Project

Architectures for Wide-Band Meta-Signal Processing in Low-Cost Devices

Document Title

Executive Summary Report

Responsible Contractor	Document Responsibility	Name	Signature
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Document Information		
Document Reference	IGA-HAN	IDS-CD-ESR
Issue. Revision/DDL	1.0 / ESF	R
Date	10-Augu	st-2024
Document Category	R	[I: for Information] [R: for Review] [A: for Approval]
Classification Level	U	[U: Unclassified] [R: Restricted] [C: Confidential] [S: Secret]
Document Pages	8	





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Document Change Log

Docum	ent Change	e Status		
Issue	Revision	Date	Reason(s) for Change	Sections affected



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1. Introduction

1.1. Purpose and Scope

This Executive Summary highlights the key technological achievements of the HANDS-CD project, focusing on innovations in signal processing, system design, and comprehensive testing that have collectively advanced the field of GNSS technology.

1.2. Reference Documents

The following table contains the reference documents used.

Table 1.1: Reference Documents

Ref.	Title
[RD-1]	

1.3. Definitions and Acronyms

The acronyms and abbreviations used within this document are given in the table below.

Table 1.2: Definitions and Acronyms

Acronym	Explanation
AltBOC	Alternative BOC
BJ	Bump Jumping
BOC	Binary Offset Carrier
BPSK	Binary Phase Shift Keying
CD	Concept Demonstrator
DDT	Double Discriminator Tracking
DE	Double Estimate
DLL	Delay Locked Loop
EKF	Extended Kalman Filter
FLL	Frequency Locked Loop
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
iDDT	Improved Double Discriminator Tracking
LAMBDA	Least-squares AMBiguity Decorrelation Adjustment
LOS	Line-of-Sight
NCO	Numerically Controlled Oscillator
NLOS	Non-Line-of-Sight
RF	Radio Frequency
RFFE	Radio Frequency Front-End
SAGE	Space-Alternating Generalized Expectation maximization technique



2. Project Overview

The HANDS-CD project represents a significant milestone in advancing GNSS technology, particularly for handheld and low-cost devices. The project aimed to develop a CD capable of achieving high positioning accuracy in challenging environments such as urban canyons and deep urban areas.

3. Proposed Signal Processing Techniques

The HANDS-CD project successfully developed and implemented innovative signal processing techniques, each tailored to enhance GNSS performance in environments with weak or obstructed signals.

3.1. BPSK-like Method

IGASPIN's approach introduces post-correlation shifts, where the E5a and E5b pilot components are correlated separately and then combined to produce E5ab BPSK-like correlation values. This requires deriving the E5a and E5b NCOs from a single E5ab NCO, ensuring that the code and carrier generators are aligned to accurately reproduce the BPSK-like E5ab components.

3.2. iDDT Method

The iDDT provides a smoother and faster transition to the main correlation peak than the traditional BJ algorithm, making it ideal for handling multiple side peaks in high-order BOC signals and meta-signals. By combining techniques like differential evolution, side-peak transition, and Double Discriminator Tracking (DDT), iDDT enhances tracking accuracy and reduces pseudorange errors, especially in multipath conditions.

3.3. SAGE Method

The SAGE algorithm, traditionally used in communication systems, has proven effective in GNSS navigation as well. In this context, SAGE is applied after the local correlation step, where ML estimation is used on the post-correlated signal to estimate the relative delay and Doppler of the signal paths. These estimations are then utilized to drive the GNSS tracking loops, similar to the role of DLL and PLL in classical navigation, enhancing the accuracy of time delay and phase measurements for LOS signals.

3.4. M-SiPE Method

The M-SiPE integrated the LAMBDA method for sub-carrier ambiguity resolution, achieving decimeter-level positioning accuracy even in challenging environments.

