Jet Propulsion Laboratory
California Institute of Technology

Final Report

“Digital Twin Interoperability for Space Exploration Missions Using the Spatial Web”

Niki Namian

Dr. Thomas Lu

May 2025

ABSTRACT

As the technology known to mankind rapidly grows, the need for digital twins has become critical. A digital twin can be defined as a virtual representation of a real-world physical object that also mirrors the behavior of its counterpart[1]. This project serves as an investigation into the potential of digital twin systems. Utilizing the Spatial Web, we are able to explore the communication of digital twins across various platforms. The goal of this project is to close the gaps within the current digital twin framework in order to allow data to be transmitted in real time across several different platforms. In our project, we test across Unity, Unreal Engine, and Omniverse Isaac Sim. We utilize the Hyperspatial Modeling Language (HSML) messages to allow communication between the different platforms. Finally, in this project, we also ensure that these messages are secure and only available for use by authenticated users. Once the user is registered and authenticated, they may begin the communication between several agents and entities[2].

ACKNOWLEDGEMENTS

Interning at NASA's Jet Propulsion Laboratory and working on a project that has the potential to change space exploration as we know it is truly a dream come true. Throughout my life, I have been utterly fascinated by space exploration and am so thankful to have been able to connect my passion for computer systems and coding with space exploration at JPL.

I would like to especially thank my mentors and supervisors, **Dr. Thomas Lu** (Senior Researcher, Advanced Electronics Systems & Technology Group, JPL), **Dr. Edward Chow** (Manager, Civil Program Office, JPL), and **Jinan Darwiche** (Professor, Santa Monica College). The guidance, mentorship, and support that I have received in these past 4 months have been invaluable.

Team at NASA Jet Propulsion Laboratory (JPL):

- Group 345C Interns: Alicia Sanjurjo, Gerald Parish, Jared Carrillo, Joshua Drye, Sohee Kim, Diego Cordova, Aaron Hui, Gabriel Venezia, Subhobrata Chakraborty, and Sydni Yang

- Jenny Tieu (SIRI Coordinator), Devyn Payne (SIRI Program Support), Jen Pino, Phillippa Kennedy, Arpine Margaryan

Santa Monica College:

- **Jinan Darwiche and Howard Stahl (Faculty Supervisors)**

I want to especially thank my parents and my sister who have always believed in me. They have always encouraged me to pursue my passions and never give up. I truly wouldn't be here without their continuous support. Additionally, I want to thank all of the friends I have made at JPL who have shown me what a strong, supportive community looks like.

Lastly, I want to thank everyone at Santa Monica College for their unconditional support. I am so grateful to Jinan Darwiche for supporting me throughout this entire internship. I want to thank all of the professors, counselors, and faculty at Santa Monica College who made this a possible experience for me.

REPORT

Overview:

Coming into this project, many of the virtual environments were already set up by previous interns. Using the knowledge we had from the moon environment (from past lunar explorations), we were able to create an accurate virtual environment for a rover on the moon. In the virtual environments, we are able to move the rovers and make sure they interact properly; for example, we may stimulate a crash between them. Now that we have most of the virtual environments set up, we are able to start testing if the rovers across different platforms are able to communicate and receive messages from one another. We also must ensure that only registered and authenticated users are able to access this system. This is where my focus is in the project.

