Brief information about the project

Name of the project	AP09260469 «Development of a control system for configuration keeping of the spacecraft formation with taking into account the uncertainties» (0121PK00371)
Relevance	At present, in the tasks of space exploration, an increasing number of researchers prefer to consider the spacecraft formation instead of a single satellite. This is because in the formation, small spacecrafts are involved, the development of which takes less time and money. In addition, with the help of formations, it is possible to solve a whole class of new problems that cannot be solved by a single satellite. For example, the simultaneous measurement of any indicators at different spatial points is important when studying magnetic or gravitational fields, ionosphere, atmosphere, etc. The potential of spacecraft formation is interesting for the tasks of astronomical observations, stereographic imaging of the Earth's surface, and remote sensing of the Earth in real time. Along with new opportunities for researchers, new challenges arise. One of the key tasks in the performance of a mission by a formation is to build a control system for keeping or rebuilding the configuration of spacecrafts. Depending on the mission, various configurations are selected, and in each case, the control system is developed for the specific tasks. Therefore, the development of a control system for a formation in a tetrahedral configuration in cases of unperturbed and perturbed reference orbits of the major spacecraft, taking into account the shape of the Earth, perturbations from the gravitational fields of the Moon and the Sun and from uncertainties is an actual scientific and technical problem which has great applied value.
Purpose	Development of a control system able to keep the required configuration of spacecraft formation for the performed mission purposes, taking into account the uncertainties caused by external disturbances
Objectives	• Development of a mathematical model of the spacecraft formation motion in the case of an unperturbed reference orbit. Measurable indicators: determination of the major spacecraft's position in an unperturbed reference orbit, also the relative positions of any spacecraft in the formation at any time. Task role: determination of stability conditions of the configuration for further development of control algorithms for keeping the required configuration. • Constructing control algorithms of formation configuration in case of an unperturbed reference orbit. Measurable indicators: control algorithm for keeping the spacecraft formation configuration in case of an unperturbed reference orbit based on feedback methods. Task role: basic algorithm for further more complex task, taking into account the main perturbing forces. • Development of a mathematical model of the spacecraft formation motion in case of an unperturbed reference orbit, taking into account the main perturbing forces. Measurable indicators: determination of the major spacecraft's position in an unperturbed reference orbit, also the relative positions of any spacecraft in the formation, with accounting the inhomogeneity of the Earth

	potential field and lunisolar perturbations. Task role: determination of the stability conditions of spacecraft configuration for further development of control algorithms for keeping the configuration, taking into account the main perturbing forces. • Constructing control algorithms of the spacecraft formation configuration taking into account the main perturbing forces. Measurable indicators: control algorithm for keeping the spacecraft formation configuration taking into account the main perturbing forces based on methods such as LQR (Linear Quadratic Regulator). Task role: the basic algorithm for further more complex task, taking into account the uncertainties. • Development of a mathematical model of the spacecraft formation motion in case of a perturbed reference orbit, taking into account the main perturbing forces. Measurable indicators: determination of the of the major spacecraft's position in a perturbed reference orbit, also the relative positions of any spacecraft in the formation, with accounting the inhomogeneity of the Earth's potential field and lunisolar perturbations. Task role: determination of the stability conditions of the spacecraft configuration for further development of control algorithms for keeping the configuration taking into account uncertainties. • Constructing control algorithms of formation configuration in case of a perturbed reference orbit, taking into account uncertainties. Measurable indicators: control algorithm for keeping the spacecraft formation configuration, with accounting the main perturbing forces and uncertainties. Task role: development of a control system for keeping the spacecraft formation configuration, taking into account the uncertainties.
Expected and achieved results	• Development of a mathematical model of the spacecraft formation motion and determination of the configuration stability conditions in case of an unperturbed reference orbit. Construction of a control system for keeping the spacecraft formation configuration in case of an unperturbed reference orbit. • Development of a mathematical model of the spacecraft formation motion and determination of the configuration stability conditions in case of an unperturbed reference orbit, taking into account the main perturbing forces. Construction of a control system for keeping the spacecraft formation configuration in this case. • Development of a mathematical model of the perturbed motion of a spacecraft formation and determination of the configuration stability conditions in case of a perturbed reference orbit. Construction of a control system for keeping the spacecraft formation configuration in case of a perturbed reference orbit, taking into account uncertainties.
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List of publications with links to them	List of published works on the project 2021 1. Rakisheva Z.B., Doszhan N.S., Ibraev G.E. Vyvod uravnenij dvizheniya gruppirovki KA. Reports digest Second International Joldasbekov Symposium «FUTURE MECHANICS» - Almaty, March 1-5, 2021. ISBN 978-601-08-0953-6. p.295-302 (In Russian) 2. Rakisheva Z.B., Sakhaeva A.K. Issledovanie yavleniya apvellinga v kaspijskom more po sputnikovym dannym 2018g. Reports digest Second International Joldasbekov Symposium «FUTURE MECHANICS» - Almaty, March 1-5, 2021. ISBN 978-601-08-0953-6. p.293-294 (In Russian) 3. Kalybekova A.A., Sukhenko A.S. Monitoring vodopotrebleniya vdol' Arys'-Turkestanskogo magistral'nogo kanala putem primeneniya dannyh s BPLA i so sputnika. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-8, 2021. ISBN 978-601-04-5309-8. p. 88. (In Russian) 4. Manazhanov E. E., Rakisheva Z.B. Issledovanie vliyaniya vneshnih vozmushchenij na dvizhenie gruppirovki kosmicheskih apparatov na geostacionarnoj orbite. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-8, 2021. ISBN 978-601-04-5309-8. p. 90. (In Russian) 5. Imangazina A. A., Rakisheva Z.B. Issledovanie dvizheniya gruppirovki kosmicheskih apparatov v sluchae nevozmushchennoj opornoj orbity s uchetom figury zemli. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-8, 2021. ISBN 978-601-04-5309-8. p. 91. (In Russian) List of published works on the project 2022 1. Abdrashev A.R., Rakisheva Z.B. Issledovanie otnositel'nogo dvizheniya kosmicheskih apparatov v gruppirovke. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-8, 2022. ISBN 978-601-04-5985-4. p. 83. (In Russian) 2. Imangazina A.A., Rakisheva Z.B. Issledovanie dvizheniya gruppirovki kosmicheskih apparatov v sluchae nevozmushchennoj opornoj orbity s uchetom figury zemli. Materials of International

	Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-8, 2022. ISBN 978-601-04-5985-4. p. 84. (In Russian) 3. Manazhanov E.E., Rakisheva Z.B. Issledovanie vliyaniya vneshnih vozmushchenij na dvizhenie gruppirovki kosmicheskih apparatov na geostacionarnoj orbite. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-8, 2022. ISBN 978-601-04-5985-4. p. 86. (In Russian) 4. Xu P., Rakisheva Z.B. Orbital planning methods for spacecraft in orbit. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-8, 2022. ISBN 978-601-04-5985-4. p. 92. (In English) 5. Zaure Rakisheva, Anna Sukhenko, Nazgul Kaliyeva, Nursultan Doszhan, Gulama-Garip Alisher Ibrayev. Some Algorithms for Controlling the Motion of Satellites in a Formation. 11th Nano-Satellite Symposium. - Istanbul, Turkiye, October 17-21, 2022. https://nanosat11th.itu.edu.tr/assets/papers/SOME.pdf (In English) List of published works on the project 2023 1. Z.Rakisheva, A. Sukhenko, N. Doszhan, G.-G.A. Ibrayev, N. Kaliyeva, Sh. Nakasuka, and Y. Shabdan. Evaluation of Applicability of Some Algorithms for Controlling the Motion of Satellites in a Formation // Engineered Science. DOI:10.30919/es1025 (Published Online). 2023 (**Scopus, Percentile 98**) 2. P.Xu, N. B. Kalieva, Z.B. Rakisheva. Development of a program for the prediction of placement of spacecraft based on TLE data. International Journal of Mathematics and Physics 14, №1(2023).https://doi.org/10.26577/ijmph.2023.v14.i1.02 (**Scopus, SJR 0.11, CiteScore 0.2**) (In English) 3. Z.B. Rakisheva, N.B. Kaliyeva, N.S. Doszhan. Proektirovanie sistemy upravleniya dvizheniem gruppirovki sputnikov dlya distancionnogo zondirovaniya Zemli - Almaty: Kazakh university, 2023. - 68p. ISBN 978-601-04-6497-1. (**Monograph**) (In Russian) 4. Kaliyeva N.B., Rakisheva Z.B., Xu P. Programma dlya opredeleniya i prognozirovaniya polozheniya sputnikov na osnove dannyh TLE. Certificate № 39898 dated from «26» October 2023. (**Certificate of authorship**) (In Russian) 5. Ergazy Zh.N., Kalieva N.B., Gharysh toptamasynyn qozgalysyn zertteu. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-7, 2023. ISBN 978-601-04- 6252-6. p. 85. (In Kazakh) 6. Zhenis B.T., Ibraev G-G A.E., Kishi klasterli gharysh apparattar toptamasynyn konfiguraciyasyn saqtauga arnalgan basqaru zhujesin zhobalau. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-7, 2023. ISBN 978-601-04- 6252-6. p. 86. (In Kazakh) 7. Muqataj S., Rakisheva Z.B., Zherdin tomengi orbitalaryndagy massalarynyn arturli gharyshtyq apparatqa aser etetin syrtqy kushter. Materials of International Scientific Conference of Students and

	Young Scientists «FARABI ALEMI». - Almaty, April 6-7, 2023. ISBN 978-601-04- 6252-6. p. 88. (In Kazakh) 8. Elen S.S., Ibraev G-G A.E. Antenndi-optikalyq moduli integraciyalangan gharysh apparatynyn bagdaryn basқaru zhujesin zhasau. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-7, 2023. ISBN 978-601-04- 6252-6. p. 90. (In Kazakh) 9. Sajlaubekov A.T., Doszhan N.S., Shagyn gharysh apparattarynyn qozgaltqysh qurylgylaryn zertteu. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-7, 2023. ISBN 978-601-04- 6252-6. p. 92. (In Kazakh) 10. Xu P., Rakisheva Z. Optimizing spacecraft placement on orbit: a methodological approach. Materials of International Scientific Conference of Students and Young Scientists «FARABI ALEMI». - Almaty, April 6-7, 2023. ISBN 978-601-04- 6252-6. P.100. (In English)
Patents	-