	93.05	54.93475	23.95604	88.1182	24.4773	93.05
184	0.0998	5.7964	1	0	54.93474	23.95642	88.1367	93.03	54.93474	23.95642	88.1367	24.4824	93.03
185	0.048	5.7628	0	1	54.93473	23.95681	88.4515	92.87	54.93471	23.9568	88.3095	24.5304	98.7928
186	0.0788	5.7379	0	1	54.93472	23.9572	88.6367	93.19	54.93466	23.95717	88.5932	24.6092	104.5307
187	0.0927	5.7731	0	1	54.9347	23.95757	88.4886	92.52	54.93458	23.95754	88.9269	24.7019	110.3038
188	0.0967	5.8001	0	1	54.93468	23.95794	86.5069	92.44	54.93448	23.95789	89.275	24.7986	116.1039
189	0.0994	5.8175	0	1	54.93468	23.95832	86.1365	93.14	54.93436	23.95822	89.6329	24.898	121.9214
190	0.0533	5.7939	1	0	54.93466	23.95869	86.5069	92.93	54.93466	23.95869	86.5069	24.0297	92.93
191	0.0577	5.7157	1	0	54.93465	23.95906	86.0624	93.19	54.93465	23.95906	86.0624	23.9062	93.19
192	0.0706	5.8	1	0	54.93465	23.95942	84.4327	92.86	54.93465	23.95942	84.4327	23.4535	92.86
193	0.0646	5.7798	1	0	54.93465	23.95979	83.1548	92.72	54.93465	23.95979	83.1548	23.0986	92.72
194	0.0657	5.8312	1	0	54.93463	23.96014	82.2288	92.45	54.93463	23.96014	82.2288	22.8413	92.45
195	0.084	5.7846	0	1	54.93462	23.9605	81.4324	92.54	54.9346	23.96049	82.5312	22.9253	98.2346
196	0.0546	5.7927	0	1	54.93462	23.96085	81.3398	92.7	54.93456	23.96084	82.7278	22.9799	104.0273

197	0.0458	5.806	0	1	54.93461	23.96121	80.6731	92.64	54.93448	23.96118	82.8926	23.0257	109.8333
198	0.0646	5.8396	0	1	54.9346	23.96154	80.3027	92.71	54.93439	23.9615	83.1252	23.0903	115.6729
199	0.0803	5.8231	0	1	54.93459	23.96187	77.8951	92.99	54.93428	23.96181	83.4143	23.1706	121.496
200	0.0798	5.75	1	0	54.93457	23.9622	76.8395	93.41	54.93457	23.9622	76.8395	21.3443	93.41
201	0.1024	5.694	1	0	54.93455	23.96253	75.7283	92.33	54.93455	23.96253	75.7283	21.0356	92.33
202	0.109	5.6965	1	0	54.93456	23.96286	75.7838	92	54.93456	23.96286	75.7838	21.0511	92
203	0.1069	5.7612	1	0	54.93454	23.96321	75.1542	92.28	54.93454	23.96321	75.1542	20.8762	92.28
204	0.0974	5.8293	1	0	54.93453	23.96355	74.8023	92.56	54.93453	23.96355	74.8023	20.7784	92.56
205	0.0431	5.7917	0	1	54.93452	23.96389	78.4322	92.65	54.9345	23.96387	74.9575	20.8215	98.3517
206	0.0105	5.7998	0	1	54.93451	23.96422	76.6172	92.69	54.93446	23.96419	74.9953	20.832	104.1515
207	-0.0734	5.7714	0	1	54.93449	23.96456	76.9136	92.84	54.93439	23.9645	74.731	20.7586	109.9229
208	-0.0797	5.7656	0	1	54.93447	23.96486	70.2093	91.82	54.93431	23.96479	74.4441	20.6789	115.6885
209	0.0274	5.7411	0	1	54.93448	23.96514	63.3384	91.69	54.93422	23.96507	74.5427	20.7063	121.4296
210	0.1199	5.7687	1	0	54.93449	23.9654	59.5788	92.7	54.93449	23.9654	59.5788	16.5497	92.7
211	0.1378	5.9262	1	0	54.93448	23.96565	60.4863	92.48	54.93448	23.96565	60.4863	16.8018	92.48
212	0.1395	5.9642	1	0	54.93447	23.96592	57.8935	92.19	54.93447	23.96592	57.8935	16.0815	92.19
213	0.1412	5.9084	1	0	54.93445	23.96619	62.8939	92.69	54.93445	23.96619	62.8939	17.4705	92.69
214	0.1948	5.7185	1	0	54.93444	23.96647	64.5607	92.45	54.93444	23.96647	64.5607	17.9335	92.45
215	0.2007	5.649	0	1	54.93445	23.96676	67.3387	92.55	54.93442	23.96675	65.2832	18.1342	98.099
216	0.1991	5.6876	0	1	54.93444	23.96705	71.1353	92.58	54.93438	23.96703	66	18.3333	103.7866
217	0.1113	5.7238	0	1	54.93443	23.96737	75.1356	92.27	54.93432	23.9673	66.4007	18.4446	109.5104
218	0.0597	5.7627	0	1	54.9344	23.96771	77.0432	93.37	54.93425	23.96757	66.6156	18.5043	115.2731
219	0.0604	5.8433	0	1	54.93438	23.96805	77.3951	93.41	54.93417	23.96782	66.833	18.5647	121.1164
220	0.0837	5.9868	1	0	54.93438	23.96837	78.9322	92.65	54.93438	23.96837	78.9322	21.9256	92.65
221	0.0985	6.0657	1	0	54.93439	23.9687	74.7838	93.04	54.93439	23.9687	74.7838	20.7733	93.04
222	0.1026	6.0317	1	0	54.93439	23.96902	74.7838	93.53	54.93439	23.96902	74.7838	20.7733	93.53
223	0.1216	5.8952	1	0	54.93438	23.96934	75.1171	93.46	54.93438	23.96934	75.1171	20.8659	93.46
224	0.1415	5.9264	1	0	54.93437	23.96967	74.8393	93.35	54.93437	23.96967	74.8393	20.7887	93.35
225	0.1365	6.0258	0	1	54.93436	23.97	77.1728	93.68	54.93434	23.96999	75.3307	20.9252	99.3758
226	0.1219	6.0638	0	1	54.93434	23.97034	78.71	94.1	54.93429	23.97031	75.7695	21.0471	105.4396
227	0.1269	6.0541	0	1	54.93433	23.97069	80.2657	94.19	54.93422	23.97062	76.2264	21.174	111.4937
228	0.099	6.2256	0	1	54.93431	23.97103	81.5806	94.17	54.93413	23.97091	76.5828	21.273	117.7193
229	0.1052	6.4939	0	1	54.93428	23.97139	82.1177	95.21	54.93402	23.97119	76.9615	21.3782	124.2132
230	0.1012	6.7339	1	0	54.93426	23.97174	82.2103	96.36	54.93426	23.97174	82.2103	22.8362	96.36
231	0.1064	6.6842	1	0	54.93424	23.9721	82.5807	97.39	54.93424	23.9721	82.5807	22.9391	97.39
232	0.1144	6.6119	1	0	54.9342	23.97245	82.6918	98.37	54.9342	23.97245	82.6918	22.9699	98.37
233	0.1023	6.4262	1	0	54.93417	23.97281	83.377	98.79	54.93417	23.97281	83.377	23.1603	98.79
234	0.1187	6.343	1	0	54.93414	23.97316	83.2659	99.38	54.93414	23.97316	83.2659	23.1294	99.38
235	0.1248	6.3861	0	1	54.9341	23.97351	84.4882	99.55	54.93408	23.97351	83.7152	23.2542	105.7661
236	0.1171	6.3066	0	1	54.93407	23.97387	84.4142	100.48	54.934	23.97385	84.1367	23.3713	112.0727
237	0.1051	6.3376	0	1	54.93403	23.97424	85.5994	100.85	54.9339	23.97417	84.5151	23.4764	118.4103
238	0.0956	6.1378	0	1	54.93398	23.97462	85.5994	101.71	54.93378	23.97448	84.8593	23.572	124.5481
239	0.1158	6.0775	0	1	54.93393	23.97498	85.5994	101.65	54.93364	23.97476	85.2761	23.6878	130.6256
240	0.1122	5.908	1	0	54.93388	23.97534	86.6736	101.8	54.93388	23.97534	86.6736	24.076	101.8
241	0.042	5.8117	1	0	54.93384	23.9757	85.8772	102.19	54.93384	23.9757	85.8772	23.8548	102.19
242	0.0576	5.7643	1	0	54.93379	23.97608	86.2662	102.1	54.93379	23.97608	86.2662	23.9628	102.1
243	0.0332	5.7664	1	0	54.93376	23.97643	81.7288	102.25	54.93376	23.97643	81.7288	22.7024	102.25
244	-0.0208	5.7458	1	0	54.93371	23.97677	79.3767	102.36	54.93371	23.97677	79.3767	22.0491	102.36
245	0.0484	5.7404	0	1	54.93367	23.97709	75.8764	102.29	54.93365	23.9771	79.2025	22.0007	108.1004
246	-0.0512	5.7005	0	1	54.93363	23.97741	70.7464	102.19	54.93357	23.97742	79.0181	21.9495	113.8009
247	0.029	5.6753	0	1	54.9336	23.9777	65.5238	101.71	54.93347	23.97771	79.1225	21.9785	119.4762
248	0.0794	5.7465	0	1	54.93356	23.97796	61.079	101.92	54.93335	23.978	79.4084	22.0579	125.2227
249	0.1093	5.8613	0	1	54.93352	23.97819	59.6529	101.74	54.93322	23.97826	79.8018	22.1672	131.084
250	0.1253	5.9421	1	0	54.93349	23.97844	59.5048	101.97	54.93349	23.97844	59.5048	16.5291	101.97
251	0.1476	5.87	1	0	54.93347	23.97869	59.5603	102.2	54.93347	23.97869	59.5603	16.5445	102.2
252	0.1579	5.7933	1	0	54.93344	23.97894	60.9123	102.05	54.93344	23.97894	60.9123	16.9201	102.05
253	0.1612	5.7681	1	0	54.9334	23.9792	62.5976	102.13	54.9334	23.9792	62.5976	17.3882	102.13
254	0.159	5.787	1	0	54.93337	23.97948	64.5422	101.78	54.93337	23.97948	64.5422	17.9284	101.78
255	0.1487	5.8293	0	1	54.93333	23.97976	66.2831	101.84	54.93333	23.97975	65.0775	18.0771	107.6093
256	0.1515	5.8309	0	1	54.93329	23.98006	68.0054	102.24	54.93326	23.98001	65.6229	18.2286	113.4402
257	0.1786	5.9268	0	1	54.93327	23.98034	69.6537	102.37	54.93318	23.98026	66.2659	18.4072	119.367
258	0.1766	6.2033	0	1	54.93322	23.98064	71.7094	102.34	54.93309	23.9805	66.9016	18.5838	125.5703
259	0.1766	6.4903	0	1	54.93318	23.98094	73.8763	103.24	54.93297	23.98072	67.5374	18.7604	132.0606
260	0.1541	6.4743	1	0	54.93313	23.98126	75.6912	103.98	54.93313	23.98126	75.6912	21.0253	103.98
261	0.0001	5.9231	1	0	54.93308	23.98158	78.3766	103.97	54.93308	23.98158	78.3766	21.7713	103.97
262	-0.065	5.438	1	0	54.93302	23.98191	77.8951	103.45	54.93302	23.98191	77.8951	21.6375	103.45
263	-0.0693	5.0774	1	0	54.93298	23.98224	78.8026	103.07	54.93298	23.98224	78.8026	21.8896	103.07
264	-0.0651	5.1658	1	0	54.93297	23.98252	67.6165	102.13	54.93297	23.98252	67.6165	18.7824	102.13
265	-0.0644	5.4845	0	1	54.93295	23.98279	60.7456	100.72	54.93292	23.98281	67.3847	18.718	107.6145
266	-0.0455	6.4012	0	1	54.93293	23.98304	55.3007	100.13	54.93285	23.98307	67.2209	18.6725	114.0157
267	0.0097	8.3228	0	1	54.9329	23.98328	51.2263	102.94	54.93276	23.98332	67.2558	18.6822	122.3385
268	0.0852	10.9636	0	1	54.93291	23.98347	46.5778	104.48	54.93265	23.98353	67.5625	18.7674	133.3021
269	0.117	13.2933	0	1	54.93284	23.98366	43.985	111.88	54.93251	23.9837	67.9837	18.8844	146.5954
270	0.082	15.0496	1	0	54.93279	23.98381	42.096	119.57	54.93279	23.98381	42.096	11.6933	119.57
271	0.0643	15.8466	1	0	54.93268	23.98395	42.0589	131.48	54.93268	23.98395	42.0589	11.683	131.48
272	0.0979	16.3547	1	0	54.93259	23.98406	41.0774	142.16	54.93259	23.98406	41.0774	11.4104	142.16
273	0.1553	16.5405	1	0	54.9325	23.98415	39.5958	149.48	54.9325	23.98415	39.5958	10.9988	149.48
274	0.1387	16.937	1	0	54.9324	23.9842	38.0771	160.44	54.9324	23.9842	38.0771	10.577	160.44
275	0.1514	17.1896	0	1	54.93228	23.98423	38.466	173.87	54.9323	23.98421	38.6221	10.7284	177.6296
276	0.1583	17.6185	0	1	54.93217	23.98418	41.0218	187.16	54.93221	23.98416	39.192	10.8867	195.2481
277	0.1396	17.6293	0	1	54.93204	23.98414	45.1147	199.48	54.93212	23.98407	39.6946	11.0263	212.8774
278	0.1179	17.59	0	1	54.93195	23.98407	48.0224	208.65	54.93206	23.98393	40.119	11.1442	230.4674
279	0.1349	17.031	0	1	54.93186	23.98391	46.9852	223.81	54.93202	23.98377	40.6047	11.2791	247.4984
280	0.1375	15.6358	1	0	54.93178	23.98371	47.8557	234.76	54.93178	23.98371	47.8557	13.2933	234.76