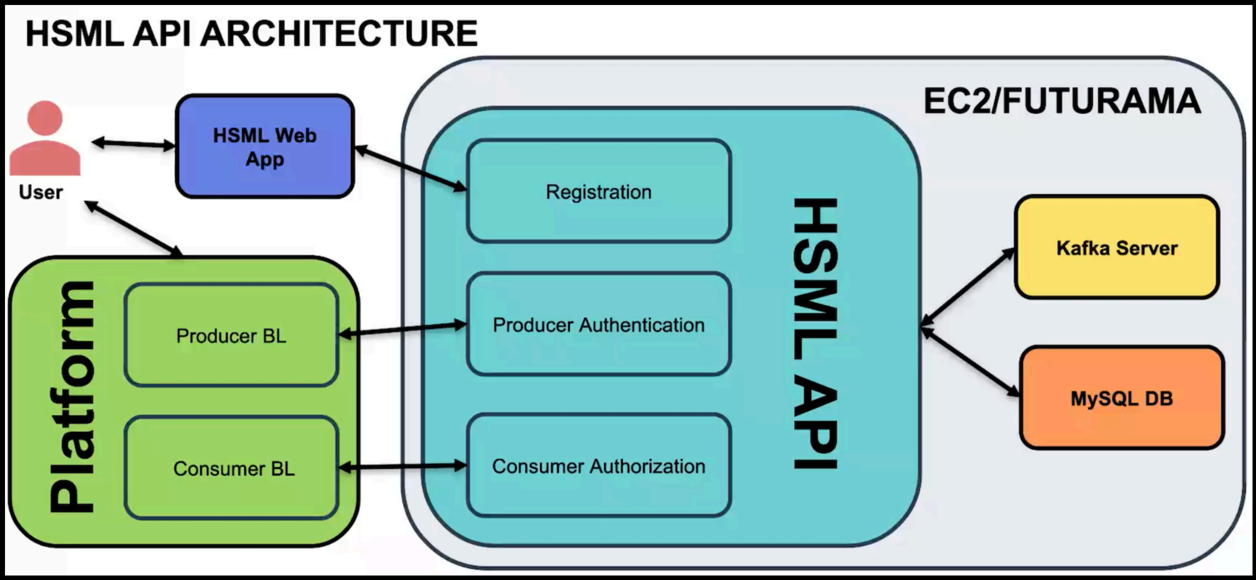
Methods:

Functionality:

Throughout this project, I focused greatly on the system for registration and authentication. Before beginning to code, I spent a lot of time speaking with my team lead about what functions we wanted to implement in this system to make sure it served its intended purpose, which is only allowing authenticated users who are registered in the system to access entities and agents. There are many functions within the program that go into ensuring this. Using JSON files (a file holding a user's information), we were able to create example users to test the program. Examples of functions needed include, a function making sure the JSON file has all of the required information (name, birthday, organization, etc.), a function adding the users information into the database (if new), a function ensuring the user is already in the database (authenticating already registered users). Implementing these functions was my main task in this project. I also implemented several functions focused more on the details of the program, such as, generating a random topic name for an entity being registered. Another important thing to keep in mind was that none of the entities can have the same name, so I also implemented a function to check the database for the name. If the name already existed, the program would generate another random name. There is a lot of detail in these types of functions, so I found it very important to discuss ideas often with my team lead to make sure we were covering all possibilities. Before sending this project out to other users, we want to make sure the system is fully secure, and I found that communication was one of my best methods. By speaking with others in my team, we were able to build on each other's ideas and create a fully secure program that functioned well without compromising its performance.

Shown below is the architecture of our system.

HSML API Architecture Block Diagram



This diagram shows the logic behind the registration and authentication components of the project. The user may use the HSML Web App to register themselves into the system. The HSML API is used to allow the platforms to connect. Once the user provides their private key, the system checks the database to validate their credential. If they are authenticated, they may access the system.

Latency:

One of the most important aspects of a system is its latency or performance. Another crucial part of my work included testing the latency of the program I helped create. We want to make sure that users are able to register and authenticate themselves in real time, or within milliseconds (and no later)[3]. After implementing several functions (discussed above), I began to test our system. My method included setting up several timestamps within the program to keep track of how long each function is taking to execute. I ran several tests in order to obtain enough data to come to an accurate conclusion of how well our program is performing. I ran four tests for each part that I was testing. My results can be found below. To help with further analysis of the data, I calculated the mean/average, standard deviation, median, and mode. I have also added concise notes to my findings, which can be possible explanations for the times we obtained. My latency tests were successful, and after analyzing the times with my mentor and team lead, we were able to conclude that the times obtained were mostly ideal. We see that we were able to respond to user requests within milliseconds, which was the goal of the program. As we continue to add to our project, it's important to note that we should not compromise its current performance.

