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WatcherCatcher: A Real-time Function of SPACEMAP to Predict Spy Satellites in Timeline

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Abstract

Space is busy and will be busier in the New Space Age. One of the phenomena is mega-constellations such as Starlink, OneWeb, Planet Labs, Capella Space, etc. with applications of internet communication, imagery, Earth and space observations, and so on. Suppose that you want to predict satellites which can take your picture tomorrow while you are at a fixed location. Consider a bit more complicated but similar in its nature that you are driving a car. Suppose that you want to predict the satellites in a communication constellation, e.g., Starlink or OneWeb, which can uplink and downlink data with your data terminal. SPACEMAP can produce real-time solutions to these problems, and many more applications, using its WatcherCatcher function. WatcherCatcher can be even used for airplane and satellites flying in midair and orbits, respectively. The efficiency of SPACEMAP is possible by taking a full advantage of Voronoi diagrams. SPACEMAP runs on AWS and exploits elastic compute and auto scaling features. SpaceMap currently uses the TLE data from Space-Track. Currently, WatcherCatcher function is running via SPACEMAP's webservice (https://www.spacemap42.com).

Keywords: mega-constellations, adversarial satellites, earth & space observation, internet communication, Voronoi diagram

1. Introduction

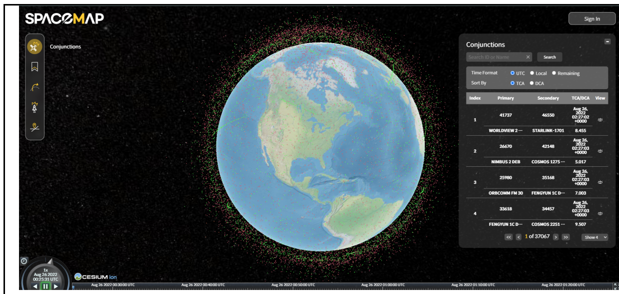
Space gets crowded rapidly as more satellites are deployed into orbit. The cheaper manufacturing and launching costs of satellites will accelerate this trend [1]. One such example is mega-constellations such as Starlink, OneWeb, Planet Labs, Capella Space [2-4], etc with applications of communication, imagery, earth and space observations, and so on [5-7].

Due to this sharp rise in space population, space community faces two critical issues: the safety of spaceflight and long-term sustainability of space activites [8]. It is estimated that 100 million or more tiny debris smaller than one millimetre in size in LEO [9,10]. This number will increase rapidly due to accidental satellite collisions [11], anti-satellite missile test [12, 13], new satellite launches, etc. The increasing space objects, particularly in LEO, significantly accelerate conjunction/collision risks among space objects [14].

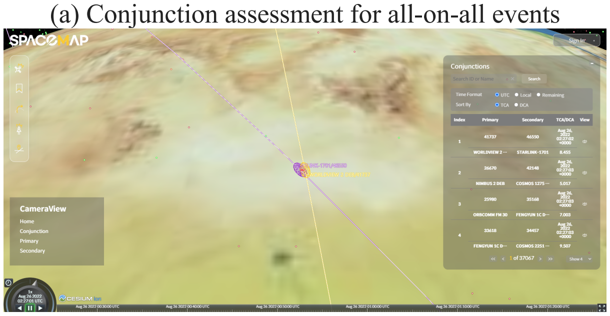
SPACEMAP [15] is a real-time decision-making platform to make the space safer, more sustainable, and efficient by solving spatial reasoning problems among space objects including satellites, launch vehicles, debris, etc.

The SPACEMAP services fall into three categories: Safety, efficiency, and intelligence. Safety includes conjunction assessments for space objects and their optimal avoidance. SPACEMAP provides conjunction assessment service among space objects registered in TLE (Two-line element set) data (Refer to Fig. 1). Higher accuracy data is expected to be employed in near future. SPACEMAP aims to contribute to safe and sustainable space by assisting launch companies, satellite constellation owners/operators, insurance companies, etc.

Efficiency category includes problems related with optimizations such as optimal data transmission through constellation, optimal earth observation scheduling of constellation, optimal vehicle's visit scheduling among space objects, etc. Intelligence category includes problems related with collecting information about satellite operations of both friend and/or foe. A simple example is to predict the satellites in a communication constellation, such as Starlink or OneWeb, which can uplink and downlink with your data gateway. Another one is to identify all adversarial satellites which will approach own asset within, e.g. 10 km during 24h tomorrow.



(a) Conjunction assessment for all-on-all events



(b) Conjunction assessment for events of an object

Fig. 1. Conjunction assessment service of SPACEMAP among space objects registered in TLE (Two-line element set) data. The service can be tested at https://www.spacemap42.com.

