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**Kauno technologijos universitetas**

Elektros ir elektronikos fakultetas

**ESA spiečiaus palydovai**

Semestro projektas

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Turinys

[Paveikslų sąrašas 3](#_Toc149511617)

[Santrumpų ir terminų sąrašas 4](#_Toc149511618)

[Įvadas 5](#_Toc149511619)

[1. Kosmoso palydovai 6](#_Toc149511620)

[2. Palydovo architektūra 10](#_Toc149511621)

[3. Realūs panaudojimai 11](#_Toc149511622)

[Išvados 12](#_Toc149511623)

[Literatūros sąrašas 13](#_Toc149511624)

Paveikslų sąrašas

[1 pav. Palydovų patikimumas nuo laiko [2] 7](#_Toc122688019)

[2 pav. Kubinių palydovų patikimumas [3] 7](#_Toc122688020)

[3 pav. Žalingas radiacijos poveikis tranzistoriui 10](#_Toc122688021)

[4 pav. Palydovo posistemių blokinė diagrama 12](#_Toc122688022)

[5 pav. Sematinio versijavimo pavyzdys 14](#_Toc122688023)

[6 pav. ,,Nanoavionics“ *FlatSat* su tarpusavyje sujungtomis posistemėmis 15](#_Toc122688024)

[7 pav. Standartinė programos pasileidimo seka 16](#_Toc122688025)

[8 pav. Programos struktūra vidinėje atmintyje 16](#_Toc122688026)

[9 pav. Tipinė priežiūros laikmačio schema 18](#_Toc122688027)

Santrumpų ir terminų sąrašas

**Santrumpos:**

ESA

NASA

AOCS –

ADCS – pokrypio nustatymo ir valdymo sistema (*angl. Attitude Determination and Control System*)

COTS – rinkoje laisvai prienami produktai (*angl. Commercial off-the-shelf*)

FC – skrydžio valdiklis (*angl. Flight controller*)

**Terminai:**

**aaaaa**

**Propulsija (angl. *propulsion*)** – sistema, naudojama kosmoso palydovams manevruoti.

**Femtopalydovai** – itin maži palydovai, kurių tūris mažesnis nei 10cm3.

Įvadas

PERRASYTI??? -> akcentuoti kam reikalingas magnetins laukas ir jo zinojimas

Mūsų planetos šerdis yra ta vieta, kur atsiranda didžioji dalis Žemės magnetinio lauko. Jis gaminamas savaimio dinamo proceso metu, kai naudojama išlydyta geležis, judanti turbulenciniais judesiais. Tačiau pagrindinis magnetinio lauko komponentas, esantis už šerdies, yra magnetinis dipolis. Šis komponentas, šiuo metu krinta greičiu, nei kažkada anksčiau. Per pastaruosius 150 metų dipolio momentas sumažėjo maždaug 8%.

Pietų Atlanto anomalijoje, kur laukas ir taip yra silpniausias, šis praradimas prisidėjo prie daug didesnių regioninių poslinkių – net 10 % per pastaruosius 20 metų, kartu su nedipoliais pokyčiais.

Būtent todėl žemės magnetinis laukas yra begalo svasbus.

Šiandien, tyrinėdami Žemės magnetinio lauko paslaptis ir jos įtaką mūsų planėtai, negalime nepasigilinti į Europos kosmoso agentūros (ESA) inovatyvią misją – spiečiaus palydovų sistemą "Swarm". Tai ne tik technologinis šuolis žemės mokslų srityje, bet ir unikalus būdas tyrinėti geomagnetinius reiškinius iš orbitos. Šiame referate išsamiai yra išanalizuota "Swarm" palydovų misiją, jos tikslai bei duomenų rinkimo metodika. Be to, darbe yra aptariame kaip šie palydovai praplečia mūsų supratimą apie Žemės magnetinį lauką ir jo kintamumus. Ši misija buvo pradėta siekiant giliau suprasti Žemės magnetinio lauko kilmę, dinamiką ir sąveiką su aplinkos veiksniais. Būtent dėl šių priežasčių šiame darbe yra nagrinėjamos "Swarm" palydovų konstrukcijos, jų tyrimų tikslai bei svarbiausi rezultatai, kurie praplečia mūsų supratimą apie Žemės magnetinį lauką.

# Kosmoso palydovai

Kosminiai palydovai yra dirbtiniai objektai, kurie yra iškeliami į orbitą aplink Žemę ar kitus dangaus kūnus. Jie paleidžiami į kosmosą naudojant raketas ir naudojami įvairiems tikslams, įskaitant ryšį, navigaciją, orų prognozes ir mokslinius tyrimus.

