3D Navigation With 3D Hand-Motion Gestures

Practical 3

Student: Nathan Poole (170004680)

Abstract

The transition of computer interaction being based around virtual 2D environments to 3D environments has long been occurring. More recently, this idea of interacting with a 3D computer environment has been emphasized by augmented and virtual reality technologies. The reach of such technologies is pervasive and ever-growing. Thus, it appears the march towards a 'Meta-verse' is increasingly likely, where human-computer interaction is dominated by a need to interact with a 3D world.

This project is a case study, specifically exploring the more niche domain of 3D websites as an interesting area with which to apply the knowledge I have gathered in this module. 3D websites differ from their traditional counterparts in that web content is embedded within a 3D environment of some form [4]. To this end, this project saw the creation of a glove device which translates 3D hand gestures into controls for navigating and interacting with 3D website environments. Such a device can be used to transition users towards more intuitive, 3D-appropriate interactions without the need for VR [1]. The use of gloves as input devices is likely more appropriate than current hand-held VR controllers on the market [2]. The use of gloves for 3D interaction has been explored with success in other domains as well, such as for semi-immersive exploration of 3D medical-imaging data [3].

The prototype for the interactive system combines and extends upon many concepts within the module: Micro:Bits have been used for bidirectional wireless interaction using a custom IO device, various inputs and outputs have been connected via circuitry (buttons, capacitive touch, custom finger switches, potentiometer, accelerometer, LED displays, and 3D environment display), PyAutoGUI has been used for generalizing interaction for many applications, and a 3D website has been created showcasing different applications of the 3D hand-gesture glove within the context of 3D websites.

Furthering the quality of this system, various components have been refined with quality-of-life improvements: set-up of the system follows a handshake protocol and the status of this is shown to the user, the sensitivity of interactions can be adjusted by the user on the glove, and 3D hand-gesture interactions involve self-calibration for increased ergonomic use of the glove.

Interaction Overview

There are two distinct interaction phases showcased: set-up of the system, and system use.

In the former case, the user may initialize any of the components of the system (i.e., 3D website, python script, relay, or agent) in any order, and the system manages connection set-up and relays the status of said set-up to the user.

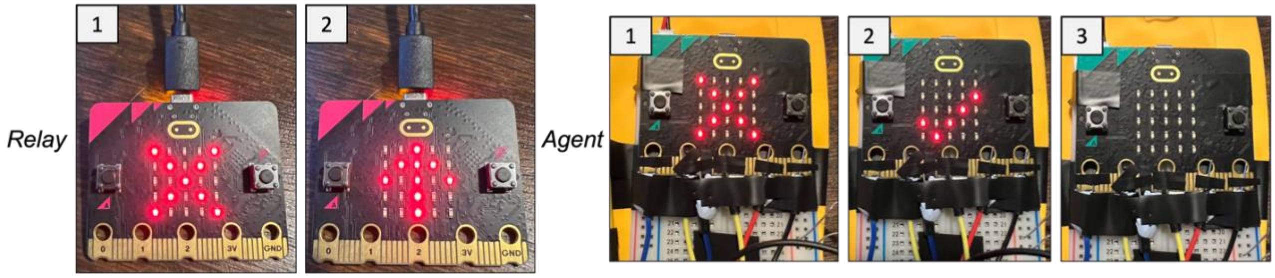

Figure 1: Interaction when the system is set-up. Initially, both the relay and the agent display crosses showing they are not connected to the computer. When the agent connects, an arrow pointing to the serial output is shown, indicating it is ready to forward messages. When the agent connects, a tick is shown briefly to show it is connected, and then the screen is cleared so it can be used for the interactions.

