Range Instrumentation Complex for the Precision-Guided Weapons Testing

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***Abstract*—The report is devoted to the problem of creating a modern range instrumentation complex (RIC) for the testing of the precision-guided weapons. RIC will provides extremely achievable accuracy and reliability of estimation the trajectory parameters of the highly dynamic objects being tested.**

Keywords—range instrumentation complex (RIC), precision-guided weapons, Phase Comparison and Doppler Radio System (PDRS), Laser Opto-Electronic Station (LOES), trajectory measurements.

I. INTRODUCTION

At present, in Ukraine, the problem of creating a modern Range Instrumentation Complex (RIC) for flight-design tests of precision-guided weapons (highly dynamic flying vehicle – HDFV) – aeroballistic, cruising and antiaircraft missiles, air-launched weapons, etc. is extremely urgent.

In the course of field tests using trajectory measurement systems (TMS), the parameters of the HDFV trajectories (coordinates, velocity vector components and acceleration vector components) are determined [1–12, 28–33]. These independent high-precision measuring instruments make it possible in the RIC Information and Analytical Center (IAC) to compare the data of the on-board HDFV navigation systems and the independent TMS determinations transmitted via telemetry channels and objectively assess the quality of functioning of the on-board HDFV guidance systems, as well as identify the causes of emergency situations at all stages of flight of various types of precision-guided weapons.

The accuracy of determining the HDFV trajectory parameters using the TMS should be several times (usually ~5–10 times) higher than the accuracy of the on-board navigation systems of the HDFV guidance loop, which makes it possible to objectively perform the metrological control and certification of the on-board HDFV navigation and guidance means. The results of the preliminary analysis show that depending on the HDFV type and the tasks they solve, the root-mean-square (RMS) errors for determining the parameters of surface objects trajectories (including determining the rendezvous point position) in a given rectangular topocentric coordinate system should be in the range from ~0.1–0,5 m to ~3–5 m. The RMS of the velocity vector components determination should not exceed ~3–7 cm/s. The range instrumentation for trajectory determination existing in Ukraine [12, 28–33] do not satisfy such requirements or partially satisfy.

Currently, for field tests the radio location stations (RLS) and Laser Opto-Electronic Stations (LOES) [13–21] are used, which provide the measurements of azimuth, elevation, range (RLS, LOES), as well as Doppler frequency shifts (RLS) of the monitoring objects. Based on the results of the measurements, the required HDFV trajectory parameters are determined in given rectangular or in other coordinate systems. Analysis of the RLS capabilities [12] to ensure testing of the existing and prospective HDFV samples showed the unsatisfactory level of trajectory determination accuracy (from several tens up to hundreds of meters in coordinates). As for the existing LOES, their angular coordinates measurement errors are in the range from ~10–30 to ~60–100 angular seconds. [11] that is also not enough in order to achieve the modern requirements for the accuracy of the trajectory parameter determination for a limited operational range of LOES (~10–20 km) [11].

Taken together, this causes the necessity of the development and implementation of modern high-precision measuring systems, opto-electronic and radio engineering ones, as well as the creation of technologies for cooperative centralized processing (complexation/data fusion) the measuring information of TMS, included in the RIC, in order to improve the trajectory determination validity and accuracy during field tests of the already existing and prospective weapons.

II. PURPOSE OF THE PROJECT

The report considers the systemic solution to the problem of creating a modern RIC which will provide centimeter/decimeter accuracy and validity of the assessment of the trajectory parameters of the HDFV samples by complexation (data fusion) the measuring information (with spatial-temporal redundancy) of the TMS with different physical principles of architecting and functioning.

The cooperative operation and processing of the redundant results of trajectory measurements of several systems will provide a significant increase in the validity and accuracy of trajectory determination results, will allow evaluating the error parameter models of the measurements of each of the systems, will identify and eliminate unaccounted systematic errors of RIC measuring systems, to carry out the certification of other measuring instruments, in particular, the on-board measuring systems of navigation (radio engineering, inertial, etc.) and HDFV motion guidance. It is expected that the determination of the HDFV movement parameters will be carried out with centimeter/decimeter accuracy throughout the entire coverage area of the measuring systems that are part of the RIC.

III. THE STRUCTURE OF THE RANGE INSTRUMENTATION COMPLEX

To ensure the spatial and temporal redundancy of trajectory measurements, it is proposed to use small-sized LOES, united by an information and communication subsystem into opto-electronic systems (OES), as well as to use multi-position Phase Comparison and Doppler Radio systems (PDRS) which use the Global Navigation Satellite Systems (GNSS) signals.