Kosminiai palydovai yra svarbi mūsų šiuolaikinės visuomenės dalis ir turi daug praktinių pritaikymų, pavyzdžiui, suteikia prieigą prie interneto, įgalina GPS navigaciją ir padeda numatyti bei sekti orų tendencijas. Be jų mūsų šiuolaikinis gyvenimas nebūtų galimas, tačiau dirbtiniai palydovai tapo realybe tik XX amžiaus viduryje. Pirmasis dirbtinis palydovas buvo *Sputnik 1*, Rusijos kosminis zondas, pakilęs 1957 m. spalio 4 d. Šis veiksmas sukrėtė didžiąją dalį Vakarų pasaulio, nes buvo manoma, kad sovietai neturėjo galimybių siųsti palydovų į erdvę.

Šiuo metu kosmose skrieja tūkstančiai žmogaus sukurtų palydovų. Vieni fotografuoja žemę, kad padėtų meteorologams prognozuoti orą ir sekti uraganus, kiti fotografuoja kitas planetas, saulę, juodąsias skyles, tamsiąją materiją ar tolimas galaktikas. Šie vaizdai padeda mokslininkams suprasti Saulės sistemą ir visatą. Maždaug pusė visų kosmoso palydovų vykdo mokslinių tyrimų misijas, kurios dažniausiai būna susijusios su atmosferos, visata ar Žemės tyrinėjimu [1]. Konkrečiau mokslo tyrimų sritys apima: biologijos mokslą, netoli Žemės esančių objektų, klimato kaitos, sniego / ledo dangos, orbitos šiukšlių, planetų tyrinėjimo ir tolimojo kosmoso astronomijos tyrimus. Du trečdaliai visų misijų yra naujų technologijų kūrimas arba demonstravimas. Duomenų perdavimo sistemos, propulsijos sistemos, nauji navigacijos ir valdymo algoritmai bei radiacijos bandymai yra dažniausiai pasitaikančios misijų rūšys. Kitos galimos technologijos yra saulės burės, femtopalydovai (itin maži) ir išmaniųjų telefonų palydovai. Pastaraisiais metais itin sumažėjusios pakilimo į orbitą išlaidos leidžia vykdyti didesnės rizikos veiklą, kuri nebūtų įmanoma didelės apimties ESA ar NASA misijose.

## Europos Kosmoso agentūra

Europos Kosmoso agentūra (ESA) yra tarptautinė organizacija, įkurta 1975 metais, kurios tikslas yra plėtoti ir koordinuoti Europos kosmoso tyrimus. ESA yra sudaryta iš 22 valstybių narių, įskaitant daugelį Europos Sąjungos valstybių. Jos veikla yra orientuota į taikius kosmoso tyrimus, technologijų plėtrą ir kosmoso naudojimą moksliniams, ekonominiams ir saugumo tikslams.

ESA yra žinoma dėl įvairių sėkmingų kosmoso misijų, kurios apima palydovų siuntimus, tarptautinius kosminius stoties projektus ir kitus ambicingus tyrimus. Misijos yra kuriamos siekiant atsakyti į įvairius mokslinius klausimus, suprasti kosmoso reiškinius ir pritaikyti kosminę technologiją žmogaus naudai. ESA taip pat įgyvendina kitas misijas, įskaitant palydovų tyrimus apie klimato kaitą, Žemės atmosferos stebėjimus, Marsą tyrinėjančius aparatus ir daugelį kitų projektų.

Vienos iš žymiausių ESA misijų yra Hubble kosmoso teleskopas, Gaia kosmoso observatorija ir marso orbitos misja – Mars express.

Kiekviena iš šių misijų padeda mums giliau suprasti mūsų planetą, kosmoso reiškinius ir platesnį Visatos kontekstą.

### ESA MAGsat misija

**Magsat** mission from about 20 years ago. Due to the 2000 launches of two more magnetic mapping satellites, CHAMP and SAC-C, which have all provided high-precision geomagnetic data over the first few years of this decade, this activity has changed to what it is now.

Despite having comparable magnetic equipment, their orbits, science payloads, and spacecraft architecture differ. They so generate data with distinctly diverse properties. This reduces the benefit to science that comes from comparing data that is simultaneously collected at various locations by several satellites. Specifically, it is then challenging to represent the irregularly fluctuating fields caused by the external currents. This also happens to be the primary constraint on the current geomagnetic field models' accuracy. It is just not possible for single-satellite missions to fully benefit from the remarkable advancements in instruments made over the last ten years.