In the latter case, the system comprises multiple forms of interaction that may occur in any order. First, the user may switch between 3D scenes using the ‘A’ and ‘B’ buttons on the agent Micro:Bit. Pressing the logo will also reset the current scene. Orbital 3D navigation controls are used in the 3D website, which is summarized as the camera operating on the circumference of a sphere to inspect a 3D object. As such, pinching with the index finger initializes a rotation interaction; tilting the glove whilst pinching allows the user to rotate around the 3D object. Pinching with the middle finger initializes a zooming interaction, where tilting the glove forwards and backwards zooms in and out on the object respectively. Pinching with the ring finger initializes a translation interaction, where tilting the glove allows the user to move around the object. In all cases, the potentiometer can be altered to adjust the sensitivity of interaction; a higher sensitivity means the 3D navigations are more responsive to slighter movements of the glove.

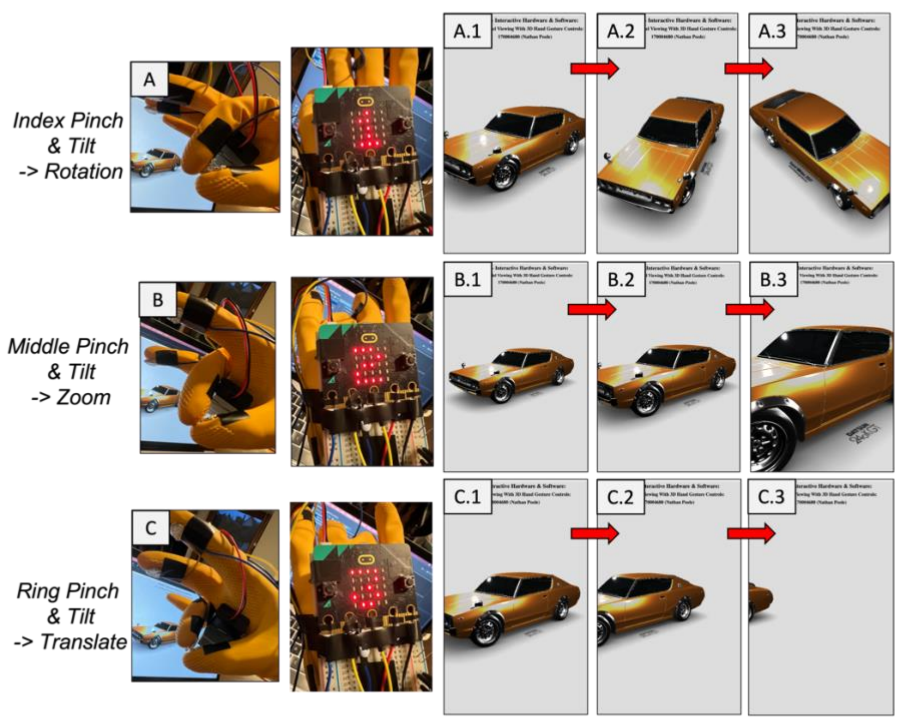

Figure 2: Interaction using the glove to inspect a 3D environment. Different pinch gestures enact different navigation controls. The currently activated finger is shown on the display. The index finger enacts rotation, the middle finger enacts zooming, and the ring finger enacts translation in this project’s 3D website.

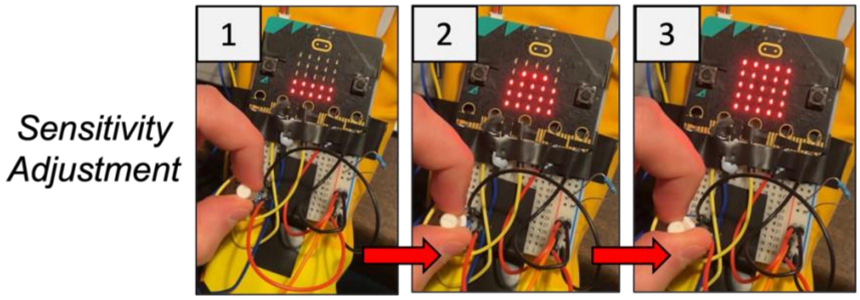

Figure 2b: Sensitivity adjustment interaction shows the level of sensitivity (from low to high) as a bar chart on the Micro:Bit display. The effect of sensitivity adjustment is better shown within the demonstration video.