281	0.0882	14.4134	1	0	54.93172	23.98351	49.578	243.95	54.93172	23.98351	49.578	13.7717	243.95

282	0.1072	13.7271	1	0	54.93167	23.98329	50.6707	251.85	54.93167	23.98329	50.6707	14.0752	251.85
283	0.112	13.3101	1	0	54.93164	23.98305	51.5041	258.4	54.93164	23.98305	51.5041	14.3067	258.4
284	0.0515	12.6058	1	0	54.93162	23.98282	52.819	267.34	54.93162	23.98282	52.819	14.6719	267.34
285	0.0287	13.7042	0	1	54.93163	23.98257	52.8561	273.95	54.93164	23.98259	52.9223	14.7006	281.0442
286	0.0548	15.9529	0	1	54.93164	23.98233	53.3006	281.73	54.93171	23.98238	53.1196	14.7554	296.9971
287	0.132	18.4505	0	1	54.93169	23.98215	47.7446	294.3	54.9318	23.98222	53.5948	14.8874	315.4476
288	0.1145	19.1613	0	1	54.93176	23.98198	47.8742	310	54.93193	23.98212	54.007	15.0019	334.6089
289	0.085	18.1977	0	1	54.93184	23.98183	48.8743	320.25	54.93206	23.98209	54.313	15.0869	352.8066
290	0.0945	17.2577	1	0	54.93198	23.98171	46.9852	331.44	54.93198	23.98171	46.9852	13.0514	331.44
291	0.1213	16.9182	1	0	54.93209	23.98163	45.837	343.56	54.93209	23.98163	45.837	12.7325	343.56
292	0.0949	17.8591	1	0	54.93222	23.98164	45.874	353.19	54.93222	23.98164	45.874	12.7428	353.19
293	0.1137	18.0626	1	0	54.93233	23.98165	44.2258	6.25	54.93233	23.98165	44.2258	12.2849	6.25
294	0.1021	18.0819	1	0	54.93244	23.98172	43.7257	15.31	54.93244	23.98172	43.7257	12.146	15.31
295	0.1554	16.703	0	1	54.93254	23.98181	42.2071	30.18	54.93253	23.98182	44.2851	12.3014	32.013
296	0.149	13.9073	0	1	54.93262	23.98191	41.7626	41.63	54.93261	23.98196	44.8215	12.4504	45.9203
297	0.1602	10.5306	0	1	54.93269	23.98209	43.2442	47.94	54.93267	23.98213	45.3983	12.6106	56.4509
298	0.1748	7.0496	0	1	54.93275	23.98226	44.8369	50.98	54.93273	23.9823	46.0275	12.7854	63.5005
299	0.1967	5.8963	0	1	54.93283	23.98242	47.5594	52.25	54.93277	23.98249	46.7357	12.9821	69.3968
300	0.1629	5.4457	1	0	54.93291	23.98258	50.6337	51.78	54.93291	23.98258	50.6337	14.0649	51.78
301	0.0517	5.4879	1	0	54.93299	23.98278	54.0043	49.16	54.93299	23.98278	54.0043	15.0012	49.16
302	0.0452	5.8384	1	0	54.93307	23.98294	55.4674	51.7	54.93307	23.98294	55.4674	15.4076	51.7
303	0.0707	6.4106	1	0	54.9332	23.9831	55.8378	48.58	54.9332	23.9831	55.8378	15.5105	48.58
304	0.1037	6.7574	1	0	54.93329	23.98331	56.949	52.26	54.93329	23.98331	56.949	15.8192	52.26
305	0.1139	6.4307	0	1	54.93336	23.98353	57.4676	50.14	54.93336	23.98352	57.359	15.9331	58.6907
306	0.1108	5.8887	0	1	54.93344	23.9837	52.282	52.34	54.93343	23.98375	57.7579	16.0439	64.5794
307	0.1068	5.5635	0	1	54.9335	23.98386	52.8376	52.98	54.93348	23.98398	58.1424	16.1507	70.1429
308	0.1365	5.6252	0	1	54.93358	23.98405	53.245	51.68	54.93351	23.98423	58.6338	16.2872	75.7681
309	0.1466	6.0129	0	1	54.93367	23.98421	52.7264	52.58	54.93353	23.98449	59.1616	16.4338	81.781
310	0.1493	6.1842	1	0	54.93375	23.98441	55.3192	51.86	54.93375	23.98441	55.3192	15.3664	51.86
311	0.1052	6.1334	1	0	54.93383	23.98459	57.0046	52.61	54.93383	23.98459	57.0046	15.8346	52.61
312	0.0733	5.6199	1	0	54.93392	23.9848	58.338	53.2	54.93392	23.9848	58.338	16.205	53.2
313	0.094	5.5087	1	0	54.934	23.98499	57.4676	52.66	54.934	23.98499	57.4676	15.9632	52.66
314	0.0922	5.6518	1	0	54.93408	23.98517	57.5046	52.24	54.93408	23.98517	57.5046	15.9735	52.24
315	0.0987	6.0084	0	1	54.93418	23.98538	57.8194	52.88	54.93416	23.98539	57.8599	16.0722	58.2484
316	0.1107	6.1567	0	1	54.93427	23.98557	57.7268	52.17	54.93422	23.98561	58.2584	16.1829	64.4051
317	0.1182	6.0327	0	1	54.93437	23.98578	58.3936	53.67	54.93427	23.98586	58.684	16.3011	70.4378
318	0.1364	5.6368	0	1	54.93446	23.98597	58.0417	52.29	54.9343	23.9861	59.175	16.4375	76.0746
319	0.1412	5.4023	0	1	54.93456	23.98618	58.338	51.37	54.93432	23.98636	59.6833	16.5787	81.4769
320	0.1748	5.4022	1	0	54.93466	23.98638	58.6343	51.91	54.93466	23.98638	58.6343	16.2873	51.91
321	0.1617	5.6708	1	0	54.93476	23.9866	59.0047	52.47	54.93476	23.9866	59.0047	16.3902	52.47
322	0.0874	5.8658	1	0	54.93486	23.98682	66.0423	51.51	54.93486	23.98682	66.0423	18.3451	51.51
323	0.0972	5.9137	1	0	54.93497	23.98705	67.7091	52.15	54.93497	23.98705	67.7091	18.8081	52.15
324	0.1195	5.8838	1	0	54.93507	23.98728	66.7831	52.47	54.93507	23.98728	66.7831	18.5509	52.47
325	0.1038	5.8714	0	1	54.93518	23.98751	67.635	52.17	54.93516	23.98753	67.1568	18.6547	58.3414
326	0.1096	5.8144	0	1	54.93528	23.98774	67.9869	52.76	54.93523	23.9878	67.5513	18.7643	64.1558
327	0.1378	5.7893	0	1	54.93539	23.98798	68.4314	52.05	54.93529	23.98808	68.0474	18.9021	69.9451
328	0.1452	5.7713	0	1	54.93549	23.98821	68.524	51.86	54.93533	23.98836	68.5701	19.0473	75.7164
329	0.147	5.7442	0	1	54.9356	23.98845	71.6909	51.85	54.93536	23.98866	69.0993	19.1943	81.4606
330	0.1151	5.7415	1	0	54.93572	23.98869	73.8022	52.13	54.93572	23.98869	73.8022	20.5006	52.13
331	0.1068	5.7571	1	0	54.93584	23.98896	73.4133	53.34	54.93584	23.98896	73.4133	20.3926	53.34
332	0.0885	5.7296	1	0	54.93595	23.98922	74.08	53.06	54.93595	23.98922	74.08	20.5778	53.06
333	0.0968	5.6282	1	0	54.93605	23.98949	75.7653	52.42	54.93605	23.98949	75.7653	21.0459	52.42
334	0.1146	5.609	1	0	54.93616	23.98976	75.9135	52.9	54.93616	23.98976	75.9135	21.0871	52.9
335	0.1193	5.7803	0	1	54.93628	23.99	75.4875	51.78	54.93626	23.99004	76.343	21.2064	58.6803
336	0.097	5.9108	0	1	54.9364	23.99025	76.3024	51.78	54.93634	23.99035	76.6922	21.3034	64.5911
337	0.0992	5.9832	0	1	54.93652	23.99051	76.3024	52.77	54.93641	23.99066	77.0493	21.4026	70.5743
338	0.1061	5.8285	0	1	54.93663	23.99076	75.006	52.15	54.93645	23.99099	77.4313	21.5087	76.4028
339	0.1019	5.761	0	1	54.93673	23.99102	75.4505	53.04	54.93648	23.99132	77.7981	21.6106	82.1638
340	0.1096	5.7666	1	0	54.93685	23.99129	75.5246	51.89	54.93685	23.99129	75.5246	20.9791	51.89
341	0.1197	5.8467	1	0	54.93697	23.99155	77.5062	51.59	54.93697	23.99155	77.5062	21.5295	51.59
342	0.1286	5.8906	1	0	54.93709	23.9918	78.0062	50.44	54.93709	23.9918	78.0062	21.6684	50.44
343	0.1302	5.8022	1	0	54.93722	23.99207	78.8582	51.85	54.93722	23.99207	78.8582	21.9051	51.85
344	0.0979	5.6883	1	0	54.93735	23.99234	80.2657	52.84	54.93735	23.99234	80.2657	22.296	52.84
345	0.0944	5.6668	0	1	54.93748	23.99262	81.1917	51.94	54.93746	23.99264	80.6055	22.3904	58.5068
346	0.0927	5.7235	0	1	54.9376	23.9929	81.2102	52.32	54.93755	23.99296	80.9393	22.4831	64.2303
347	0.0941	5.7712	0	1	54.93771	23.99319	80.1175	51.33	54.93761	23.99329	81.278	22.5772	70.0015
348	0.1001	5.7873	0	1	54.93783	23.99345	81.2472	51.23	54.93766	23.99364	81.6384	22.6773	75.7888
349	0.0997	5.7498	0	1	54.93795	23.99371	79.5249	52.27	54.9377	23.99399	81.9973	22.777	81.5386
350	0.1032	5.7309	1	0	54.93806	23.99398	79.5434	52.22	54.93806	23.99398	79.5434	22.0954	52.22
351	0.1207	5.7778	1	0	54.93819	23.99426	79.5619	51.89	54.93819	23.99426	79.5619	22.1005	51.89
352	0.1193	5.8117	1	0	54.93831	23.99453	79.4878	51.67	54.93831	23.99453	79.4878	22.0799	51.67
353	0.0974	5.8831	1	0	54.93843	23.99482	79.3582	52.52	54.93843	23.99482	79.3582	22.0439	52.52
354	0.1151	5.8614	1	0	54.93856	23.99511	79.21	52	54.93856	23.99511	79.21	22.0028	52
355	0.1117	5.8609	0	1	54.93869	23.99537	79.4508	51.01	54.93866	23.9954	79.6121	22.1145	57.8609
356	0.1122	5.7686	0	1	54.93882	23.99563	79.5249	52.02	54.93875	23.99571	80.016	22.2267	63.6295
357	0.1006	5.7019	0	1	54.93895	23.9959	81.3584	52.69	54.93882	23.99604	80.3782	22.3273	69.3314
358	0.0818	5.709	0	1	54.93908	23.99618	82.2103	53.02	54.93887	23.99638	80.6727	22.4091	75.0404
359	0.0957	5.7807	0	1	54.93921	23.99647	81.7843	53.08	54.93891	23.99673	81.0172	22.5048	80.8211
360	0.0901	5.7582	1	0	54.93933	23.99675	82.0992	52.69	54.93933	23.99675	82.0992	22.8053	52.69
361	0.0957	5.7251	1	0	54.93945	23.99704	80.4509	53.53	54.93945	23.99704	80.4509	22.3475	53.53
362	0.0918	5.7526	1	0	54.93958	23.9973	81.6362	51.52	54.93958	23.9973	81.6362	22.6767	51.52
363	0.0973	5.8389	1	0	54.93971	23.99759	81.2843	51.97	54.93971	23.99759	81.2843	22.579	51.97
364	0.1141	5.8741	1	0	54.93983	23.99786	81.5806	52.41	54.93983	23.99786	81.5806	22.6613	52.41
365	0.1094	5.7762	0	1	54.93996	23.99814	81.2472	52.41	54.93994	23.99816	81.9744	22.7707	58.1862
366	0.1115	5.7359	0	1	54.94009	23.99841	82.7844	51.83	54.94003	23.99848	82.3758	22.8822	63.9221
367	0.1103	5.7543	0	1	54.94021	23.9987	82.451	52.02	54.9401	23.99882	82.7729	22.9925	69.6764
368	0.0749	5.8242	0	1	54.94035	23.99897	83.4882	51.78	54.94015	23.99918	83.0426	23.0674	75.5006

369	0.0882	5.8014	0	1	54.94047	23.99928	83.8586	52.57	54.94019	23.99953	83.3601	23.1556	81.302
370	0.0555	5.797	1	0	54.94061	23.99955	83.7845	52.17	54.94061	23.99955	83.7845	23.2735	52.17
371	0.0794	5.7167	1	0	54.94074	23.99982	82.5251	51.49	54.94074	23.99982	82.5251	22.9236	51.49
372	0.0761	5.6696	1	0	54.94086	24.0001	82.5807	51.8	54.94086	24.0001	82.5807	22.9391	51.8
373	0.0874	5.7049	1	0	54.94097	24.00036	82.2103	50.62	54.94097	24.00036	82.2103	22.8362	50.62
374	0.1031	5.9179	1	0	54.9411	24.00065	80.136	50.86	54.9411	24.00065	80.136	22.26	50.86
375	0.0977	5.9777	0	1	54.94121	24.00092	80.0064	52.41	54.94121	24.00095	80.4877	22.3577	56.8377
376	0.1008	5.8554	0	1	54.94133	24.0012	79.8953	51.59	54.9413	24.00126	80.8506	22.4585	62.6931
377	0.0913	5.5576	0	1	54.94146	24.00146	80.0249	52.31	54.94138	24.00159	81.1793	22.5498	68.2507
378	0.0971	5.6378	0	1	54.94159	24.00175	80.0434	51.9	54.94143	24.00193	81.5288	22.6469	73.8885