Most SPACEMAP services are related with hard problems which are computationally expensive to solve. As many more satellites will be deployed in forthcoming years, there will be many requests to solve these problems to find good solutions in near real-time. SPACEMAP is based on the theory of Voronoi diagrams and its robust software implementation that have been studied for more than twenty years [16-19]. SPACEMAP has now started to attract both giant space tech companies and start-ups.

This paper introduces the services of SPACEMAP mainly focusing on the services related with intelligence and efficiency. The rest of this paper is organized as follows. Section 2 presents SPACEMAP's WatcherCatcher service and its related applications. Section 3 presents other services of SPACEMAP. Section 4 concludes the paper.

2. WatcherCatcher Service

A satellite mega-constellation in LEO have become important with many projects for global communications coverage, imagery, earth and space observations. Especially, earth-observing constellations have many useful applications such as weather/climate and natural disasters monitoring, scientific research for meteorology, oceanography, terrestrial ecology, atmospheric science, etc.

Suppose that you want to observe some site on earth surface via satellite constellation in the timeline. Then we may want to predict which satellites can take the picture of your site in your preference time. Or suppose that you want to predict the satellites in a communication constellation, such as Starlink or OneWeb, which can uplink and downlink with your data terminal. SPACEMAP can provide a real-time report of the solutions to these problems via WatcherCatcher service.

Fig. 2 shows input page of WatcherCatcher service. SPACEMAP takes the following system parameters for this service: latitude, longitude, altitude of your target site, field-of-view (FOV), prediction time window.

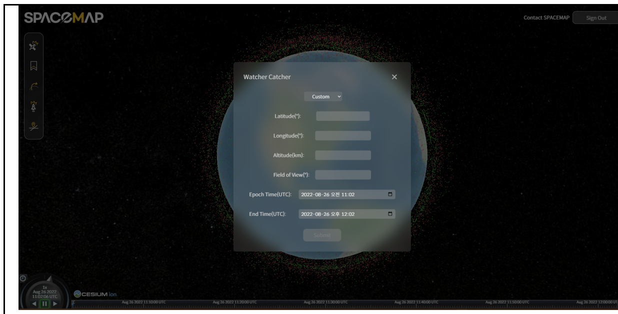


Fig. 2. Input page of WatcherCatcher

Fig. 3 illustrates a result of WatcherCatcher with a target site of Seoul, Korea, 100 degrees of FOV, and 1hr time window. A user can simulate predicted result using animation function of WatcherCatcher. Fig. 3 shows a snapshot of the animation result. The yellow cone represents the FOV. SPACEMAP predicts the satellites which will fly over your site within this yellow cone at your time window. The green line segments correspond to going-away satellites within the FOV. The red ones to approaching satellites. Table of the figure shows the list of satellites which will be within the cone during prediction time window.

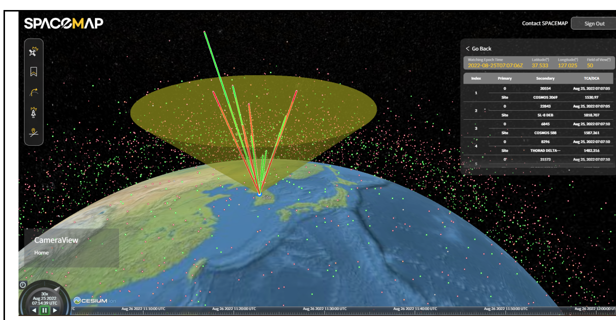


Fig. 3. WatcherCatcher, Site: Seoul, Korea, FOV: 100°

WatcherCatcher can also be used to determine the best satellite for uplinking and downlinking of transmitted data. Fig. 4 shows an example of WatcherCatcher at Ann Arbor, MI with 100 degrees of FOV. The blue line segments represent satellites of Starlink and red ones those of OneWeb.

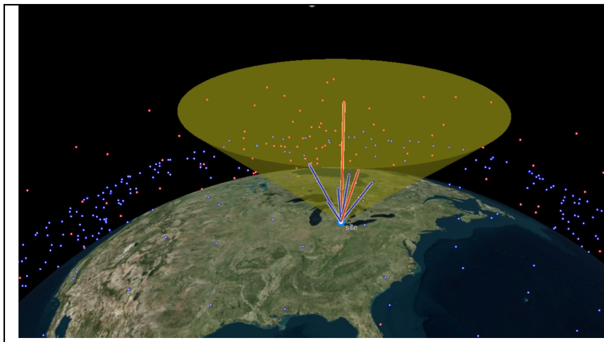


Fig. 4. Blue: Starlink, Red: OneWeb, Site: Ann Arbor, MI, FOV: 100°

Suppose that we want to monitor disasters at a target location using a satellite constellation. Since urgent observation is critical, the best satellite to observe would be the one that is available at the time. WatcherCatcher function can assist in finding the optimal satellite to observe a hot spot using the constellation. Given a location-of-interest (LOI) within a FOV, WatcherCatcher efficiently finds the satellites above the LOI within the FOV in near-real time. Then we may choose the best satellite among the candidates from WatcherCatcher considering, if any, other necessary criteria.