Parts List

The following details the parts required to make the prototype developed for this practical:

Hardware

- 2 BBC Micro:Bits – *one acting as a relay, the other acting as an agent.*
- Micro:Bit Compatible External Battery Pack With Batteries – *for the agent.*
- Micro-USB Cable – *with relevant adapter for computer (i.e., Micro-USB to USB-C for MacBook).*
- Computer With Screen/Display.
- Wiring – *red VCC wires, black ground wires, and coloured signal wires recommended.*
- Breadboard – *for wiring connection convenience.*
- 1 10kΩ Resistor
- 1 Potentiometer.
- 1 Rubber Glove.
- Tinfoil.
- Insulating Tape/Blue Tack.

Other

- Browser - *Chrome recommended.*
- External Web Libraries – *provided Three.js libraries.*
- External Web Resources – *provided 3D model files.*
- VSCode with Live Server Extension – *for running the provided website code.*
- Python – *for running the provided PyAutoGUI script.*
- MakeCode – *for editing/loading the provided Micro:Bit code file to the Micro:Bits.*

Process

The steps to replicate this project are divided into four phases: hardware setup, Micro:Bit coding, PyAutoGUI script coding, and website coding. A system overview is given to understand how these phases connect and combine into the finished product (Figure 3).

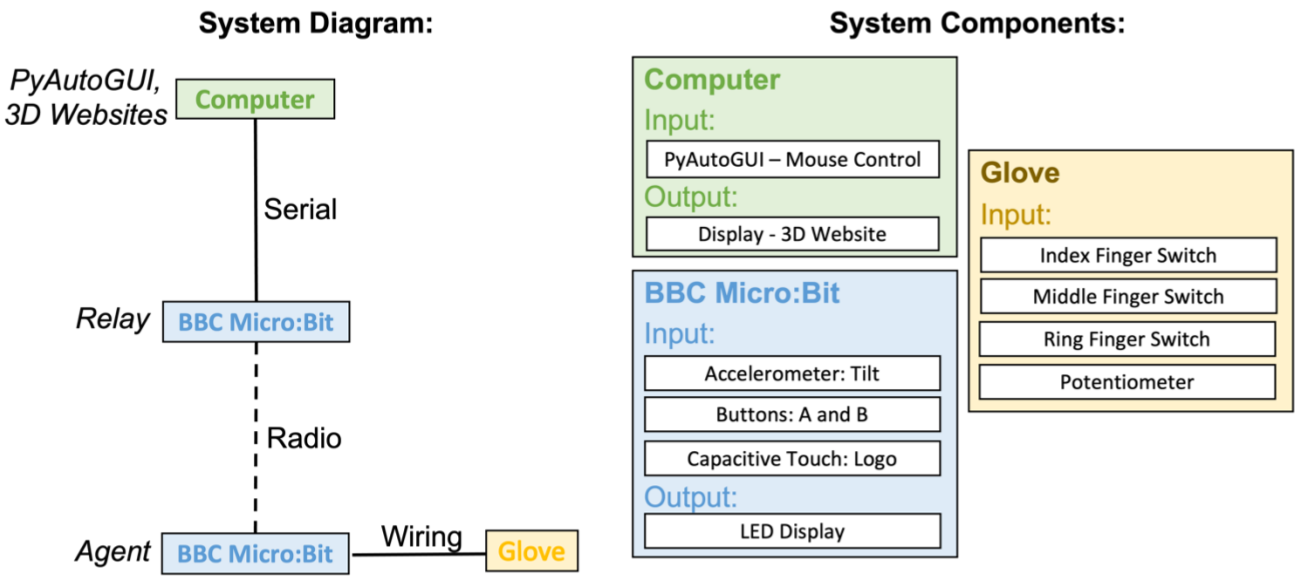

Figure 3: System Overview – A system diagram (left) gives an overview of the project architecture. The inputs and outputs of this system (right) are also highlighted.