379	0.0892	5.7909	0	1	54.94172	24.00201	79.5619	51.98	54.94147	24.00228	81.85	22.7361	79.6794
380	0.0693	5.9245	1	0	54.94184	24.00229	80.0434	51.96	54.94184	24.00229	80.0434	22.2343	51.96
381	0.045	5.8925	1	0	54.94197	24.00254	80.0064	51.99	54.94197	24.00254	80.0064	22.224	51.99
382	0.046	5.8156	1	0	54.9421	24.00282	78.4878	52.62	54.9421	24.00282	78.4878	21.8022	52.62
383	0.0552	6.2312	1	0	54.94221	24.00311	78.9878	51.55	54.94221	24.00311	78.9878	21.9411	51.55
384	0.0575	6.5274	1	0	54.94233	24.00336	74.0244	51.89	54.94233	24.00336	74.0244	20.5623	51.89
385	0.0147	6.334	0	1	54.94243	24.00362	73.4318	53.52	54.94243	24.00364	74.0773	20.577	58.224
386	-0.0157	5.7776	0	1	54.94253	24.00388	71.8391	54.04	54.94251	24.00393	74.0208	20.5613	64.0016
387	-0.0429	5.1332	0	1	54.94264	24.00411	68.6722	53.64	54.94258	24.00423	73.8664	20.5184	69.1348
388	-0.0669	5.1129	0	1	54.94273	24.00434	64.3755	53.24	54.94263	24.00454	73.6255	20.4515	74.2477
389	-0.0848	5.3548	0	1	54.94283	24.00453	59.4862	51.55	54.94266	24.00485	73.3202	20.3667	79.6025
390	-0.0747	5.6274	1	0	54.94291	24.00469	53.1894	51.9	54.94291	24.00469	53.1894	14.7748	51.9
391	0.0018	5.8408	1	0	54.94298	24.00488	48.2631	51.92	54.94298	24.00488	48.2631	13.4064	51.92
392	-0.0041	6.3782	1	0	54.94304	24.00504	43.1886	52.93	54.94304	24.00504	43.1886	11.9968	52.93
393	-0.0072	8.8076	1	0	54.94309	24.00515	39.9662	51.85	54.94309	24.00515	39.9662	11.1017	51.85
394	0.0657	11.9951	1	0	54.94313	24.00529	34.7065	58.61	54.94313	24.00529	34.7065	9.6407	58.61
395	0.1006	14.7823	0	1	54.94316	24.00542	32.0396	65.22	54.94316	24.00544	35.0687	9.7413	73.3923
396	0.1128	15.2478	0	1	54.94318	24.00555	31.0766	76.26	54.94316	24.00559	35.4747	9.8541	88.6401
397	0.1139	15.1776	0	1	54.94319	24.00568	30.4284	84.56	54.94314	24.00574	35.8848	9.968	103.8177
398	0.1189	15.43	0	1	54.94318	24.00581	31.1136	94.93	54.9431	24.00588	36.3128	10.0869	119.2477
399	0.1737	16.1763	0	1	54.94316	24.00595	29.7431	103.66	54.94304	24.00599	36.9381	10.2606	135.424
400	0.1961	15.9526	1	0	54.94313	24.00607	29.3172	111.27	54.94313	24.00607	29.3172	8.1437	111.27
401	0.1836	13.9687	1	0	54.94309	24.0062	32.3359	118.62	54.94309	24.0062	32.3359	8.9822	118.62
402	0.161	10.8116	1	0	54.94304	24.00632	35.2806	126.39	54.94304	24.00632	35.2806	9.8002	126.39
403	0.1281	7.9361	1	0	54.94297	24.00644	38.003	133.58	54.94297	24.00644	38.003	10.5564	133.58
404	0.0799	6.372	1	0	54.94289	24.00654	39.9106	133.53	54.94289	24.00654	39.9106	11.0863	133.53
405	0.0402	5.8224	0	1	54.94282	24.00667	41.5404	137.27	54.94282	24.00665	40.0553	11.1265	139.3524
406	-0.0082	5.6678	0	1	54.94273	24.00679	39.3735	135.88	54.94274	24.00675	40.0258	11.1183	145.0202
407	-0.0754	6.115	0	1	54.94264	24.0069	36.9474	138.4	54.94265	24.00683	39.7544	11.0429	151.1352
408	-0.0988	8.2814	0	1	54.94257	24.00698	31.7248	137.82	54.94255	24.00689	39.3987	10.9441	159.4166
409	-0.0179	12.1322	0	1	54.94252	24.00707	28.0948	140.34	54.94246	24.00692	39.3342	10.9262	171.5488
410	0.0554	17.6763	1	0	54.94247	24.00713	23.2426	146.39	54.94247	24.00713	23.2426	6.4563	146.39
411	0.1418	22.8855	1	0	54.94244	24.00717	20.0016	158.73	54.94244	24.00717	20.0016	5.556	158.73
412	0.1758	24.9871	1	0	54.94239	24.00717	18.2607	176.56	54.94239	24.00717	18.2607	5.0724	176.56
413	0.1944	23.5302	1	0	54.94235	24.00715	19.8349	198.27	54.94235	24.00715	19.8349	5.5097	198.27
414	0.1938	18.5868	1	0	54.94231	24.00709	23.613	215.96	54.94231	24.00709	23.613	6.5592	215.96
415	0.1461	12.4651	0	1	54.94227	24.00699	27.1318	227.83	54.94227	24.00701	24.139	6.7053	228.4251
416	0.0729	7.8723	0	1	54.94224	24.00687	31.2988	232.62	54.94223	24.00692	24.4014	6.7782	236.2974
417	0.0182	5.3528	0	1	54.9422	24.00676	32.1137	232.65	54.94221	24.00682	24.4669	6.7964	241.6502
418	-0.0656	5.3742	0	1	54.94215	24.00665	30.521	231.35	54.94218	24.00673	24.2308	6.7308	247.0244
419	-0.0532	5.5317	0	1	54.9421	24.00655	26.428	230.98	54.94217	24.00663	24.0392	6.6776	252.5561
420	-0.025	8.992	1	0	54.94207	24.00646	20.5942	231.21	54.94207	24.00646	20.5942	5.7206	231.21
421	0.0456	16.165	1	0	54.94204	24.0064	16.8532	239.18	54.94204	24.0064	16.8532	4.6814	239.18
422	0.1102	24.4464	1	0	54.94202	24.00634	13.5011	252.9	54.94202	24.00634	13.5011	3.7503	252.9
423	0.2016	29.9827	1	0	54.94202	24.00628	11.2416	274.45	54.94202	24.00628	11.2416	3.1227	274.45
424	0.2316	25.2554	1	0	54.94203	24.00623	12.1121	300.73	54.94203	24.00623	12.1121	3.3645	300.73
425	0.2027	17.9315	0	1	54.94207	24.00618	17.0014	317.28	54.94206	24.00619	12.8418	3.5672	318.6615
426	0.1828	9.5335	0	1	54.94211	24.00611	21.6314	321.75	54.94208	24.00616	13.4999	3.75	328.195
427	0.1551	6.7664	0	1	54.94217	24.00604	23.8908	321.42	54.94211	24.00614	14.0583	3.9051	334.9614
428	0.097	5.7518	0	1	54.94221	24.00597	26.428	323.28	54.94215	24.00611	14.4075	4.0021	340.7132
429	0.0927	5.6039	0	1	54.94228	24.00589	29.3727	325.49	54.94218	24.0061	14.7412	4.0948	346.3171
430	0.0908	5.7986	1	0	54.94232	24.00582	27.6318	325.25	54.94232	24.00582	27.6318	7.6755	325.25
431	0.0886	5.8329	1	0	54.94236	24.00575	27.6504	322.65	54.94236	24.00575	27.6504	7.6807	322.65
432	0.0898	5.6125	1	0	54.94241	24.00568	26.7984	323.81	54.94241	24.00568	26.7984	7.444	323.81
433	0.0972	5.3453	1	0	54.94247	24.00561	26.7429	324.08	54.94247	24.00561	26.7429	7.4286	324.08
434	0.0629	5.3512	1	0	54.94252	24.00552	25.965	324.28	54.94252	24.00552	25.965	7.2125	324.28
435	0.0335	5.4095	0	1	54.94258	24.00545	26.0762	325.02	54.94258	24.00546	26.0856	7.246	329.6895
436	-0.0008	5.4544	0	1	54.94264	24.00538	25.5206	323.04	54.94264	24.00541	26.0827	7.2452	335.1439
437	-0.0303	5.1783	0	1	54.94269	24.00531	24.0575	323.01	54.9427	24.00538	25.9736	7.2149	340.3222
438	-0.0458	1.2788	0	1	54.94274	24.00525	20.3164	321.35	54.94276	24.00534	25.8088	7.1691	341.601
439	0.0012	-5.8151	0	1	54.94277	24.0052	16.6124	318.82	54.94282	24.00529	25.8131	7.1703	335.7859
440	-0.0358	-13.1535	1	0	54.94279	24.00516	13.6307	312.91	54.94279	24.00516	13.6307	3.7863	312.91
441	-0.1008	-15.5252	1	0	54.9428	24.00511	11.612	284.06	54.9428	24.00511	11.612	3.2256	284.06
442	-0.0669	-12.3506	1	0	54.94279	24.00506	12.7047	254.97	54.94279	24.00506	12.7047	3.5291	254.97
443	0.0007	-8.5526	1	0	54.94277	24.00504	13.6678	234.42	54.94277	24.00504	13.6678	3.7966	234.42
444	0.0136	-9.0311	1	0	54.94275	24.005	12.4454	221.54	54.94275	24.005	12.4454	3.4571	221.54
445	-0.0183	-11.6644	0	1	54.94272	24.00497	11.2231	203.19	54.94271	24.00497	12.5113	3.4754	209.8756
446	0.0681	-14.1403	0	1	54.94269	24.00496	11.112	180.09	54.94268	24.00496	12.7564	3.5435	195.7353
447	0.0578	10.5244	0	1	54.94267	24.00496	10.1304	159.73	54.94265	24.00495	12.9645	3.6013	185.2109
448	0.1186	-2.6001	0	1	54.94264	24.00498	8.9081	146.4	54.94261	24.00495	13.3915	3.7199	182.6108
449	0.109	8.3277	0	1	54.94262	24.00499	6.9265	154.07	54.94258	24.00493	13.7839	3.8289	190.9385
450	0.0814	18.5975	1	0	54.94261	24.005	7.5932	176.79	54.94261	24.005	7.5932	2.1092	176.79

451	0.1131	24.6149	1	0	54.94259	24.005	6.8154	195.76	54.94259	24.005	6.8154	1.8932	195.76
452	0.1633	24.5845	1	0	54.94259	24.00499	6.945	219.99	54.94259	24.00499	6.945	1.9292	219.99
453	0.1391	19.6443	1	0	54.94257	24.00497	8.76	227.34	54.94257	24.00497	8.76	2.4333	227.34
454	0.1142	14.4408	1	0	54.94255	24.00494	11.1676	228.57	54.94255	24.00494	11.1676	3.1021	228.57
455	0.1051	10.0419	0	1	54.94254	24.0049	11.7232	238.32	54.94254	24.0049	11.546	3.2072	238.6119
456	0.0939	7.9725	0	1	54.94252	24.00485	13.2418	239.35	54.94253	24.00485	11.884	3.3011	246.5844
457	0.089	5.8751	0	1	54.9425	24.0048	14.3345	238.29	54.94252	24.0048	12.2044	3.3901	252.4595
458	0.0849	4.9401	0	1	54.94249	24.00475	14.2419	236.14	54.94252	24.00475	12.51	3.475	257.3996
459	0.083	4.938	0	1	54.94247	24.0047	13.8715	235.18	54.94251	24.00469	12.8088	3.558	262.3376
460	0.0795	5.1249	1	0	54.94245	24.00465	12.6492	239.63	54.94245	24.00465	12.6492	3.5137	239.63
461	-0.0175	5.0994	1	0	54.94243	24.0046	12.2417	240.21	54.94243	24.0046	12.2417	3.4005	240.21
462	0.0271	1.7876	1	0	54.94241	24.00456	10.4638	234.86	54.94241	24.00456	10.4638	2.9066	234.86
463	0.0324	-3.0339	1	0	54.9424	24.00453	8.7414	226.96	54.9424	24.00453	8.7414	2.4282	226.96
464	-0.0075	-6.4253	1	0	54.94239	24.00451	6.2227	216.06	54.94239	24.00451	6.2227	1.7285	216.06
465	0.0371	-3.6526	0	1	54.94238	24.00449	4.9819	216.06	54.94237	24.00449	6.3563	1.7656	212.4074
466	0.0527	0.6061	0	1	54.94237	24.00449	0	216.06	54.94236	24.00447	6.546	1.8183	213.0135
467	0.0938	2.2152	0	1	54.94237	24.00448	0	216.06	54.94234	24.00446	6.8837	1.9121	215.2287
468	0.1241	0.1923	0	1	54.94238	24.00449	0	216.06	54.94233	24.00444	7.3304	2.0362	215.421
469	0.1128	-1.5251	0	1	54.94238	24.00449	0	216.06	54.94231	24.00442	7.7365	2.149	213.8959
470	0.1039	-1.4154	1	0	54.94238	24.0045	0.1482	216.06	54.94238	24.0045	0.1482	0.0412	216.06
471	0.1217	-0.7127	1	0	54.94238	24.0045	0.1667	216.06	54.94238	24.0045	0.1667	0.0463	216.06
472	0.1371	0.6637	1	0	54.94239	24.0045	0.1667	216.06	54.94239	24.0045	0.1667	0.0463	216.06
473	0.1065	2.9363	1	0	54.94239	24.0045	0.2037	216.06	54.94239	24.0045	0.2037	0.0566	216.06
474	0.0833	4.5126	1	0	54.94239	24.0045	0.1852	216.06	54.94239	24.0045	0.1852	0.0514	216.06
475	0.0876	3.8523	0	1	54.9424	24.0045	0	216.06	54.94239	24.0045	0.5006	0.139	219.9123