## ESA’s Swarm satellites misija

The Swarm mission is based on a mission proposal (FriisChristensen et al., 2002) submitted in response to the ESA Earth Observation Programme call for Opportunity Mission proposals. Among 25 submitted proposals Swarm was one of the three candidates selected for feasibility studies. The Phase-A studies were finalised during 2004 and the results were included in an evaluation report (ESA SP-1279(6) and Technical and Programmatic Annex, 2004) presented for the final mission selection. Figure 3 shows the spacecraft designs proposed by the industrial consortia in Phase A. In May 2004 the Swarm mission was selected as the fifth Earth Explorer Mission in ESA’s Living Planet Programme aiming at a launch in 2010

The Swarm mission was selected as the 5th mission in ESA’s Earth Explorer Programme in 2004. The mission will provide the best ever survey of the geomagnetic field and its temporal evolution that will lead to new insights into the Earth system by improving our understanding of the Earth’s interior and its effect on Geospace, the vast region around the Earth where electrodynamic processes are influenced by the Earth’s magnetic field. Scheduled for launch in 2010, the mission will comprise a constellation of three satellites, with two spacecraft flying sideby-side at lower altitude (450 km initial altitude), thereby measuring the East-West gradient of the magnetic field, and the third one flying at higher altitude (530 km). High-precision and high-resolution measurements of the strength, direction and variation of the magnetic field, complemented by precise navigation, accelerometer and electric field measurements, will provide the necessary observations that are required to separate and model the various sources of the geomagnetic field. This results in a unique “view” inside the Earth from space to study the composition and processes of its interior. It also allows analysing the Sun’s influence within the Earth system. In addition practical applications in many different areas, such as space weather, radiation hazards, navigation and resource management, will benefit from the Swarm concept

the Swarm mission refers to a group of three satellites operated by the European Space Agency (ESA). These satellites are designed to study the Earth's magnetic field and its variations with unprecedented precision. The Swarm mission was launched on November 22, 2013, with the aim of providing new insights into the Earth's magnetic field and its interactions with the Earth system.

Key objectives of the Swarm mission include:

Magnetic Field Mapping: Swarm aims to create high-resolution maps of the Earth's magnetic field, allowing scientists to understand its structure and behavior in detail.

Geophysical Processes: By studying the Earth's magnetic field, scientists can gain insights into geophysical processes occurring deep within the planet, such as the movement of molten iron in the outer core.

Ionospheric and Magnetospheric Studies: The Swarm satellites also contribute to the study of the Earth's ionosphere and magnetosphere, helping researchers understand the complex interactions between the solar wind and the Earth's magnetic field.

Each Swarm satellite carries a suite of instruments, including magnetometers, accelerometers, and GPS receivers, to measure various aspects of the Earth's magnetic field and related phenomena. By having multiple satellites in orbit simultaneously, the mission can provide three-dimensional mapping of the Earth's magnetic field and monitor changes over time.

These precise measurements are valuable for a range of scientific disciplines, including geophysics, space weather research, and studies related to the Earth's interior dynamics. The Swarm mission enhances our understanding of the Earth's magnetic field, which has practical applications in navigation, satellite technology, and a better understanding of environmental changes.

Moryvacija:

The motivation behind the Swarm mission lies in the scientific interest and practical applications associated with understanding the Earth's magnetic field. The Earth's magnetic field is a dynamic and complex system that plays a crucial role in various geophysical processes. Here are some key motivations for the Swarm mission:

Scientific Exploration: The Earth's magnetic field is generated by the motion of molten iron in the outer core of the Earth. Studying the magnetic field provides insights into the Earth's interior dynamics and processes, such as the movement of molten iron and the generation of magnetic anomalies.

Geomagnetic Variations: The Earth's magnetic field is not constant and undergoes variations over time. These variations can be caused by changes in the Earth's core, as well as external factors such as interactions with the solar wind. Understanding these variations is crucial for advancing our knowledge of Earth's geophysics.

Space Weather: The Earth's magnetic field interacts with the solar wind, and this interaction can influence space weather phenomena. Space weather events, such as solar flares and geomagnetic storms, can impact satellite operations, communication systems, and power grids on Earth. Studying the Earth's magnetic field helps in better understanding and predicting space weather.

Navigation and Satellite Technology: Precise knowledge of the Earth's magnetic field is essential for navigation and the operation of satellites. It allows for accurate navigation systems and helps mitigate the effects of magnetic anomalies on satellite instruments.

Ionospheric and Magnetospheric Studies: The Swarm mission contributes to the study of the Earth's ionosphere and magnetosphere. These regions are influenced by the Earth's magnetic field and play a crucial role in the interaction between the Earth and the solar wind.

By deploying a constellation of three satellites (Swarm Alpha, Bravo, and Charlie), the mission aims to provide detailed and comprehensive measurements of the Earth's magnetic field. The simultaneous measurements from multiple satellites allow scientists to create high-resolution maps and three-dimensional models of the magnetic field, improving our understanding of its structure and dynamics. The data collected by Swarm contributes to advancements in geophysics, space weather research, and various scientific and practical applications.