SPACEMAP's efficiency service category is related with optimization such as optimal data transmission through constellation, optimal earth observation scheduling of constellation, optimal vehicle's visit scheduling among space objects, etc. We want to note here both optimal satellite scheduling and optimal data transmission services in WatcherCatcher's point of view.

The rapid increase in satellite mission planning and mega-constellation inevitably lead to satellite scheduling system to optimally allocate user requests and to efficiently carry out communications between satellites and ground station. Variations of satellite scheduling formulations have been studied where the key issue is whether they can be efficiently solved to achieve best ground stations usage and to allow the largest number of mission planning requests [20]. However, it turns out that satellite scheduling problem with visibility window (time window) is NP-hard [20]: even worse, it is very challenging to find a feasible solution due to the complex constraints of the problem [21].

WatcherCatcher can help this satellite scheduling problem. Even though the results of Fig. 3 and 4 correspond to a single target site, WatcherCatcher can be easily extended to multiple target sites with near-real time performance as in the case of a single target site. Given a set of target sites and a FOV, WatcherCatcher efficiently finds the satellites above each target site within the FOV in the future timeline. The number of satellite candidates at each site provided by WatcherCatcher during prediction time window is bounded by O(1). Thus, SPACEMAP can find feasible solutions of satellites scheduling very efficiently by checking out if each candidate from WatcherCatcher satisfies other necessary constraints (e.g. the visibility window of ground station) in the timeline.

Whatever the target location or target moving object is given as an input, WatcherCatcher can help to find the best solution. Suppose that you want to predict adversarial satellites that might be able to monitor you while you are driving, assuming that the set of adversarial satellites is known a priori. The WatcherCatcher can quickly report you the candidate schedules of the satellites. This capability can be extended to identify the time interval and traveling path that will be safe from being monitored by satellites, possibly through an optimization procedure based on, e.g., the generate-and-test scheme. WatcherCatcher can be applied to the case that you are flying in an airplane, instead of driving a car.

With the benefit of low latency for mega-constellation in LEO and development of inter-satellite link (ISL) technology, satellite internet is expected to have an important part of next generation global communication systems [22]. However, due to the high speed of satellites in LEO, communication network topology changes very fast and becomes more complicated than that of MEO and GEO. In this respect, routing optimization in satellite network with ISLs will be critical to developing satellite internet communications. SPACEMAP can help this optimization because SPACEMAP can identify neighbour satellites of each moving one very efficiently. Then the best one may be chosen among those neighbours so that the shortest route can be obtained.

3. Other Services in SPACEMAP

Conjunction assessment service of SPACEMAP predicts possible conjunction events among space objects in TLE data. Fig 1(a) shows all-on-all conjunction events in TLE in the timeline of 48 hours for a given threshold (default value: 10km). If user inputs a particular object, SPACEMAP can provide conjunction events of the object only as shown in Fig 1(b). Results may be sorted with respect to TCA (time of closest approach) or DCA (distance of closest approach). User may register favourite assets and receive the conjunction report via email (See Fig. 5).

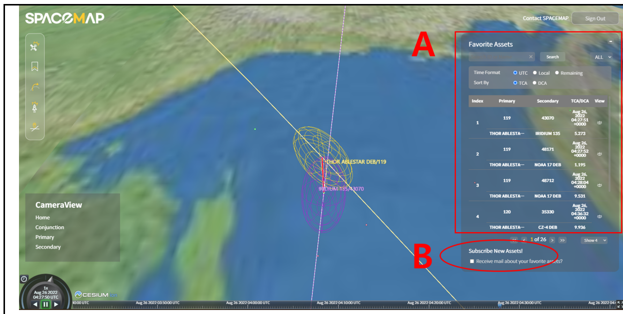
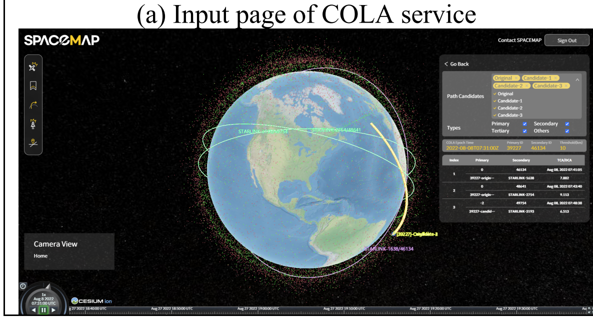