476	0.0901	2.2445	0	1	54.9424	24.0045	2.0557	216.06	54.94239	24.0045	0.8249	0.2291	222.1568
477	0.1345	1.3804	0	1	54.9424	24.0045	2.4076	216.06	54.94239	24.0045	1.3091	0.3636	223.5372
478	0.0774	2.9488	0	1	54.94241	24.0045	2.2409	216.06	54.94239	24.00449	1.5878	0.441	226.486
479	0.1123	4.9238	0	1	54.94241	24.00449	2.315	216.06	54.94239	24.00449	1.992	0.5533	231.4098
480	0.1339	6.6206	1	0	54.94241	24.00449	2.9817	216.06	54.94241	24.00449	2.9817	0.8282	216.06
481	0.1157	6.6688	1	0	54.94242	24.00448	2.8521	216.06	54.94242	24.00448	2.8521	0.7922	216.06
482	0.1016	6.3267	1	0	54.94242	24.00448	2.2224	216.06	54.94242	24.00448	2.2224	0.6173	216.06
483	0.1334	5.798	1	0	54.94243	24.00447	1.889	216.06	54.94243	24.00447	1.889	0.5247	216.06
484	0.0752	5.795	1	0	54.94243	24.00447	0	216.06	54.94243	24.00447	0	0	216.06
485	0.1666	5.7856	0	1	54.94243	24.00447	0	216.06	54.94243	24.00447	0.5998	0.1666	221.8456
486	0.0798	5.7834	0	1	54.94243	24.00447	0	216.06	54.94243	24.00447	0.887	0.2464	227.629
487	0.1057	5.7731	0	1	54.94243	24.00447	0	216.06	54.94243	24.00446	1.2676	0.3521	233.4021
488	0.1042	5.7649	0	1	54.94243	24.00447	0	216.06	54.94243	24.00445	1.6427	0.4563	239.167
489	0.1036	5.7642	0	1	54.94243	24.00447	0	216.06	54.94243	24.00444	2.0156	0.5599	244.9312
490	0.1041	5.7692	1	0	54.94243	24.00447	1.6112	216.06	54.94243	24.00447	1.6112	0.4476	216.06
491	0.1035	5.7708	1	0	54.94243	24.00447	0	216.06	54.94243	24.00447	0	0	216.06
492	0.1026	5.775	1	0	54.94243	24.00447	0	216.06	54.94243	24.00447	0	0	216.06
493	0.103	5.7735	1	0	54.94243	24.00447	0	216.06	54.94243	24.00447	0	0	216.06
494	0.103	5.7816	1	0	54.94243	24.00447	0	216.06	54.94243	24.00447	0	0	216.06
495	0.1029	5.7789	0	1	54.94243	24.00447	0	216.06	54.94243	24.00447	0.3704	0.1029	221.8389
496	0.1033	5.7803	0	1	54.94243	24.00447	0	216.06	54.94243	24.00447	0.7423	0.2062	227.6192
497	0.103	5.7692	0	1	54.94243	24.00447	0	216.06	54.94243	24.00446	1.1131	0.3092	233.3884
498	0.103	5.7679	0	1	54.94243	24.00447	0	216.06	54.94243	24.00446	1.4839	0.4122	239.1563
499	0.103	5.7702	0	1	54.94243	24.00447	0	216.06	54.94243	24.00445	1.8547	0.5152	244.9265

2 priedas. system_defines.h kodas

```
/*
 * system_defines.h
 *
 *  Created on: 4 Dec 2021
 *      Author: tomku
 */

#ifndef SRC_SYSTEM_DEFINES_H_
#define SRC_SYSTEM_DEFINES_H

#include "math.h"
#include "stdint.h"
#include "usart.h"
#include "stdlib.h"
#include "string.h"

//#define GNSS_TEST 1

#define ACC_SAMPLE_PERIOD 0.001

#define UART_TX_TIMEOUT 10
#define UART4_RX_SIZE 1000
#define UART4_TX_SIZE 19
#define SET_NMEA_BAUDRATE_115200 "$PMTK251,115200"

#define FILTER_SIZE 100
#define FILTER_SIZE_CALIBRATION 300
#define MAX_FILTER_SIZE FILTER_SIZE_CALIBRATION

#define LOGGING_BUFFER_SIZE 200

#define BUFFSIZE 1418

#define PI 3.14159

#define TRUE 1u
#define FALSE 0u

#define UNIT 1

#ifdef UNIT
    #define UNIT_SAMPLES 500
#endif


extern UART_HandleTypeDef huart4;
extern UART_HandleTypeDef huart7;
extern DMA_HandleTypeDef hdma_uart4_rx;
extern I2C_HandleTypeDef hi2c3;
extern TIM_HandleTypeDef htim3;

typedef struct
```

```
{
    uint8_t uart4_rx_interrupt :1;
    uint8_t acc_ready :1;
    uint8_t acc_calibrated :1;
    uint8_t gnss_initiated :1;
    uint8_t tim3_interrupt :1;
    uint8_t tim4_interrupt :1;
    uint8_t gnss_active :1;
    uint8_t ins_begin :1;
//  uint8_t gnss_lock :1;
}flag_t;

typedef struct
{
    float velocity_m_s;
    float velocity_km_h;
    float acceleration_2d;
    float acceleration_3d;
    float velocity_initial;
}ins_t;

typedef struct {
    float lon;     //gnss Latitude and longitude
    float lat;
    float lon_rad;
    float lat_rad;
    float lon_last;
    float lat_last;
    float lon_last_rad;
    float lat_last_rad;
    float bearing;
    uint8_t lon_area;
    uint8_t lat_area;
    uint8_t time_h;   //Time
    uint8_t time_m;
    uint8_t time_s;
    uint8_t status;   //1:Successful positioning 0:Positioning failed
    double knots;
    double kmh;
    double m_s;
    uint16_t no_packet_counter;
    uint8_t last_timestamp;
}gnss_t;

typedef struct
{
    float latitude;
    float longitude;
    float bearing;
    float velocity_m_s;
    float velocity_kmh;
    float distance;
}joint_result_t;

typedef struct
{
    int16_t raw;
    float value;
    float offset;
    float value_filtered;
}acc_t;

typedef struct
{
    int16_t raw;
    float value;
    float offset;
    float value_filtered;
}gyro_t;

typedef struct
{
    float value;
    float moving_sum;
    uint16_t window_index;
    float buf[MAX_FILTER_SIZE];
    uint16_t buf_size;
    uint16_t filter_size;
}filter_t;

typedef struct
{
    uint8_t acc_read;
    uint8_t gnss_parse;
    uint8_t test_ins;
    uint8_t uart4_error;
//  uint8_t gnss;
    uint8_t pps;
    uint8_t tim3;
    uint8_t tim4;
}counter_t;

typedef struct
{
    uint8_t uart4_rx[UART4_RX_SIZE];
    uint8_t uart4_tx[UART4_TX_SIZE];

    uint8_t uart7_tx[LOGGING_BUFFER_SIZE];

    uint8_t i2c3_rx[10];
    uint8_t i2c3_tx[10];
}buffer_t;

typedef struct
{
    joint_result_t unit[500];

    buffer_t buffer;

    counter_t counter;

    flag_t flag;

    ins_t ins;
    gnss_t gnss;
    joint_result_t joint_result;

    acc_t acc_x;
    acc_t acc_y;
    acc_t acc_z;

    gyro_t gyro_x;
    gyro_t gyro_y;
    gyro_t gyro_z;

    filter_t filter_acc_x;
    filter_t filter_acc_y;
    filter_t filter_acc_z;

    filter_t filter_gyro_x;
    filter_t filter_gyro_y;
    filter_t filter_gyro_z;
}g_t;

g_t g; //global system structure

#endif /* SRC_SYSTEM_DEFINES_H_ */
```

3 priedas. main.c kodas

```
/* USER CODE BEGIN Header */
/**
  ******************************************************************************
  * @file           : main.c
  * @brief          : Main program body
  ******************************************************************************
  * @attention
  *
  * <h2><center>&copy; Copyright (c) 2021 STMicroelectronics.
  * All rights reserved.</center></h2>
  *
  * This software component is licensed by ST under BSD 3-Clause license,
  * the "License"; You may not use this file except in compliance with the
  * License. You may obtain a copy of the License at:
  *                        opensource.org/licenses/BSD-3-Clause
  *
  ******************************************************************************
```

```c
  */
/* USER CODE END Header */
/* Includes ------------------------------------------------------------------*/
#include "main.h"
#include "dma.h"
#include "i2c.h"
#include "tim.h"
#include "usart.h"
#include "gpio.h"

/* Private includes ----------------------------------------------------------*/
/* USER CODE BEGIN Includes */
#include "system_defines.h"
#include "imu.h"
#include "gnss.h"
#include "ins.h"
#include "moving_average_filter.h"
#include "logging.h"
#include "unit.h"
#include "stdio.h"

/* USER CODE END Includes */

/* Private typedef -----------------------------------------------------------*/
/* USER CODE BEGIN PTD */

/* USER CODE END PTD */

/* Private define ------------------------------------------------------------*/
/* USER CODE BEGIN PD */

void acc_init();
void acc_handle();

void gnss_init();
void gnss_handle();

/* USER CODE END PD */

/* Private macro -------------------------------------------------------------*/
/* USER CODE BEGIN PM */

/* USER CODE END PM */

/* Private variables ---------------------------------------------------------*/

/* USER CODE BEGIN PV */



/* USER CODE END PV */

/* Private function prototypes -----------------------------------------------*/
void SystemClock_Config(void);
/* USER CODE BEGIN PFP */

/* USER CODE END PFP */

/* Private user code ---------------------------------------------------------*/
/* USER CODE BEGIN 0 */



/* USER CODE END 0 */

/**
  * @brief  The application entry point.
  * @retval int
  */
int main(void)
{
  /* USER CODE BEGIN 1 */

  /* USER CODE END 1 */

  /* MCU Configuration--------------------------------------------------------*/

  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();

  /* USER CODE BEGIN Init */

  /* USER CODE END Init */

  /* Configure the system clock */
  SystemClock_Config();

  /* USER CODE BEGIN SysInit */

  /* USER CODE END SysInit */

  /* Initialize all configured peripherals */
  MX_GPIO_Init();
  MX_I2C3_Init();
  MX_DMA_Init();
  MX_UART4_Init();
  MX_TIM3_Init();
  MX_UART7_Init();
  MX_TIM4_Init();
  /* USER CODE BEGIN 2 */

#ifdef UNIT
  unit_test();
#endif

  HAL_TIM_Base_Start_IT(&htim3);//period 10ms
  HAL_TIM_Base_Start_IT(&htim4);//period 1s

  acc_init();
  gnss_init();

  /* USER CODE END 2 */

  /* Infinite loop */
  /* USER CODE BEGIN WHILE */
  while (1)
  {


      gnss_handle();
      acc_handle();

    /* USER CODE END WHILE */

    /* USER CODE BEGIN 3 */
  }
  /* USER CODE END 3 */
}

/**
  * @brief System Clock Configuration
  * @retval None
  */
void SystemClock_Config(void)
{
  RCC_OscInitTypeDef RCC_OscInitStruct = {0};
  RCC_ClkInitTypeDef RCC_ClkInitStruct = {0};
  RCC_PeriphCLKInitTypeDef PeriphClkInitStruct = {0};

  /** Configure the main internal regulator output voltage
  */
  __HAL_RCC_PWR_CLK_ENABLE();
  __HAL_PWR_VOLTAGESCALING_CONFIG(PWR_REGULATOR_VOLTAGE_SCALE1);
  /** Initializes the RCC Oscillators according to the specified parameters
  * in the RCC_OscInitTypeDef structure.