Shown below are the diagrams of my findings.
HSML API Latency Tables

Registering a User

Test 1	0.88s
Test 2	0.49s
Test 3	0.50s
Test 4	0.52s

Mean/Average: 0.5975 seconds
Standard Deviation: 0.163 seconds
Median: 0.51 seconds
Mode: None

Note:
The connection to the Kafka server is likely an explanation as to why the first test took the longest.

Registering an Entity

Test 1	0.46s
Test 2	0.48s
Test 3	0.79s
Test 4	0.90s

Mean/Average: 0.6575 seconds
Standard Deviation: 0.1916 seconds
Median: 0.635seconds
Mode: None

Note:
Exhaustion of resources, connection to the server, and/or unoptimized software can be an explanation for these varying times.

Authenticating A User

Test 1	0.01s
Test 2	0.01s
Test 3	0.01s
Test 4	0.01s

Mean/Average: 0.01 seconds
Standard Deviation: 0.00 seconds
Median: 0.01 seconds
Mode: 0.01

Note:
The times are consistent for registering a user. This is an ideal amount of time.

In each table, we see the time it took for each test. Data analysis and additional notes can be found on the right. These times are optimal as none of them go above one second, ensuring our system is providing real time results.

CONCLUSION

Results:

The outcome of my project has, so far, proven to be successful. Looking at our progress, during my time here, we were able to create the HSML Web App which can be utilized by users in order to access the system. The latency tests for this were also successful. We found that users are able to be registered and authenticated in milliseconds. At the end of April, Dr. Thomas Lu and Dr. Edward Chow, presented our demonstration use case of the digital twin system. We received an overwhelming response where many shared how fascinating and innovative our project is. Our consistent teamwork, hard work, dedication, and effective communication proved to be successful.

Conclusion:

Being a part of this project has taught me invaluable information that I will carry throughout my career. This project investigates the newest forms of technology and how we can integrate these advancements into space exploration. This project has shown that it is possible to have digital twins communicating across several platforms. We have demonstrated that if there are two rovers (originating from separate platforms), it is possible for them to communicate through the utilization of HSML messages. My team and I conducted extensive research on where and how to host these operations, which led to the overall success of this project. With several trials, and the overcoming of many obstacles, we have found that the answer to our question is yes. Looking forward, we can see a clear advancement on the way for space exploration. In regards to continuation of this project, we will be passing this on to the next set of interns. After several discussions with my mentor, we have decided that we want to expand the system to ensure it’s user-friendly. We will also be adding more schemas to broaden the ability of the software. We are also working on an AI assistant to help guide users as they use it. Though we have already seen success with this project, it will continue to grow and evolve.

REFERENCES

1. Ibm. “What Is a Digital Twin?” *IBM*, 17 Apr. 2025, www.ibm.com/think/topics/what-is-a-digital-twin#:~:text=A%20digital%20twin%20is%20a,reasoning%20to%20help%20make%20decisions.

2. Carrillo, J., Chakraborty, S., Mridha, R., Janvisloo, N. E., Sadler, E., Li, B., Ho, N., de Fourtou, G. B., Lu, T., Chow, E., Petersen, C., Eslami, A., Muzzi, A., Percivall, G. and Hynes, J. (2025), ‘Enabling Interoperable Digital Twins for Collaborative Lunar Exploration’, Presented at the IEEE Aerospace Conference .

3. “Real Time Systems.” *GeeksforGeeks*, GeeksforGeeks, 18 Apr. 2023, www.geeksforgeeks.org/real-time-systems/.