The opto-electronic system being created assumes the use of a group (network) of stations (LOES), which are located along the HDFV flight route. Each LOES in its area of the responsibility is programmed to support the HDFV on the predicted trajectory section. The programming process is automated and is carried out simultaneously for all LOES. In the process of tracking each LOES transmits through the communication channel the current HDFV coordinates for the LOES, which is next in line in the standby mode. Based on these data, the coordinates of the expected capture point and the HDFV flight path are corrected in relation to the predicted one. The number of LOES in the optical-electronic system is determined depending on the length of the route and the maximum flight altitude of the controlled HDFV. It is expected that the joint use of a group (network) of LOES will significantly increase (in relation to individual LOES) the accuracy and validity of the HDFV trajectory determinations and achieve a centimeter/decimeter accuracy level in the autonomous mode of operation.

PDRS includes the equipment that is installed on board the HDFV: an on-board GNSS-receiver, an onboard transmit/receive antenna system, a telemetric radio line «airborne-ground», a network of ground (or sea) GNSS base stations located along the HDFV flight path. PDRS is based on the principles of accurate GNSS positioning using on-board dual-frequency code, carrier-phase and Doppler GNSS observations [16–20], which are transmitted via telecommunication channels to the center for gathering and processing of measurement information. To achieve high accuracy in determining the trajectory parameters of the HDFV movement it is proposed to use base GNSS stations and the method of differential and autonomous carrier-phase GNSS-positioning, which implements the centimeter/decimeter accuracy of the trajectory parameters [17, 18, 20]. For reliable reception of GNSS signals (under conditions of HDFV maneuvering and/or rotation while in motion) and the simultaneous transmission in real time of measurement results from the HDFV to receiving stations, the implementation of on-board antennas of various configurations are considered. The expected accuracy (RMS) of autonomous HDFV trajectory determinations using PDRS is (depending on the implementation method) from ~3–5 cm to several decimeters for coordinates and ~5 cm/s for velocity vector components.

The cooperative processing and analysis of measurement information is provided by IAC of the RIC. The RIC equipped with OES and PDRS will ensure the operation in the widest possible range of weather conditions and time of day, assessment of the parameters of trajectories of all types of HDFV in the specified ranges of altitudes, speeds and overloads from the moment of launch to the moment of rendezvous with various air-based, surface-based and sea-based objects.

In the course of work it is supposed to develop and test (both by mathematical modeling and by carrying out real field measurements) a RIC prototype, including OES and PDRS prototype units, as well as a prototype of mathematical and software complex for autonomous and cooperative processing of observations in the IAC.

IV. CONCLUSIONS

The structure of a modern RIC, including high-precision Opto-Electronic System and Phase Comparison and Doppler Radio System, as well as an Information and Analytical Center with the functions of complexation (data fusion) of the redundant trajectory measurements is proposed. Such a complex will provide the opportunity of carrying out the reliable tests of existing and promising samples of domestic high-precision weapons which will help to increase the defense capability and security of Ukraine.

REFERENCES

[1] Range Instrumentation, Ernest H. Ehling, Published by Prentice-Hall, Englewood Cliffs, N. J., 1967, 634 p.

[2] MISTRAM – Missile Trajectory Measurement System [Електронний ресурс] // Режим доступу: http://maps.thefullwiki.org/MISTRAM, https://en.wikipedia.org/wiki/MISTRAM

[3] AZUSA. A Precision, Operational, Automatic Tracking System [Електронний ресурс] // Режим доступу: http://maps.thefullwiki.org/AZUSA, http://www.chemeurope.com/en/encyclopedia/AZUSA.html

[4] Литус Ю.П., Малафеев Е.Е., Михайлов Ю.В. Высокоточная многопараметрическая система внешнетраекторных измерений

параметров движения летательных аппаратов «ВЕГА» // Прикладная радиоэлектроника, 2006, Том 5. № 4. С. 448–453.

[5] Thompson T., Levy L. J., Westerfield E. E. The SATRACK System: Development and Applications // Johns Hopkins APL TECHNICAL DIGEST, Volume 19, Number 4 (1998). P. 436–447.

[6] Craig Desiree L. LOCATA Corporation. USAF's New Reference System. Truth on the Range // Inside GNSS, No. 3, May/June 2012. P. 37–48.