  */
  RCC_OscInitStruct.OscillatorType = RCC_OSCILLATORTYPE_HSE;
  RCC_OscInitStruct.HSEState = RCC_HSE_ON;
  RCC_OscInitStruct.PLL.PLLState = RCC_PLL_ON;
  RCC_OscInitStruct.PLL.PLLSource = RCC_PLLSOURCE_HSE;
  RCC_OscInitStruct.PLL.PLLM = 8;
  RCC_OscInitStruct.PLL.PLLN = 216;
  RCC_OscInitStruct.PLL.PLLP = RCC_PLLP_DIV2;
  RCC_OscInitStruct.PLL.PLLQ = 2;
  if (HAL_RCC_OscConfig(&RCC_OscInitStruct) != HAL_OK)
  {
    Error_Handler();
  }
  /** Activate the Over-Drive mode
  */
```

```
  if (HAL_PWREx_EnableOverDrive() != HAL_OK)
  {
    Error_Handler();
  }
  /** Initializes the CPU, AHB and APB buses clocks
  */
  RCC_ClkInitStruct.ClockType = RCC_CLOCKTYPE_HCLK|RCC_CLOCKTYPE_SYSCLK
                              |RCC_CLOCKTYPE_PCLK1|RCC_CLOCKTYPE_PCLK2;
  RCC_ClkInitStruct.SYSCLKSource = RCC_SYSCLKSOURCE_PLLCLK;
  RCC_ClkInitStruct.AHBCLKDivider = RCC_SYSCLK_DIV1;
  RCC_ClkInitStruct.APB1CLKDivider = RCC_HCLK_DIV4;
  RCC_ClkInitStruct.APB2CLKDivider = RCC_HCLK_DIV2;

  if (HAL_RCC_ClockConfig(&RCC_ClkInitStruct, FLASH_LATENCY_7) != HAL_OK)
  {
    Error_Handler();
  }
  PeriphClkInitStruct.PeriphClockSelection = RCC_PERIPHCLK_UART4|RCC_PERIPHCLK_UART7
                              |RCC_PERIPHCLK_I2C3;
  PeriphClkInitStruct.Uart4ClockSelection = RCC_UART4CLKSOURCE_PCLK1;
  PeriphClkInitStruct.Uart7ClockSelection = RCC_UART7CLKSOURCE_PCLK1;
  PeriphClkInitStruct.I2c3ClockSelection = RCC_I2C3CLKSOURCE_PCLK1;
  if (HAL_RCCEx_PeriphCLKConfig(&PeriphClkInitStruct) != HAL_OK)
  {
    Error_Handler();
  }
}

/* USER CODE BEGIN 4 */

//void HAL_UART_RxCpltCallback(UART_HandleTypeDef *huart)
//{
//  /* Prevent unused argument(s) compilation warning */
//  UNUSED(huart);
//  if (huart->Instance == UART4)
//  {
//    HAL_UART_AbortReceive(&huart4);
//    g_flag.uart4_rx = 1;
//  }
//}

void HAL_UART_ErrorCallback(UART_HandleTypeDef *huart)
{
    if (huart->Instance == UART4)
    {
        g.counter.uart4_error++;
        HAL_UART_AbortReceive(&huart4);
        HAL_UART_Receive_DMA(&huart4, (uint8_t *)g.buffer.uart4_rx, UART4_RX_SIZE);
    }
}

void HAL_GPIO_EXTI_Callback(uint16_t GPIO_Pin)
{
  HAL_UART_AbortReceive(&huart4);
  g.counter.pps++;
  g.flag.uart4_rx_interrupt = TRUE;
//  if(0x0400 != GPIO_Pin)
//  {
//    uint8_t breakpoint = 0;
//  }
}

void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
{
  if (htim->Instance == TIM3)
  {
      g.flag.tim3_interrupt = TRUE;
      g.counter.tim3++;
  }
  else if (htim->Instance == TIM4)
  {
      g.flag.tim4_interrupt = TRUE;
      g.counter.tim4++;
  }
}

void acc_init()
{
    //wait for 5s before calibration
    while(g.counter.tim4 < 4)
    {
        uint8_t i = 0;
    }

    imu_init_acc();

    moving_average_filter_reset(&g.filter_acc_x, FILTER_SIZE_CALIBRATION);
    moving_average_filter_reset(&g.filter_acc_y, FILTER_SIZE_CALIBRATION);
    moving_average_filter_reset(&g.filter_acc_z, FILTER_SIZE_CALIBRATION);

    moving_average_filter_reset(&g.filter_gyro_x, FILTER_SIZE_CALIBRATION);
    moving_average_filter_reset(&g.filter_gyro_y, FILTER_SIZE_CALIBRATION);
    moving_average_filter_reset(&g.filter_gyro_z, FILTER_SIZE_CALIBRATION);
}

void acc_handle()
{

  if(TRUE == g.flag.tim3_interrupt)
  {
      imu_read_acc(&g.acc_x, &g.acc_y, &g.acc_z);
      imu_read_gyro(&g.gyro_x, &g.gyro_y, &g.gyro_z);

      moving_average_filter_update_float(&g.filter_acc_x, g.acc_x.value);
      moving_average_filter_update_float(&g.filter_acc_y, g.acc_y.value);
      moving_average_filter_update_float(&g.filter_acc_z, g.acc_z.value);

      moving_average_filter_update_float(&g.filter_gyro_x, g.gyro_x.value);
      moving_average_filter_update_float(&g.filter_gyro_y, g.gyro_y.value);
      moving_average_filter_update_float(&g.filter_gyro_z, g.gyro_z.value);

      g.acc_x.value_filtered = g.filter_acc_x.value;
      g.acc_y.value_filtered = g.filter_acc_y.value;
      g.acc_z.value_filtered = g.filter_acc_z.value;

      g.gyro_x.value_filtered = g.filter_gyro_x.value;
      g.gyro_y.value_filtered = g.filter_gyro_y.value;
      g.gyro_z.value_filtered = g.filter_gyro_z.value;

      if(g.filter_acc_x.buf_size >= FILTER_SIZE_CALIBRATION || g.flag.acc_calibrated == 1)
      {
          if(g.flag.acc_calibrated == 0)
          {
              imu_calibrate_acc(&g.acc_x, &g.acc_y, &g.acc_z);
              imu_calibrate_gyro(&g.gyro_x, &g.gyro_y, &g.gyro_z);

              moving_average_filter_reset(&g.filter_acc_x, FILTER_SIZE);
              moving_average_filter_reset(&g.filter_acc_y, FILTER_SIZE);
              moving_average_filter_reset(&g.filter_acc_z, FILTER_SIZE);

              imu_read_acc(&g.acc_x, &g.acc_y, &g.acc_z);
              imu_read_gyro(&g.gyro_x, &g.gyro_y, &g.gyro_z);

              g.flag.acc_calibrated = 1;

              HAL_GPIO_TogglePin(GPIOA, LD2_Pin);
              HAL_Delay(250);
              HAL_GPIO_TogglePin(GPIOA, LD2_Pin);
              HAL_Delay(250);
              HAL_GPIO_TogglePin(GPIOA, LD2_Pin);
              HAL_Delay(250);
              HAL_GPIO_TogglePin(GPIOA, LD2_Pin);
          }

          g.ins.acceleration_2d = ins_calculate_2d_acceleration(g.acc_x.value_filtered, g.acc_y.value_filtered);
          g.ins.acceleration_3d = ins_calculate_3d_acceleration(g.acc_x.value_filtered, g.acc_y.value_filtered, g.acc_z.value_filtered);

          g.ins.velocity_m_s = ins_calculate_velocity(&g.ins.velocity_initial, g.ins.acceleration_3d, ACC_SAMPLE_PERIOD);
          g.ins.velocity_km_h = g.ins.velocity_m_s * 3600 / 1000;

          g.counter.acc_read++;
      }

      g.flag.tim3_interrupt = FALSE;
  }
}

void gnss_init()
{
        //Pradetas daryti baudrate pakeitimas i 115200
```

```
//  strncpy(uart4_tx_buffer, SET_NMEA_BAUDRATE_115200, 15);
//  strcpy(uart4_tx_buffer[15], "*");
//
//  L76X_Send_Command((uint8_t *)uart4_tx_buffer);
//
    HAL_UART_Receive_DMA(&huart4, (uint8_t *)g.buffer.uart4_rx, UART4_RX_SIZE);

    #ifdef GNSS_TEST
      L76X_parse_GNRMC(buff_t, BUFFSIZE);
    #endif
}

void gnss_handle()
{
  if(TRUE == g.flag.uart4_rx_interrupt)
  {
//        GNRMC gnss_result;
//        gnss_result = L76X_Gat_GNRMC();

    #ifndef GNSS_TEST
      gnss_parse_GNRMC(g.buffer.uart4_rx, UART4_RX_SIZE);
    #endif

//    g.flag.gnss_initiated = TRUE;
      g.counter.gnss_parse++;

      if(g.counter.gnss_parse % 10 == 0 && g.counter.test_ins == 0)
      {
          g.counter.test_ins = 5;
      }

      if(g.counter.test_ins > 0)
      {
          g.flag.gnss_active = FALSE;
          g.counter.test_ins--;
      }
      else
      {
          g.flag.gnss_active = TRUE;
      }

      joint_result_calculate_bearing(&g.joint_result, &g.gnss, &g.acc_x, &g.gyro_z);

      g.gnss.no_packet_counter = 0;

      if(TRUE == g.flag.acc_calibrated && TRUE == g.flag.gnss_initiated && g.gnss.lat < 90)
      {
          logging();
      }

      g.gnss.last_timestamp = 0;

      HAL_GPIO_TogglePin(GPIOA, LD3_Pin);

      g.flag.uart4_rx_interrupt = FALSE;
      HAL_UART_Receive_DMA(&huart4, (uint8_t *)g.buffer.uart4_rx, UART4_RX_SIZE);
  }
  //Detection if there was lost gnss packets
//  else if(g.flag.tim4_interrupt > 1)
//  {
//    if(g.gnss.last_timestamp > 0)
//    {
//        g.gnss.no_packet_counter++;
//        g.flag.gnss_active = FALSE;
//    }
//    else
//    {
//        g.gnss.last_timestamp++;
//    }
//
//    g.flag.tim4_interrupt = 0;
//  }
}

/* USER CODE END 4 */

/**
  * @brief  This function is executed in case of error occurrence.
  * @retval None
  */
void Error_Handler(void)
{
  /* USER CODE BEGIN Error_Handler_Debug */
  /* User can add his own implementation to report the HAL error return state */
  __disable_irq();
  while (1)
  {
  }
  /* USER CODE END Error_Handler_Debug */
}

#ifdef  USE_FULL_ASSERT
/**
  * @brief  Reports the name of the source file and the source line number
  *         where the assert_param error has occurred.