4. Proposed Architecture

The HANDS-CD system was built with a modular architecture, allowing for flexibility in system upgrades and integration of various signal processing techniques. The system was optimized for low power consumption while maintaining high accuracy though impairment induced by the low-grade devices.



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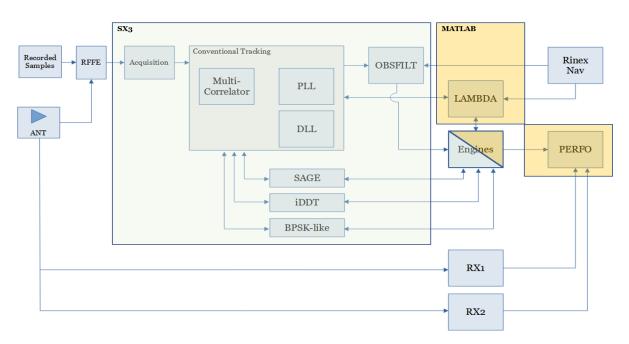


Figure 4.1: The high-level design of the HANDS-CD.

After simulations and trade-offs, the iDDT together with MSiPE methods were implemented for meta-signal processing on the SX3 platform, supporting both E5a+E5b and L2+L5 signals.

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	38	39	40	41	42	43	44	45	46	47	48	49 4	✓ GPS	Week	Seconds in Week	Time System
System	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo	✓ Galileo	2303	477480	GPS
Service	E5a	E5b	E5a+b	E1	E5a	E5b	E5a+b	E1	E5a	E5b	E5a+b	E1	✓ Glonass	Applied Clock Error	Residual Clock Error	
PRN	15	15	15	21	21	21	21	27	27	27	27	34	✓ BeiDou	-17.91000000	-0.00004691	-212.99920930 +/- 0.1325
C/N0 [dBHz]	48.79	50.14	50.09	51.52	50.64	51.97	52.03	51.67	49.20	51.08	50.76	43.19	✓ SBAS		+/- [ns] 5.77	+/- 0.1325
Elevation [deg]	50.57	50.57	50.57	67.08	67.08	67.08	67.08	54.61	54.61	54.61	54.61	8.97	_	Interfrequency Bia	L2C3="3.0, L3=1.4	
Azimuth [deg]	67.49	67.49	67.49	307.11	307.11	307.11	307.11	106.68	106.68	106.68	106.68	33.33	✓ QZSS	IFBs [m]:	F5a=-0.1 . F5h=-2.1	. F5a+h=1.2 . *
.ock Time [s]	141.50	141.50	114.75	137.79	141.50	141.50	114.75	137.79	141.50	141.50	23.43	122.19	✓ IRNSS	WGS84 Coordinate		
Receiver ID / MC	2/-	3/-	4 / Active	1/-	2/-	3/-	4 / Active	1/-	2/-	3/-	4 / Active	1/-	✓ Other	X-Coordinate [m] 4196302,752	Y-Coordinate [m] 1156466.233	Z-Coordinate [m] 4646970.363
Range Rate [m/s]	108.62	108.63	108.63	-241.71	-241.71	-241.75	-241.75	235.90	235.92	235.92	235.90	495.67		X-Velocity [m/s]	Y-Velocity [m/s]	Z-Velocity [m/s]
Pseudorange [m]	2442441	2442441	2442441	2378878	2378879	2378878	2378879	2425009	2425009	2425009	2425009	2796284	Show IDs	-0.007	0.023	-0.021
Carrier Phase [cyc]	F 49420.3	F 50711.7	F 48895.9	F -15662	F -11696	F -12001	F -11554	F 149493.2	F 111633.9	F 114547.2	S -40686	F 316583.5	Channels:	Latitude [deq]	Longitude [deg]	Height (Ellipsoid)
Doppler [Hz]	-426.24	-437.39	-431.85	1270.17	948.51	973.42	961.06	-1239.66	-925.78	-949.94	-937.78	-2604.78	52 Tracked	47.06445980	15.40776511	438.810
CMC Doppler [Hz]	-0.16	-5.21	0.38	-5.29	1.57	2.91	-0.12	3.23	-1.15	-6.74	0.03	-2.21	49 SPP Ok	Estimated Accurac		
4	1	1	1	1	((1	1	1	1	1	· · · ·	Compact	3D Position Acc. [m]	: 2.36 3D Velocity	Acc. [m/s]: 0.04
3		Spe	ctrum				1 🗙 🌗			Corr	elation 3D			- 🗆 🗙 🌒	Sky Plot	- 0;
-50 - -55 - [7+bw/(8P] CGa -70 - 53/RP3 -70 - 53/RP3 -75 - 51/RP1	/Master: 1 /Master: 1		MHz, AG= MHz, AG=		⊨ n/a, RMS ⊨ n/a, RMS		as as	2e+7- 1.5e+7- 1e+7- 5e+6-	20.0212		79.919, C/I	20	Multi-Correlator Store Curre Multi-Correlator Cocc urre: 23:5 Elevation: 54.6 C/N0: 50.8 dB Doppler: 937.1 Chip nominal: Start Multi- Stop Multi-	nt MC View Info Center 'S ◆ ▲ Z BHZ ↓ Correlator		F1 7 G20
-6	-4	-2 F	0 Frequency	2 [MHz]			6						Multi-Correlator		nal Strength [dBH 30	