# Palydovo architektūra

The three Swarm Satellites each weigh 472 Kilograms at launch including 106 Kilograms of propellant. Each spacecraft is 9.1 by 1.5 by 0.85 meters in size being designed with special focus on magnetic cleanliness, field vector attitude knowledge, a low ballistic coefficient and Center of Gravity location for accelerometer measurements.

To meet these requirements, the Swarm satellites include a 4-meter long boom that is deployed in orbit to accommodate the magnetometer as far away from the satellite bus as possible, minimizing any magnetic disturbance. The vector magnetometer is installed on an ultra-stable silicon carbide-carbon fiber compound optical bench that provides a high thermal stability.

The Swarm Attitude and Orbit Control Subsystem is closely coupled with the propulsion system called the Orbit Control Subsystem. Precise attitude data is provided by a star tracker assembly that consists of three heads, three magnetometers and six Coarse Sun and Earth Sensors that are used for pointing in safe and acquisition mode. A dual frequency GPS receiver is used to provide Precise Positioning Service for spacecraft control and the instruments as well as precise timing data for time-tagging. All sensors are redundant in architecture. Data from the AOCS sensors is provided to the AOCS computers that actuate the propulsion and attitude control system.

The satellites are equipped by several instruments to measure the Earth’s magnetic field, to monitor the ionospheric plasma environment and to determine the orbit and orientation of the satellites as best as possible (e.g., by Global Navigation Satellite Systems-GNSS, laser retroreflector, accelerometers).

Each satellite is nine metres long, which a main body covered in solar panels and a four metre boom on which the sensitive magnetic field measuring instruments sit - away from electrical and magnetic interference. [ref archk 1]

The magnetic field is measured by two instruments - (1) by the scalar instrument at the end of the boom which measures the strength of the field and (2) the vector instrument in the middle of the boom, which measures the direction of the field, using star cameras for accurate orientation of the satellite.

In this work, we analysed the data of the Vector Field Magnetometer (VFM) and the Absolute Scalar Magnetometer (ASM) placed at the middle and at the end of a four-meter boom, respectively, both located at the back of each satellite. ESA downloads the raw data from Swarm satellites to the Kiruna and Svalbard stations and processes them in almost real-time (with a delay of 3–4 days only).

The satellites also measures the electric field in the ionosphere using novel Langmuir probes and an electric field instrument sited on the front of the satellite, giving a full physical measurement of the field in the upper atmosphere for the first time.



[ref archk 1] - <http://www.geomag.bgs.ac.uk/education/swarm_overview.html>

The Agency provides calibrated magnetic open access data at Level 1b, where the measurements are provided not only in the instrumental frame but are also oriented in the Earth frame system NEC (North, East, Centre) at the original sampling frequency of 50 Hz (HR = High Resolution) and resampled at 1 Hz at the GPS o’clock seconds (LR = Low Resolution).

Solar panels

Gps antenos

S-band Kommunikaciai naudotas S-band kas dabar jau praktikoje nera labai taikomas del savo mazo greicio.

Akseleroetras

Laser retro

## Pagrindinė naudingoji apkrova (angl. *payload*)

Tie du magnetometrai.

Vector Field Magnetometer (VFM) and the Absolute Scalar Magnetometer (ASM) placed at the middle and at the end of a four-meter boom, respectively

## Modeliai ir skaičiavimai

Kadangi sukurti realias

# Realūs panaudojimai

Detaliau šiame darbe yra

## Pavyzdys

Furthermore, the Swarm Bravo satellite, i.e., that one at highest orbit, passed above the epicentral area 15 min before the earthquake and detected an anomaly mainly in the Y component. These analyses applied to the Ridgecrest earthquake not only intend to better understand the physical processes behind the preparation phase of the medium-large earthquakes in the world, but also demonstrate the usefulness of a satellite constellation to monitor the ionospheric activity and, in the future, to possibly make reliable earthquake forecasting.

In order to extract magnetic anomalies possibly related to the major seismic events, we need to remove the main magnetic field. We then apply an approach successfully used in previous works and well described in the Methods section of [15] under the name of the MASS (MAgnetic Swarm anomaly detection by Spline analysis) algorithm.

## Duomenys

Misijos duomenys yra viesai pasiekiami

<https://earth-planets-space.springeropen.com/articles/10.5047/eps.2013.07.011>

Nauojami space weather aptikimams kad galima butu isjungti satus kitus:

https://link.springer.com/article/10.1007/s11214-022-00916-0#Sec8

Išvados

1. Darbe apžvelgti palydovų kūrimo specifika ir
2. Išanalizuota, kad
3. Detaliai išanalizuoti
4. Pateiktos palydovus kuriančios

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