[7] Власов И. Б., Гаврилов А. И., Кушнир А. А., Михайлицкий В. П., Мыкольников Я. В., Пельтин А. В., Пудловский В. Б., Рауткин Ю. В. Комплекс аппаратно-программных средств внешнетраекторных измерений на основе использования ретранслированных сигналов навигационных спутников // Вестник МГТУ им. Н. Э. Баумана. Сер. «Приборостроение», 2012. С. 82–89.

[8] Волотов Е. М., Митрофанов И. В. Сравнительный анализ средств траекторных измерений на базе спутниковых навигационных систем, применяемых при испытаниях авиационной техники и вооружения. Государственный лётно-испытательный центр имени В. П. Чкалова, Астраханская область, Ахтубинск, Россия // Труды Международного симпозиума «Надежность и качество», 2015, том 1. С. 338–342.

[9] Високоточна багатофункціональна система визначення траєкторій літальних апаратів авіаційних, ракетних і космічних комплексів (шифр «Вега-V»), аванпроект/технічна пропозиція – пояснювальна записка, Харківський національний університет радіоелектроніки, НДЦ ПРЕСТ, 2017. 225 с. (з додатками на 194 с.).

[10] Жалило О. О., Дохов А. И., Катюшина Е. В., Васильева Е. М., Яковченко А. И., Лукьянова О .А. Разработка высокоточной системы определения траекторий космических аппаратов и других высокодинамичных объектов // Прикладная радиоэлектроника, 2017, Том 16, № 3, 4. С. 112–116.

[11] Путятин В. Г., Додонов А. Г. Об одной задаче высокоточных траекторных измерений оптическими средствами // Реєстрація, зберігання і обробка даних, 2017, Т. 19, № 2. С. 36–54.

[12] Додонов А. Г., Путятин В. Г. Радиотехнические средства внешнетраекторных измерений (обзор) // Математичні машини і системи, 2018, № 1. С. 3–30.

[13] Шапиро Л., Стокман Д. Компьютерное зрение. М.: Издательство «БИНОМ. Лаборатория знаний», 765 с.

[14] Szeliski Richard. Computer Vision: Algorithms and Applications. Springer, 2010. 933 с.

[15] Shostko I., Tevyashev A., Kulia, Y., Koliadin A. Optical-electronic system of automatic detection and high-precise tracking of aerial objects in real-time // The Third International Workshop on Computer Modeling and Intelligent Systems, CMIS, 2020. P. 784–803.

[16] http://ceur-ws.org/Vol-2608/paper59.pdf

[17] Experimental researches on determination of angles of side illumination by laser radiation of optical devices and optoelectronic devices / Avchinnikov Evgeniy, Shostko Igor, Tevyashev Andriy, Neofitnyi Mykhaylo, Kulia Yuliia // Problems of Infocommunications. Science and Technology (PICS&T-2019): International Scientific-Practical Conference, Kyiv, 2019. El. access: 47496-CFP19PIA-USB/papers/picst19_319.pdf

[18] Tevyashev Andrey, Shostko Igor, Neofitniy Mihail, Koliadin Anton. Laser Opto-Electronic Airspace Monitoring System in The Visible and Infrared Ranges // 2019 IEEE 5th International Conference Actual Problems of Unmanned Aerial Vehicles Developments, APUAVD 2019 – Proceedings, 2019. С. 170–173, 8943887.

[19] Mathematical model and method of optimal placement of optical-electronic systems for trajectory measurements of air objects at test / A. D. Tevjashev, I. S. Shostko, M. V. Neofinyi, S. V. Kolomiyets, I. Yu. Kyrychenko, Yu. D. Pryimachov // Odessa Astronomical Publications. Vol. 32 (2019). С. 171–175. https://doi.org/10.18524/1810-4215.2019.32.182231

[20] Shostko I., Tevyashev A., Neofitnyi M., Kulia Y. Information-measuring system of polygon based on wireless sensor infocommunication network // Chapter in the book Lecture Notes on Data Engineering and Communications Technologies, 48. Publisher: Springer Nature, 2021. С. 649–674.

[21] Shostko I., Tevyashev A., Kulia Y., Koliadin A. Optical-electronic system of automatic detection and high-precise tracking of aerial objects in real-time. CEUR Workshop Proceedings, 2020. С. 784–803.