Figure 4-2: A screenshot of the SX3 software receiver when processing the E5ab signals using the proposed iDDT method.



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٠						Channel Viev	v							- 🗆 🗙	3	Position	- 0:
	3	4	5	6	7	8	9	10	11	12	13	14	-	✓ GPS	Week	Seconds in Week	Time System
System	GPS	GPS	GPS	GPS	GPS	GPS	GPS	GPS	GPS	GPS	GPS	GPS		✓ Galileo	2303	477684	GPS
Convico	1100	1205	10	CDC 1 2 . 1 5	LICA	1000	1104	1205	15	CDC LD LLE	1104	1205			Applied Clock Error	Residual Clock Error	Clock Drift [Hz] @ I

Service	GPS L1CA	GPS L2CS	GPS L5	GPS GPS L2+L5	GPS	GPS L2CS	GPS L1CA	GPS L2CS		GPS GPS L2+L5	GPS	GPS L2CS	✓ Galileo	2303 Applied Clock Error	477684 Residual Clock Error	GPS Clock Drift [Hz] @ I
PRN	11	11	11	11	12	12	18	18		18	20	idle	✓ Glonass	-17.91000000	-0.00007469	-214.17817227
C/N0 [dBHz]	42.81	45.50	45.02	46.48	45.22	43.55	44.25	45.16			41.65	-	✓ BeiDou		+/- [ns] 3.48	+/- 0.1218
Elevation [deg]	18.77	18.77	18.77	18.77	24.66	24.66	25.11	25.11		25.11	19.08	-	SBAS	Interfrequency Bia	L2CS=-13.0 , L5=-8	.3 , E1=-1.4 ,
Azimuth [deg]	41.59	41.59	41.59	41.59	109.54	109.54	185.92	185.92	185.92	185.92	67.68	-	✓ QZSS	IFBs [m]:	F5a=-8.7 . F5b=-9.4	• . F5a+h=-4.3 . *
Lock Time [s]	333.84	311.40	338.51	177.87	333.84	311.41	333.84	300.84	338.52	299.85	333.84	-	✓ IRNSS	WGS84 Coordinate		
Receiver ID / MC	0/-	5/-	6/-	7 / Active	0/-	5/-	0/-	5/-	6/-	7 / Active	0/-	-/-	✓ Other	X-Coordinate [m] 4196285.913	Y-Coordinate [m] 1156461.678	Z-Coordinate [m] 4646954.438
Range Rate [m/s]	519.96	519.89	519.87	519.69	563.28	563.37	-727.80	-727.81	-727.82 -	-727.80	-177.06	-		4196285.913 X-Velocity [m/s]	Y-Velocity [m/s]	2-Velocity [m/s]
Pseudorange [m]	2400544	2400545	2400545	2400545	2333892	2333892	2345765	2345765	2345766 2	2345765	2375686	-		-0.008	-0.014	-0.046
Carrier Phase [cyc]	N 84735	F 656194.2	F 632765.1	S -48991	N 92832	F 718837.1	N -12219	F -91285	F -91251	F -89384	N -32345	-	Show IDs	Latitude [deq]	Longitude [deg]	Height (Ellipsoid)
Doppler [Hz]	-2732.39	-2128.86	-2040.08	-2083.71	-2960.04	-2306.91	3824.59	2980.25			930.48	-	Channels:	47.06447709	15.40776620	415.268
CMC Doppler [Hz]	-1502.48	-12.85	44.62	0.59	745.90	-57.56	-60.76	58.45	-80.97 ·	-0.53	-830.07	•	53 Tracked	Estimated Accuraci		
#Paths/Chi2	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	50 SPP Ok	3D Position Acc. [m]	: 1.45 3D Velocity	Acc. [m/s]: 0.03