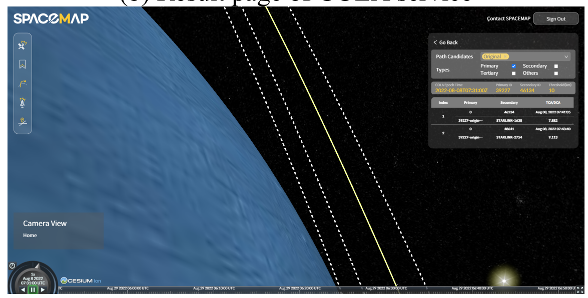
Fig. 5. Conjunction assessment service for favourite assets. A: conjunction events of favourite assets. B: a checkbox menu to consent to receive the conjunction report via email.

Suppose that we have predicted some conjunctions. We want to avoid conjunction/collision and come up with some alternatives to manoeuvre. Then SPACEMAP can evaluate those alternatives. Fig. 6(a) is the input page of collision avoidance (COLA) service of SPACEMAP. User may find some interested conjunction event via “Event Search” menu (A of Fig. 6(a)). Then user inputs some parameters for alternatives to manoeuvre as follows: Prediction time window, offset radius, the number of offsets (alternatives), and threshold as in B of Fig. 6(a). Given these parameters, SPACEMAP generates alternatives which pass through offset position from primary object’s orbit. Fig. 6(b) shows a result page of COLA service of a TLE object (id: 39227) with three alternatives where yellow corresponds to the orbit of primary, pink to that of secondary, and greens to those of tertiary (i.e. conjunctions that would occur if primary followed alternatives). Fig. 6(c) is a zoom-in of the primary orbit in solid curve and its three alternatives in broken curve.

(a) Input page of COLA service



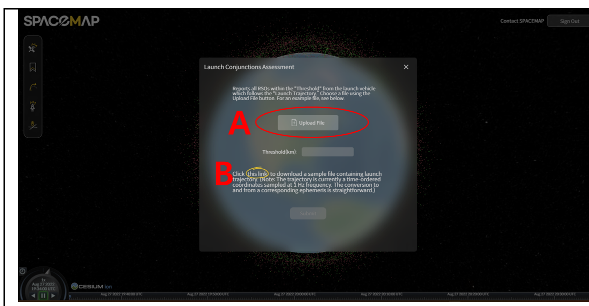
(b) Result page of COLA service



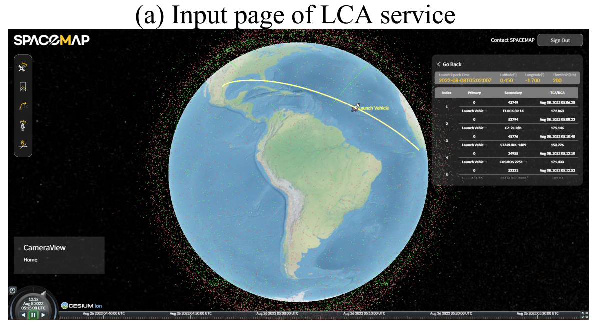
(c) Zoom-in of original and three alternatives

Fig. 6. Collision avoidance (COLA) service (a) A: User finds possible conjunction events. B: User inputs some parameters to generate alternatives: Prediction time window, offset radius, the number of offsets (alternatives), and threshold. (b): Result of COLA. (c): a zoom-in of the orbit and its three alternatives.

SPACEMAP provides conjunction assessment services for launch vehicle as well. Fig. 7(a) is an input page of launch conjunction assessment (LCA) service which takes both launch trajectory file and threshold (See A of the figure for file upload and a web ink of B for the details on file format.). Fig. 7(b) shows a result of LCA running with a virtual trajectory of a vehicle launched from Boca Chica launch site, Texas.



(a) Input page of LCA service



(b) Output page of LCA service

Fig. 7. Launch conjunction assessment (LCA) service

4. Conclusions

This paper introduces the services of SPACEMAP Inc. SPACEMAP is a start-up which was founded in

September 2021 as a spin-off of Hanyang University, Korea. SPACEMAP aims to make the space safer, more sustainable, and efficient by solving hard space problems among space objects including satellites, launch vehicles, debris, etc.

Acknowledgements

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