  * @param  file: pointer to the source file name
  * @param  line: assert_param error line source number
  * @retval None
  */
void assert_failed(uint8_t *file, uint32_t line)
{
  /* USER CODE BEGIN 6 */
  /* User can add his own implementation to report the file name and line number,
     ex: printf("Wrong parameters value: file %s on line %d\r\n", file, line) */
  /* USER CODE END 6 */
}
#endif /* USE_FULL_ASSERT */

/************************ (C) COPYRIGHT STMicroelectronics *****END OF FILE****/
```

4 priedas. imu.c kodas

```
/*
 * mpu6050.c
 *
 *  Created on: 1 Dec 2021
 *      Author: tomku
 */

#include "imu.h"

//ACC SETTINGS
#define ACC_ADDR 0xD0
#define ACC_CHECK 0x75
#define SMPLRT_DIV_REG 0x19
#define GYRO_CONFIG_REG 0x1B
#define ACCEL_CONFIG_REG 0x1C
#define ACCEL_XOUT_H_REG 0x3B
#define TEMP_OUT_H_REG 0x41
#define GYRO_XOUT_H_REG 0x43
#define PWR_MGMT_1_REG 0x6B

void imu_init_acc()
{
    //check acc
    while(g.buffer.i2c3_rx[0]!=0x68)
    {
        HAL_I2C_Mem_Read(&hi2c3, ACC_ADDR,ACC_CHECK,1, (uint8_t *)g.buffer.i2c3_rx, 1, 1000);
        if(g.buffer.i2c3_rx[0]==0x68)
            break;
    }

    // power management register 0X6B we should write all 0's to wake the sensor up
    g.buffer.i2c3_tx[0] = 0x00;
    HAL_I2C_Mem_Write(&hi2c3, ACC_ADDR, PWR_MGMT_1_REG, 1, (uint8_t *)g.buffer.i2c3_tx, 1, 1000);

    // Set DATA RATE of 1KHz by writing SMPLRT_DIV register
    g.buffer.i2c3_tx[0] = 0x07;
    HAL_I2C_Mem_Write(&hi2c3, ACC_ADDR, SMPLRT_DIV_REG, 1, (uint8_t *)g.buffer.i2c3_tx, 1, 1000);

    // Set accelerometer configuration in ACCEL_CONFIG Register
    // XA_ST=0,YA_ST=0,ZA_ST=0, FS_SEL=0 -> ± 2g
    g.buffer.i2c3_tx[0] = 0x00;
    HAL_I2C_Mem_Write(&hi2c3, ACC_ADDR, ACCEL_CONFIG_REG, 1, (uint8_t *)g.buffer.i2c3_tx, 1, 1000);

    // Set Gyroscopic configuration in GYRO_CONFIG_Register
    // XG_ST=0,YG_ST=0,ZG_ST=0, FS_SEL=0 -> ± 250 °/s
```

```
    g.buffer.i2c3_tx[0] = 0x00;
    HAL_I2C_Mem_Write(&hi2c3, ACC_ADDR, GYRO_CONFIG_REG, 1, (uint8_t *)g.buffer.i2c3_tx, 1, 1000);
}

void imu_calibrate_acc(acc_t *p_x, acc_t *p_y, acc_t *p_z)
{
    p_x->offset = g.filter_acc_x.value;
    p_y->offset = g.filter_acc_y.value;
    p_z->offset = g.filter_acc_z.value;
}

void imu_calibrate_gyro(gyro_t *p_x, gyro_t *p_y, gyro_t *p_z)
{
    p_x->offset = g.filter_gyro_x.value;
    p_y->offset = g.filter_gyro_y.value;
    p_z->offset = g.filter_gyro_z.value;
}

void imu_read_acc(acc_t *p_x, acc_t *p_y, acc_t *p_z)
{
    HAL_I2C_Mem_Read (&hi2c3, ACC_ADDR, ACCEL_XOUT_H_REG, 1, (uint8_t *)g.buffer.i2c3_rx, 6, 1000);

    p_x->raw = (int16_t)(g.buffer.i2c3_rx[0] << 8 | g.buffer.i2c3_rx[1]);
    p_y->raw = (int16_t)(g.buffer.i2c3_rx[2] << 8 | g.buffer.i2c3_rx[3]);
    p_z->raw = (int16_t)(g.buffer.i2c3_rx[4] << 8 | g.buffer.i2c3_rx[5]);

    p_x->value = (float)p_x->raw/16384 - p_x->offset;
    p_y->value = (float)p_y->raw/16384 - p_y->offset;
    p_z->value = (float)p_z->raw/16384 - p_z->offset;
}

void imu_read_gyro(gyro_t *p_x, gyro_t *p_y, gyro_t *p_z)
{
    HAL_I2C_Mem_Read (&hi2c3, ACC_ADDR, GYRO_XOUT_H_REG, 1, (uint8_t *)g.buffer.i2c3_rx, 6, 1000);

    p_x->raw = (int16_t)(g.buffer.i2c3_rx[0] << 8 | g.buffer.i2c3_rx[1]);
    p_y->raw = (int16_t)(g.buffer.i2c3_rx[2] << 8 | g.buffer.i2c3_rx[3]);
    p_z->raw = (int16_t)(g.buffer.i2c3_rx[4] << 8 | g.buffer.i2c3_rx[5]);

    p_x->value = (float)p_x->raw/131 - p_x->offset;
    p_y->value = (float)p_y->raw/131 - p_y->offset;
    p_z->value = (float)p_z->raw/131 - p_z->offset;
}
```

5 priedas. gnss.c kodas

```
/*
 * 176x.c
 *
 *  Created on: 1 Dec 2021
 *      Author: tomku
 */

#include "gnss.h"

//$GNRMC,185823.40,A,4808.7402374,N,01133.9324760,E,0.00,112.64,130117,3.00,E,A*14

void gnss_parse_GNRMC(uint8_t buf[], uint16_t buf_size)
{
      uint16_t i = 0;
    uint32_t time = 0;
    uint32_t latitude = 0;
    uint32_t longitude = 0;

    while(i < buf_size - 71)
    {
        if(buf[i] == '$' && buf[i+1] == 'G' && buf[i+2] == 'N' &&
                    buf[i+3] == 'R' && buf[i+4] == 'M' && buf[i+5] == 'C')
        {

                    time = (uint32_t)strtod(&buf[i+7],0);

                    g.gnss.time_h = time/10000;
                    g.gnss.time_m = time/100%100;
                    g.gnss.time_s = time%100;

                    if(g.gnss.time_h >= 24)
                    {
                          g.gnss.time_h = g.gnss.time_h - 24;
                    }

                    //A indicates that it has been positioned
                    //V indicates that there is no positioning.
                    if(buf[i+18] == 'A')
                    {
                          g.gnss.status = TRUE;
                          g.flag.gnss_initiated = TRUE;
                    }
                    else
                    {
                          g.gnss.status = FALSE;
                    }

                    latitude = (buf[i+20]-'0') * 10 + (buf[i+21]-'0');

                    float fractional_part_lat = strtod(&buf[i+22],0);

                    g.gnss.lat = (float)latitude + fractional_part_lat / 60;

                    g.gnss.lat_area = buf[i+30];

                    longitude = (buf[i+33]-'0') * 10 + (buf[i+34]-'0');

                    float fractional_part_lon = strtod(&buf[i+35],0);

                    g.gnss.lon = (float)longitude + fractional_part_lon / 60;

                    g.gnss.lon_area = buf[i+43];

                    g.gnss.knots = strtod(&buf[i+45],0);
                    g.gnss.kmh = 1.852 * g.gnss.knots;
                    g.gnss.m_s = g.gnss.kmh / 3.6;

                    if(g.gnss.knots >= 10)
                    {
                          //speed was 5 digits
                          g.gnss.bearing = strtod(&buf[i+51],0);
                    }
                    else
                    {
                          //speed was 4 digits
                          g.gnss.bearing = strtod(&buf[i+50],0);
                    }

        }
        i++;
    }
}

void gnss_coordinate_deg_to_rad()
{
      g.gnss.lat_rad = g.gnss.lat * PI / 180;
      g.gnss.lon_rad = g.gnss.lon * PI / 180;
      g.gnss.lat_last_rad = g.gnss.lat_last * PI / 180;
      g.gnss.lon_last_rad = g.gnss.lon_last * PI / 180;
}

void gnss_calculate_bearing(float lat_a, float lon_a, float lat_b, float lon_b)
{
      float lon_delta = lon_a - lon_b;
      if(lon_delta != 0.0f)
      {
            float x = cos(lat_b) * sin(lon_delta);
            float y = cos(lat_a) * sin(lat_b) - sin(lat_a) * cos(lat_b) * cos(lon_delta);

            g.gnss.bearing = atan2(x, y) * 180 / PI; //convert to degrees

            if(g.gnss.bearing < 0)
            {
                  g.gnss.bearing = g.gnss.bearing + 360;
            }
      }
}
```

6 priedas. moving_average_filter.c kodas

```c
/*
 * moving_average_filter.c
 *
 *  Created on: 3 Dec 2021
 *      Author: tomku
 */

#include "moving_average_filter.h"
//#include <string.h>


void moving_average_filter_update_float(filter_t *s, float input)
{
    s->moving_sum = s->moving_sum - s->buf[s->window_index] + input;
    s->buf[s->window_index] = input;
    s->window_index++;
    if (s->window_index > s->filter_size - 1)
    {
        s->window_index = 0;
        s->buf_size = s->filter_size;
    }
    if (s->buf_size == s->filter_size)
    {
        s->value = s->moving_sum / s->filter_size;
    }
}

void moving_average_filter_reset(filter_t *s, uint16_t filter_size)
{
    s->moving_sum = 0;
    s->value = 0;
    s->filter_size = filter_size;
    memset(&(s->buf), 0x00, filter_size);
//  memset(&(s->buf), 0x00, MAX_FILTER_SIZE-1);
}
```

7 priedas. logging.c kodas

```c
/*
 * logging.c
 *
 *  Created on: 5 Dec 2021
 *      Author: tomku
 */

#include "logging.h"
#include "system_defines.h"
//#include "stdint.h"
#include "stdio.h"
#include "usart.h"
#include <string.h>

void logging()
{

    uint8_t size = snprintf(g.buffer.uart7_tx, LOGGING_BUFFER_SIZE, "%d;%.4f;%.4f;%d;%d;",
            g.counter.tim4,g.acc_x.value_filtered, g.gyro_z.value_filtered, g.flag.gnss_active, g.flag.ins_begin);

    //check snprintf error
    if(size > 0)
    {
        HAL_UART_Transmit(&huart7, (uint8_t *)g.buffer.uart7_tx, size, UART_TX_TIMEOUT);
    }

    size = snprintf(g.buffer.uart7_tx, LOGGING_BUFFER_SIZE,
                "%.8f;%.8f;%.4f;%.4f;%.4f;",
                g.gnss.lat, g.gnss.lon, g.gnss.kmh, g.gnss.m_s, g.gnss.bearing);

    if(size > 0)
    {
        HAL_UART_Transmit(&huart7, (uint8_t *)g.buffer.uart7_tx, size, UART_TX_TIMEOUT);
    }

    size = snprintf(g.buffer.uart7_tx, LOGGING_BUFFER_SIZE,
                "%.8f;%.8f;%.4f;%.4f;%.4f;\n\r",
                g.joint_result.latitude, g.joint_result.longitude, g.joint_result.velocity_kmh, g.joint_result.velocity_m_s, g.joint_result.bearing);

    if(size > 0)
    {
        HAL_UART_Transmit(&huart7, (uint8_t *)g.buffer.uart7_tx, size, UART_TX_TIMEOUT);
    }

}
```

8 priedas. ins.c kodas

```c
/*
 * inertial navigation.c
 *
 *  Created on: 3 Dec 2021
 *      Author: tomku
 */

#include "ins.h"

void joint_result_calculate_bearing(joint_result_t *p_joint, gnss_t *p_gnss, acc_t *p_acc, gyro_t *p_gyro)
{
    if(FALSE == g.flag.gnss_active)
    {
        //execute only once when gnss lost
        if(FALSE == g.flag.ins_begin)
        {

//          p_joint->latitude = p_gnss->lat;
//          p_joint->longitude = p_gnss->lon;