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50 -50 - 17 dat -50 - 17 dat [74w]-60		(1207.140	MHADOW MH2, AG-1	Mana da, po	poncess ycstanti - n/a, RMS	201071 Mary 1 Mary 1 - 1.65, B1	Senc	d Time (we	ek/sec): 230			10 = 46.52 d 1e+7 5e+6 0 Co -5e+6 -1e+7	Multi-Correlator V Store Currer Multi-Correlator I Lock time: 108. Elevation: 19.2 C/N0: 46.5 dBH Doppler: -2065. Chip nominal: 2 Start Multi-	View Operations nt MC View Info Center 9 S 2 2 3. Hz 19.3 m	E4 22631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21631 21751 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 216511 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 21651 2165	E34 G11, G20,

Figure 4-3: A screenshot of the SX3 software receiver when processing the L2+L5 signals using the proposed iDDT method.

5. Testing and validation

The project involved rigorous testing across diverse environments, including urban canyons and deep urban areas. The HANDS-CD system demonstrated superior performance in positioning accuracy, signal availability, and tracking sensitivity compared to state-of-the-art professional GNSS receivers.

6. Requirements Compliance

The HANDS-CD met all the technical requirements presented under the ESA's Statement of Work. System components and their modules were tested inside out for validating against required performance.

7. Future Directions

Building on the successes of the HANDS-CD project, several future research directions are proposed:

- **1. Optimization of Hybrid Meta-Signal Techniques:** Further refinement of hybrid meta-signal processing techniques, potentially integrating peer-to-peer ranging solutions, will enhance real-time processing capabilities and system robustness.
- **2. Exploration of Additional Frequency Combinations:** Investigating other frequency combinations, such as Galileo E1/E6 and GPS L1/L5, will expand the system's versatility and improve performance in specific environments.
- **3. Development of a Flexible Breadboard Platform:** A flexible, scalable breadboard platform based on COTS hardware will be developed to serve as a proof of concept for hybrid meta-signal solutions.



- **4. Field Testing in Diverse Scenarios:** Extensive field testing in representative urban and deep-urban environments, covering both pedestrian and vehicular scenarios, will validate the practical applicability of the developed techniques.
- **5. Market Applications and Collaborations:** Leveraging the innovations from HANDS-CD, there is potential to explore new market applications and opportunities for collaboration with other ESA projects and industry stakeholders.

8. Conclusion

The HANDS-CD project has made substantial technological advancements in the field of GNSS for handheld devices, offering new possibilities for consumer and professional applications alike. The success of this project sets the stage for the next generation of GNSS systems capable of delivering high accuracy in environments previously considered too challenging for reliable positioning.