[22] Shostko I., Tevyashev A., Neofitnyi M., Ageyev D., Gulak S. Information and Measurement System Based on Wireless Sensory Infocommunication Network for Polygon Testing of Guided and Unguided Rockets and Missiles // 2018 International Scientific-Practical Conference on Problems of Infocommunications Science and Technology, PIC S and T 2018 – Proceedings, 2019. С. 705–710.

[23] AAP-6. Словник термінів та визначень НАТО [Електронний ресурс]: NATO/NSA Brussels – BE, 2005. Режим доступу до док.: http://www.nsa.nato.int.

[24] STANAG 1241. Угода НАТО з питань стандартизації. Опис структури ідентифікації НАТО для тактичного використання [Електронний ресурс]: NATO/NSA Brussels – BE, 2005. Режим доступу до док.: http://www.nsa.nato.int.

[25] Artemenko A. M. Problems of standardization of classification of air objects for providing of intergovernmental exchange information about an air situation // Системи обробки інформації, випуск 4 (78), 2009. С. 6–9.

[26] Єсілевський В. С., Тевяшев А. Д., Колядін А. В. Дослідження методу розпізнавання типів повітряних об'єктів на основі нормалізованих дескрипторів контуру та комплекснозначної нейронної мережі «Східно-Європейський журнал передових технологій», № 6(108), 2020.

[27] ГОСТ Р 54022-2010, Группа Э50, НАЦИОНАЛЬНЫЙ СТАНДАРТ РОССИЙСКОЙ ФЕДЕРАЦИИ, Глобальные навигационные спутниковые системы, СИСТЕМА ТРАЕКТОРНЫХ ИЗМЕРЕНИЙ ЛЕТАТЕЛЬНЫХ АППАРАТОВ НА БАЗЕ НАВИГАЦИОННЫХ СПУТНИКОВЫХ СИСТЕМ.

[28] Zhalilo O.O., Dokhov O.I., Yakovchenko O.I. Multi-positional phase system of trajectory measurements and experimental confirmation of its accuracy using GPS-observations of the ukrainian reference stations. Тези доповідей ІІІ-ї науково-практичної конференції »Аерокосмічні технології в Україні: проблеми та перспективи», 12–13 вересня 2019 року, Київ, НЦУВКЗ. С. 105–106.

[29] Zhalilo O. O., Yakovchenko O. I. LEOS trajectory determination using the on-board GPS-observations and PPP-technologies of their processing. Тези доповідей ІІІ-ї науково-практичної конференції «Аерокосмічні технології в Україні: проблеми та перспективи», 12–13 вересня 2019 року, Київ, НЦУВКЗ. С. 107.

[30] Жалило А. А., Дохов А. И., Яковченко А. И. Автономное (PPP) и дифференциальное (DGPS) кинематическое позиционирование. Сравнение точности на примере обработки бортовых GPS-наблюдений самолёта АН-158. Метрология, информационно-измерительные технологии и системы (МИИТС-2020). Тезисы докладов VII Международной научно-технической конференции. Харьков, 2020. С. 33. DOI: https://doi.org/10.24027/2306-7039.1A.2020.193279.

[31] Дохов О. І., Жаліло О. О., Літус Ю. П., Тевяшев А. Д., Шостко І. С., Яковченко О. І. Розробка полігонного комплексу радіотехнічних та квантово-оптичних систем траєкторних вимірювань. Збірник ХХ науково-технічної конференції «Створення та модернізація озброєння і військової техніки в сучасних умовах» ДНВЦ ЗСУ, м. Чернігів, 03–04 вересня 2020 р. С. 78–79.

[32] Жаліло О. О., Дохов О. І., Яковченко О. І., Літус Ю. П., Катюшина О. В., Лук'янова О. О., Медведський М. М., Пап В. О. Реалізація ГНСС-технології автономної PPP-навігації високодинамічних об'єктів з використанням корекцій SBAS. Збірник ХХ науково-технічної конференції «Створення та модернізація озброєння і військової техніки в сучасних умовах» ДНВЦ ЗСУ, м. Чернігів, 03–04 вересня 2020р. С. 85.

[33] Жаліло О. О., Дохов О. І., Яковченко О. І. Траєкторні визначення приземних літальних апаратів з використанням бортових GPS-спостережень. Проблеми координації воєнно-технічної та оборонно-промислової політики в Україні. Перспективи розвитку озброєння та військової техніки. Тези доповідей на VIII науково-технічній конференції («Зброя та безпека-2020»), м. Київ, жовтень 2020 р. С. 115–116.