//          p_joint->velocity_m_s = p_gnss->kmh * 5 / 18;
//          p_joint->bearing = p_gnss->bearing;

            g.flag.ins_begin = TRUE;

        }

        p_joint->bearing = p_joint->bearing + p_gyro->value_filtered;
        p_joint->velocity_m_s = p_joint->velocity_m_s + p_acc->value_filtered * 1;
        p_joint->velocity_kmh = p_joint->velocity_m_s * 3.6;
        p_joint->distance = p_joint->velocity_m_s * 1;

        joint_result_calculate_lat_lon(p_joint);
    }
    else
    {
        p_joint->bearing = p_gnss->bearing;
        p_joint->latitude = p_gnss->lat;
        p_joint->longitude = p_gnss->lon;
        p_joint->velocity_m_s = p_gnss->kmh * 5 / 18;
        p_joint->velocity_kmh = p_joint->velocity_m_s * 3.6;
        p_joint->distance = p_joint->velocity_m_s * 1;

        g.flag.ins_begin = FALSE;
    }
}

float ins_calculate_2d_acceleration(float x, float y)
{
    float result = pow(x,2) + pow(y,2);

    return result;
}

float ins_calculate_3d_acceleration(float x, float y, float z)
{
    float temp = pow(x,2) + pow(y,2);
    float result = pow(temp,2) + pow(z,2);

    return result;
}
```

```
float ins_calculate_velocity(float *velocity_0, float acceleration, float delta_t)
{
    float estimate =  *velocity_0 + acceleration*delta_t;
    if(estimate > 150)
    {
        estimate = 150;
    }
    if(estimate < 0)
    {
        estimate = 0;
    }

    *velocity_0 = estimate;

    return estimate;
}

void joint_result_calculate_lat_lon(joint_result_t *p_joint)
{
    float R = 6371000;  //meters
    float bearing_rad = p_joint->bearing * PI / 180; //convert to radians
    float lat1 = p_joint->latitude * PI / 180; //convert to radians
    float lon1 = p_joint->longitude * PI / 180; //convert to radians

    float lat2 = asin(sin(lat1)*cos(p_joint->distance/R) + cos(lat1)*sin(p_joint->distance/R)*cos(bearing_rad));
    float lon2 = lon1 + atan2(sin(bearing_rad)*sin(p_joint->distance/R)*cos(lat1), cos(p_joint->distance/R)-sin(lat1)*sin(lat2));

    lat2 = lat2 * 180 / PI; //convert to degrees
    lon2 = lon2 * 180 / PI; //convert to degrees

    p_joint->latitude = lat2;
    p_joint->longitude = lon2;
}
```

9 priedas. unit.c kodas

```
/*
 * unit.c
 *
 *  Created on: 19 Dec 2021
 *      Author: tomku
 */

#include "unit.h"
#include "system_defines.h"
#include "ins.h"

float test_acc_x[500] = {-0.0685,-0.0701,-0.0698,-0.0691,-0.0696,-0.0696,-0.0697,-0.0699,-0.0664,-0.0957,-0.0889,-0.0657,-0.0968,-0.142,-0.1913,-0.0868,-0.1124,-0.0825,-0.0267,0.0046,-0.1159,-
0.098,-0.0641,-0.055,-0.0695,-0.0649,-0.0753,-0.1578,-0.1522,-0.0803,-0.0923,-0.0737,-0.008,0.0249,-0.0252,0.013,0.0276,0.0205,-0.0612,-0.1602,-0.1836,-0.1769,-0.1626,-0.0295,-0.1255,-0.1317,-
0.1389,-0.1401,-0.1357,-0.1092,-0.0368,-0.0602,-0.1006,-0.096,-0.0931,-0.0934,-0.0896,-0.0873,-0.0918,-0.0673,-0.0597,-0.0686,-0.0696,-0.0754,-0.0799,-0.0894,-0.0971,-0.1031,-0.0857,-0.0732,-
0.0176,0.0458,0.0533,0.0369,-0.0451,-0.0719,-0.0522,0.044,0.1236,0.1195,0.0539,0.0395,-0.0188,-0.1756,-0.2737,-0.2902,-0.1323,-0.2288,-0.2023,-0.1149,-0.0813,-0.0842,-0.0743,-0.0323,-0.0146,-
0.0599,-0.082,-0.0235,0.0249,-0.0324,-0.0837,-0.0968,-0.0956,-0.079,-0.0649,-0.1096,-0.1291,-0.1235,-0.1311,-0.157,-0.153,-0.1383,-0.1131,-0.0977,-0.0929,-0.0599,-0.0556,-0.0606,-
0.0493,0.0005,0.1299,0.1576,0.0946,0.0786,-0.1365,-0.2878,-0.2468,-0.1689,-0.1394,-0.0817,-0.0601,-0.0846,-0.1168,-0.0929,-0.1702,-0.2602,-0.3125,-0.3086,-0.144,-0.1926,-0.2064,-0.1847,-0.1751,-
0.1432,-0.115,-0.0994,-0.0813,-0.1337,-0.191,-0.2118,-0.1908,-0.154,-0.1106,-0.0976,-0.1729,-0.2135,-0.1665,-0.0874,-0.0839,-0.096,-0.1006,-0.1084,-0.1203,-0.1093,-0.0933,-0.0841,-0.0745,-0.1195,-
0.1263,-0.121,-0.1344,-0.1183,-0.1162,-0.1104,-0.1284,-0.1184,-0.1359,-0.1465,-0.1367,-0.1424,-0.1278,-0.103,-0.0922,-0.0865,-0.0998,-0.048,-0.0788,-0.0927,-0.0967,-0.0994,-0.0533,-0.0577,-
0.0706,-0.0646,-0.0657,-0.084,-0.0546,-0.0458,-0.0646,-0.0803,-0.0798,-0.1024,-0.109,-0.1069,-0.0974,-0.0431,-0.0105,0.0734,0.0797,-0.0274,-0.1199,-0.1378,-0.1395,-0.1412,-0.1948,-0.2007,-0.1991,-
0.1113,-0.0597,-0.0604,-0.0837,-0.0985,-0.1026,-0.1216,-0.1415,-0.1365,-0.1219,-0.1269,-0.099,-0.1052,-0.1012,-0.1064,-0.1144,-0.1023,-0.1187,-0.1248,-0.1171,-0.1051,-0.0956,-0.1158,-0.1122,-
0.042,-0.0576,-0.0332,0.0208,0.0484,0.0512,-0.029,-0.0794,-0.1093,-0.1253,-0.1476,-0.1579,-0.1612,-0.159,-0.1487,-0.1515,-0.1786,-0.1766,-0.1766,-0.1541,-0.0001,0.065,0.0693,0.0651,0.0644,0.0455,-
0.0097,-0.0852,-0.117,-0.082,-0.0643,-0.0979,-0.1553,-0.1387,-0.1514,-0.1583,-0.1396,-0.1179,-0.1349,-0.1375,-0.0882,-0.1072,-0.112,-0.0515,-0.0287,-0.0548,-0.132,-0.1145,-0.085,-0.0945,-0.1213,-
0.0949,-0.1137,-0.1021,-0.1554,-0.149,-0.1602,-0.1748,-0.1967,-0.1629,-0.0517,-0.0452,-0.0707,-0.1037,-0.1139,-0.1108,-0.1068,-0.1365,-0.1466,-0.1493,-0.1052,-0.0733,-0.094,-0.0922,-0.0987,-
0.1107,-0.1182,-0.1364,-0.1412,-0.1748,-0.1617,-0.0874,-0.0972,-0.1195,-0.1038,-0.1096,-0.1378,-0.1452,-0.147,-0.1151,-0.1068,-0.0885,-0.0968,-0.1146,-0.1193,-0.097,-0.0992,-0.1061,-0.1019,-
0.1096,-0.1197,-0.1286,-0.1302,-0.0979,-0.0944,-0.0927,-0.0941,-0.1001,-0.0997,-0.1032,-0.1207,-0.1193,-0.0974,-0.1151,-0.1117,-0.1122,-0.1006,-0.0818,-0.0957,-0.0901,-0.0957,-0.0918,-0.0973,-
0.1141,-0.1094,-0.1115,-0.1103,-0.0749,-0.0882,-0.0555,-0.0794,-0.0761,-0.0874,-0.1031,-0.0977,-0.1008,-0.0913,-0.0971,-0.0892,-0.0693,-0.045,-0.046,-0.0552,-0.0575,-
0.0147,0.0157,0.0429,0.0669,0.0848,0.0747,-0.0018,0.0041,0.0072,-0.0657,-0.1006,-0.1128,-0.1139,-0.1189,-0.1737,-0.1961,-0.1836,-0.161,-0.1281,-0.0799,-0.0402,0.0082,0.0754,0.0988,0.0179,-0.0554,-
0.1418,-0.1758,-0.1944,-0.1938,-0.1461,-0.0729,-0.0182,0.0656,0.0532,0.025,-0.0456,-0.1102,-0.2016,-0.2316,-0.2027,-0.1828,-0.1551,-0.097,-0.0927,-0.0908,-0.0886,-0.0898,-0.0972,-0.0629,-
0.0335,0.0008,0.0303,0.0458,-0.0012,-0.0358,-0.1008,-0.0669,-0.0007,-0.0136,-0.0183,-0.0681,-0.0578,-0.1186,-0.109,-0.0814,-0.1131,-0.1633,-0.1391,-0.1142,-0.1051,-0.0939,-0.089,-0.0849,-0.083,-
0.0795,0.0175,-0.0271,-0.0324,0.0075,-0.0371,-0.0527,-0.0938,-0.1241,-0.1128,-0.1039,-0.1217,-0.1371,-0.1065,-0.0833,-0.0876,-0.0901,-0.1345,-0.0774,-0.1123,-0.1339,-0.1157,-0.1016,-0.1334,-
0.0752,-0.1666,-0.0798,-0.1057,-0.1042,-0.1036,-0.1041,-0.1035,-0.1026,-0.103,-0.103,-0.1029,-0.1033,-0.103,-0.103,-0.103};
float test_gyro_z[500] = {-5.7586,-5.7582,-5.7546,-5.7537,-5.7569,-5.7618,-5.7644,-5.7682,-5.7672,-5.7657,-5.7614,-5.9694,-6.8088,-8.7744,-14.6914,-21.3464,-25.8026,-22.7274,-15.7907,-8.0621,-
3.3208,-2.4239,-4.3531,-8.8287,-12.1942,-13.9843,-14.2939,-14.8923,-16.4569,-19.4319,-22.4414,-22.9797,-17.8706,-7.4309,2.5277,7.9831,7.5436,6.4144,7.3444,6.2939,2.4973,-2.9582,-5.8394,-5.9081,-
5.927,-6.5139,-7.0496,-7.2558,-7.3543,-7.0951,-6.9426,-6.7246,-6.7795,-6.8146,-6.877,-7.0207,-7.2438,-7.5759,-7.6074,-7.4251,-7.1854,-7.2014,-7.3151,-7.3196,-6.9204,-6.6771,-6.4447,-6.5952,-
6.4054,-6.0205,-5.7167,-5.5766,-5.9644,-6.4464,-7.7298,-9.5067,-11.3356,-12.5211,-11.643,-9.9305,-7.6054,-6.3057,-5.7204,-5.6655,-2.0325,-1.937,-1.9551,-5.6936,-5.5449,-
3.3236,0.193,3.5623,5.7041,6.4285,7.3926,7.2418,5.406,3.972,4.4828,6.7389,8.0322,6.5157,4.3252,1.3475,-1.1819,-4.3081,-7.7496,-10.0382,-12.3852,-13.4276,-13.2751,-11.3878,-8.3209,-6.5928,-6.369,-
6.2575,-6.128,-5.8708,-5.9886,-5.9184,-6.0221,-6.343,-7.7161,-9.0232,-9.641,-10.1156,-10.6655,-10.4157,-6.9967,-0.7055,5.6769,9.4703,7.3777,0.2174,-9.273,-15.7484,-17.2631,-15.1395,-12.6748,-
11.7261,-12.1037,-12.7492,-12.9344,-13.1053,-13.016,-13.1617,-12.9322,-12.6605,-11.749,-9.8532,-7.7486,-6.1882,-5.4671,-5.0575,-4.9238,-5.4659,-6.1345,-6.5778,-6.5394,-6.1424,-5.7307,-5.5903,-
5.6218,-5.8212,-5.8782,-5.8259,-5.7078,-5.6278,-5.7808,-5.8051,-5.8574,-5.7369,-5.7394,-5.7782,-5.8274,-5.8732,-5.8581,-5.7621,-5.6499,-5.6844,-5.7148,-5.8443,-5.8701,-5.871,-5.7964,-5.7628,-
5.7379,-5.7731,-5.8001,-5.8175,-5.7939,-5.7157,-5.8,-5.7798,-5.8312,-5.7846,-5.7927,-5.806,-5.8396,-5.8231,-5.75,-5.694,-5.6965,-5.7612,-5.8293,-5.7917,-5.7998,-5.7714,-5.7656,-5.7411,-5.7687,-
5.9262,-5.9642,-5.9084,-5.7185,-5.649,-5.6876,-5.7238,-5.7627,-5.8433,-5.9868,-6.0657,-6.0317,-5.8952,-5.9264,-6.0258,-6.0638,-6.0541,-6.2256,-6.4939,-6.7339,-6.6842,-6.6119,-6.4262,-6.343,-
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5.5576,-5.6378,-5.7909,-5.9245,-5.8925,-5.8156,-6.2312,-6.5274,-6.334,-5.7776,-5.1332,-5.1129,-5.3548,-5.6274,-5.8408,-6.3782,-8.8076,-11.9951,-14.7823,-15.2478,-15.1776,-15.43,-16.1763,-15.9526,-
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25.2554,-17.9315,-9.5335,-6.7664,-5.7518,-5.6039,-5.7986,-5.8329,-5.6125,-5.3453,-5.3512,-5.4095,-5.4544,-5.1783,-
1.2788,5.8151,13.1535,15.5252,12.3506,8.5526,9.0311,11.6644,14.1403,10.5244,2.6001,-8.3277,-18.5975,-24.6149,-24.5845,-19.6443,-14.4408,-10.0419,-7.9725,-5.8751,-4.9401,-4.938,-5.1249,-5.0994,-
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5.7731,-5.7649,-5.7642,-5.7692,-5.7708,-5.775,-5.7735,-5.7816,-5.7789,-5.7803,-5.7692,-5.7679,-5.7702};

uint8_t test_flag_gnss[500] =
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uint8_t test_flag_ins[500] =
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float test_gnss_lat[500] =
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,54.93146515,54.93146133,54.93144989,54.93145752,54.93144226,54.93142319,54.93141174,54.93141174,54.93140411,54.93140411,54.93138504,54.93135834,54.93133545,54.93130875,54.93128204,54.93126678,54.
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00446892,24.00446892,24.00446892,24.00446892,24.00446892,24.00446892};
float test_joint_kmh[500] = {-1.2532,0,0,0,0,0,-0.251,-0.5027,-0.7419,-1.0863,-
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5,53.4117,53.208,52.6363,52.265,51.9566,51.6931,51.6296,51.7264,46.4296,41.207,36.54,33.336,32.6481,32.8066,33.2516,33.6817,33.8759,9.9267,5.7968,0.2778,0.4445,10.9638,16.7843,15.9605,15.2324,14.8
188,14.526,35.3547,37.04,37.8919,38.7438,36.9289,36.0041,35.9195,36.0092,35.8926,35.5911,33.4656,34.262,36.0029,37.8364,37.2993,36.9087,36.4642,35.9924,35.4272,34.8765,40.5403,42.2071,43.3553,43.2
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3,73.8392,73.2193,72.789,72.3345,71.8991,71.4153,75.8764,76.9691,77.5062,78.0433,78.3396,79.4802,78.9528,78.4607,77.9481,77.4882,87.5255,88.0811,88.1182,88.1367,88.4515,88.353,88.0193,87.6712,87.3
134,87.1217,86.0624,84.4327,83.1548,82.2288,81.4324,81.1434,80.9785,80.7458,80.4568,80.1697,75.7283,75.7838,75.1542,74.8023,78.4322,76.5795,76.8437,77.1305,77.032,76.6004,60.4863,57.8935,62.8939,6
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86,78.613,78.8448,79.0087,51.2263,46.5778,43.985,42.096,42.0589,40.7248,40.1658,39.6665,39.1214,38.5517,45.1147,48.0224,46.9852,47.8557,49.578,50.2849,49.8817,49.6964,49.5933,49.396,47.7446,47.874
2,48.8743,46.9852,45.837,45.5326,45.1232,44.7557,44.1962,43.6597,43.2442,44.8369,47.5594,50.6337,54.0043,55.3045,55.0502,54.6769,54.2668,53.8679,52.8376,53.245,52.7264,55.3192,57.0046,58.0741,57.7
356,57.4036,57.0484,56.6499,58.3936,58.0417,58.338,58.6343,59.0047,65.7276,65.3776,64.9476,64.574,64.1795,68.4314,68.524,71.6909,73.8022,73.4133,73.7613,73.4127,73,72.5707,72.2216,76.3024,75.006,7
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755,59.4862,53.1894,48.2631,43.2032,43.2293,42.9929,42.6309,42.225,30.4284,31.1136,29.7431,29.3172,32.3359,34.7012,34.2401,33.9525,33.8077,33.8373,36.9474,31.7248,28.0948,23.2426,20.0016,17.6277,1
6.9279,16.2302,15.7042,15.4416,32.1137,30.521,26.428,20.5942,16.8532,13.1044,12.3787,11.5449,10.8153,10.1573,23.8908,26.428,29.3727,27.6318,27.6504,26.4751,26.1251,25.8985,25.7779,25.7806,24.0575,
20.3164,16.6124,13.6307,11.612,12.4639,12.4613,12.4124,12.3467,12.1015,10.1304,8.9081,6.9265,7.5932,6.8154,6.3572,5.8564,5.4451,5.0669,4.729,14.3345,14.2419,13.8715,12.6492,12.2417,10.3661,10.2495
,10.2765,10.1428,9.9532,0,0,0,0.1482,0.1667,-0.327,-0.7105,-1.0105,-1.3257,-1.6499,2.4076,2.2409,2.315,2.9817,2.8521,1.8566,1.3764,1.1058,0.5059,0.2187,0,-0.375,-0.7482,-1.1229,-1.4956,-
1.8649,0,0,0,0,0,-0.3708,-0.7416};
float test_joint_m_s[500] = {-0.3481,0,0,0,0,0,-0.0697,-0.1396,-0.2061,-0.3018,-
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925,18.201,16.9664,16.5703,16.5291,16.5445,16.7622,16.6009,16.4419,16.2933,16.1418,19.3483,19.9193,20.5212,21.0253,21.7713,21.7025,21.7718,21.837,21.9013,21.9469,14.2295,12.9383,12.2181,11.6933,11
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2.1277,12.0123,12.4547,13.2109,14.0649,15.0012,15.3624,15.2917,15.188,15.0741,14.9633,14.6771,14.7903,14.6462,15.3665,15.8346,16.1317,16.0377,15.9454,15.8468,15.7361,16.2204,16.1227,16.205,16.2873
,16.3902,18.2577,18.1605,18.043,17.9372,17.8276,19.0087,19.0341,19.9141,20.5006,20.3926,20.4893,20.3924,20.2778,20.1585,20.0616,21.1951,20.835,20.9585,20.979,21.5295,21.5398,21.4096,21.3117,21.217
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419,11.7292,8.4523,8.6427,8.262,8.1437,8.9822,9.6392,9.5111,9.4313,9.391,9.3992,10.2632,8.8124,7.8041,6.4563,5.556,4.8966,4.7022,4.5084,4.3623,4.2893,8.9205,8.478,7.3411,5.7206,4.6814,3.6401,3.438
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7659,1.6268,1.5125,1.4075,1.3136,1.9818,3.9561,3.8532,3.5137,3.4005,2.8795,2.8471,2.8546,2.8175,2.7648,0,0,0,0,0.0412,0.0483,-0.0308,-0.1974,-0.2807,-0.3683,-
0.4583,0.6688,0.6225,0.6431,0.8283,0.7922,0.5157,0.3823,0.3072,0.1405,0.0608,0,-0.1042,-0.2078,-0.3119,-0.4155,-0.518,0,0,0,0,0,-0.103,-0.206};
float test joint bearing[500] = {97.3008,126.11,126.11,126.11,126.11,126.11,120.3456,114.5774,108.8102,103.0444,97.2831,126.11,126.11,126.11,343.86,355.21,-9.9626,-32.69,-48.4807,-56.5428,-
59.8636,39.05,35.11,47.09,53.07,48.18,49.2661,34.3739,17.917,-1.515,-
23.9563,124.89,137.14,148.82,133.4,124.98,118.7236,125.138,132.4824,138.7763,141.2736,65.08,65.85,65.87,64.8,61.96,55.4204,48.1646,40.8103,33.7151,26.7725,70.38,71.18,73.03,74.57,75.99,70.4562,62.
8803,55.2728,47.8477,40.6624,84.75,88.16,88.75,89.77,90.04,83.0153,76.42,70.0147,63.9942,58.2774,92.66,92.43,92.61,92.08,96.38,89.1744,76.6533,65.0103,55.0798,47.4744,126.42,129.26,129.26,129.26,1
28.18,118.4249,112.7314,107.1864,103.8628,104.0559,110.51,100.16,88.91,76.08,63.42,54.226,58.198,62.6808,69.4197,77.4518,354.5,342.52,332.78,325.15,322.24,314.1004,304.0622,291.6771,278.2495,264.9
743,356.77,359.77,359.86,0.15,0.54,-4.928,-10.7989,-16.7875,-22.7059,-28.728,0.81,0.94,3.18,7.03,12.91,8.2645,-2.1511,-9.1478,-9.8533,-
4.1764,359.71,344.77,334.27,334.44,344.53,339.6369,324.4974,311.8226,300.0965,287.9928,34.69,42.05,48.16,55.88,62.44,56.7278,44.0673,32.3183,22.4651,14.7165,93.6,94.43,92.53,91.5,89.99,83.6955,77.
1178,70.5784,64.436,58.7052,93.07,92.43,92.33,92.41,92.99,87.5922,81.9644,76.1836,70.3785,64.5211,92.28,92.19,92.46,92.55,92.92,86.7019,80.9398,75.2898,69.6054,63.8906,92.31,92.6,93.05,93.03,92.87
,87.4521,81.679,75.8789,70.0614,64.2675,93.19,92.86,92.72,92.45,92.54,86.9073,81.1013,75.2617,69.4387,63.6887,92.33,92,92.28,92.56,92.65,86.8902,81.1188,75.3532,69.6121,63.8434,92.48,92.19,92.69,9
2.45,92.55,86.8924,81.1685,75.4058,69.5625,63.5757,93.04,93.53,93.46,93.35,93.68,88.0362,81.9823,75.7565,69.2626,62.5297,97.39,91.7581,85.3319,78.9889,72.6027,66.2962,100.85,101.71,101.65,101.8,10
2.19,96.3357,90.5693,84.8235,79.0831,73.3826,101.71,101.92,101.74,101.97,102.2,96.2567,90.4886,84.7016,78.8722,73.0413,102.37,102.34,103.24,103.98,103.97,98.012,92.9346,87.7688,82.2842,75.883,102.
94,104.48,111.88,119.57,131.48,125.8053,109.2648,92.3279,75.1382,57.5197,199.48,208.65,223.81,234.76,243.95,238.1229,224.8127,212.2069,198.5027,182.5498,294.3,310,320.25,331.44,343.56,335.3308,317
.2682,299.1863,282.4833,268.576,47.94,50.98,52.25,51.78,49.16,45.8616,39.451,32.6935,26.2628,20.3742,52.98,51.68,52.58,51.86,52.61,47.5801,42.0715,36.4196,30.4113,24.2546,53.67,52.29,51.37,51.91,5
2.47,45.6442,39.7305,33.8467,27.9753,22.1609,52.05,51.86,51.85,52.13,53.34,47.3304,41.7022,36.0931,30.3129,24.402,52.77,52.15,53.04,51.89,51.59,44.5494,38.7473,33.059,27.3922,21.6687,51.33,51.23,5
2.27,52.22,51.89,45.8583,39.8751,34.1138,28.2529,22.4843,52.69,53.02,53.08,52.69,53.53,45.7674,39.9285,34.0544,28.2781,22.5422,52.02,51.78,52.57,52.17,51.49,46.1304,40.4254,34.5075,28.5298,22.6744
,52.31,51.9,51.98,51.96,51.99,46.8044,40.5732,34.0459,27.7118,21.9342,53.64,53.24,51.55,51.9,51.92,46.5518,37.7442,25.7491,10.9668,-
4.2811,84.56,94.93,103.66,111.27,118.62,115.5784,107.6423,101.2703,95.4479,89.7802,138.4,137.82,140.34,146.39,158.73,151.5728,128.0426,109.4558,96.9908,89.1185,232.65,231.35,230.98,231.21,239.18,2
28.4536,198.4709,173.2155,155.2839,145.7504,321.42,323.28,325.43,325.25,322.65,318.1975,312.8523,307.5011,302.0916,296.6373,323.01,321.35,318.82,312.91,284.06,267.3206,275.8733,284.9044,296.5688,3
10.7092,159.73,146.4,154.07,176.79,195.76,195.4055,175.7611,161.3203,151.2784,143.3059,238.29,236.14,235.18,239.63,240.21,233.0724,236.1063,242.5316,246.1841,245.5781,216.06,216.06,216.06,216.06,2
16.06,215.3961,212.46,207.9474,204.0951,201.8505,216.06,216.06,216.06,216.06,216.06,209.7333,203.9353,198.1403,192.3547,186.5713,216.06,210.2951,204.531,198.7618,192.991,187.216,216.06,216.06,216.06,216.
06,216.06,216.06,210.2921,204.5219};

gnss_t gnss_temp;
acc_t acc_temp;
gyro t gyro temp;

uint16_t i;

void unit_test()
{
    for(i = 0; i < UNIT_SAMPLES; i++)
    {
        if (i == 164)
        {
            uint8_t breakpoint = 0;
        }

        //Execute every fifth index
        if (i % 5 == 0)
        {
            if (g.flag.gnss_active == FALSE)
            {
              g.flag.gnss_active = TRUE;
            }
            else
            {
              g.flag.gnss_active = FALSE;
            }
        }

        gnss temp.lat = test gnss lat[i];
        gnss_temp.lon = test_gnss_lon[i];
        gnss_temp.kmh = test_gnss_kmh[i];
        gnss_temp.bearing = test_gnss_bearing[i];

        acc temp.value filtered = test acc x[i];
        gyro_temp.value_filtered = -1 * test_gyro_z[i];

        joint result calculate bearing(&g.joint result, &gnss temp, &acc temp, &gyro temp);

        g.unit[i].bearing = g.joint_result.bearing;
        g.unit[i].latitude = g.joint result.latitude;
        g.unit[i].longitude = g.joint_result.longitude;
        g.unit[i].velocity_m_s = g.joint_result.velocity_m_s;
        g.unit[i].velocity kmh = g.joint result.velocity kmh;
        g.unit[i].distance = g.joint_result.distance;

        unit_test_logging(i);
    }

    while(1)
    {

    }
}

void unit_test_logging()
{
    uint16_t size;

    size = snprintf(g.buffer.uart7_tx, LOGGING_BUFFER_SIZE, "%d;%.4f;%.4f;%d;%d;",
                i,acc_temp.value_filtered, gyro_temp.value_filtered, g.flag.gnss_active, g.flag.ins_begin);

    //check snprintf error
    if(size > 0)
    {
        HAL_UART_Transmit(&huart7, (uint8_t *)g.buffer.uart7_tx, size, UART_TX_TIMEOUT);
    }

    size = snprintf(g.buffer.uart7 tx, LOGGING BUFFER SIZE,
                "%.8f;%.8f;%.4f;%.4f;%.4f;",
                gnss temp.lat, gnss temp.lon, gnss temp.kmh, 0.0, gnss temp.bearing);

    if(size > 0)
    {
        HAL UART Transmit(&huart7, (uint8 t *)g.buffer.uart7 tx, size, UART TX TIMEOUT);
    }

    size = snprintf(g.buffer.uart7_tx, LOGGING_BUFFER_SIZE,
        "%.8f;%.8f;%.4f;%.4f;%.4f;%.4f;\r\n",
        g.unit[i].latitude, g.unit[i].longitude, g.unit[i].velocity kmh, g.unit[i].velocity m s, g.unit[i].bearing);

    if(size > 0)
    {
        HAL_UART_Transmit(&huart7, (uint8_t *)g.buffer.uart7_tx, size, UART_TX_TIMEOUT);
    }
}
```