Hardware Setup: The hardware interface for this project has a minor and a major component. The minor component is simply that the designated relay Micro:Bit must connect with the computer via serial. The major component concerns creating the interactive glove which operates using the agent Micro:Bit. This process is more involved but is guided by Figure 4.

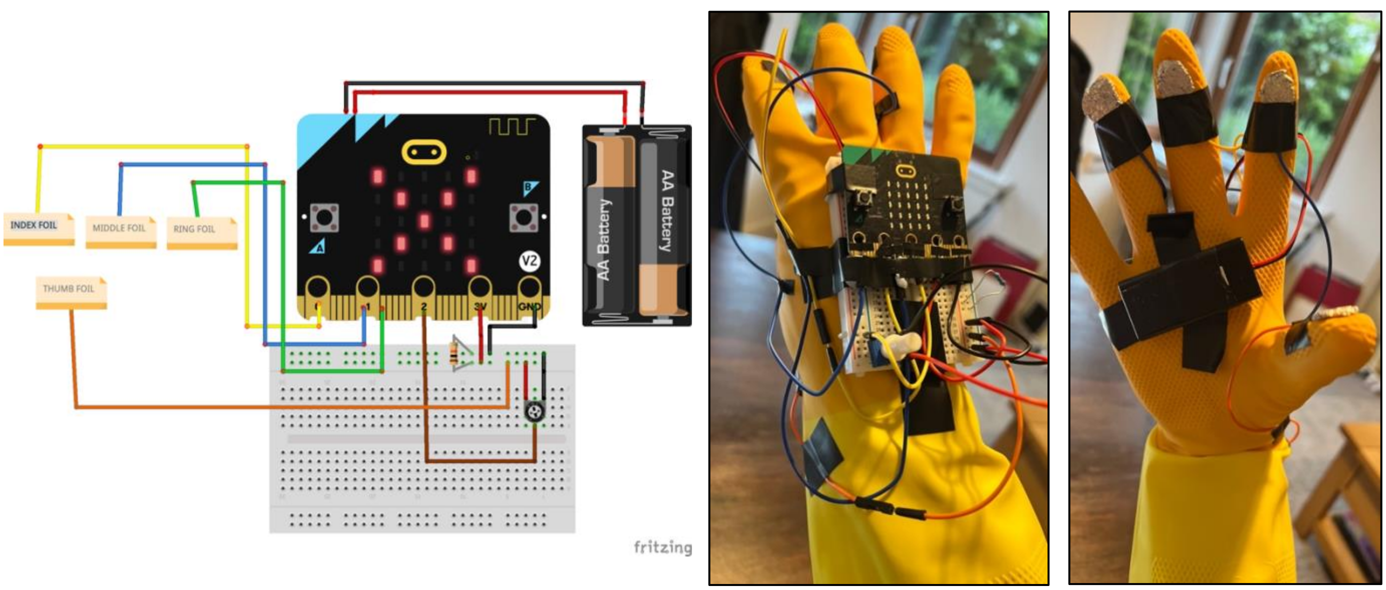

Figure 4: A circuit diagram (left) shows how the glove hardware should be connected. An example of such a circuit (middle and right) is also presented.

Firstly, for convenience, the *3V* and *GND* pins on the Micro:Bit should be connected to the *'+'* and *'–'* lines along the breadboard respectively, with the 10kΩ resistor connecting between the lines. These lines will be used to power the various glove inputs.

Next, the finger switches are to be set-up. This consists of running a signal wire from the *3V* line on the breadboard to the thumb pad area on the glove. Tinfoil can be used as an endpoint to the wire in the thumb pad area (i.e., create a large tinfoil area on the inside end of the thumb) to ease the user's ability to trigger switches by connecting their fingers. This process is similarly repeated for the index, middle, and ring fingers, but their wires connect from the finger pad areas to the P0, P1, and P8 pins respectively. These pins allow for digital signals to be read, such that connecting any finger with the thumb will produce a '1', and otherwise '0'. Overall, the thumb pad tinfoil provides power, which when connected with any finger causes a signal to be read at the respective pin (i.e., a switch using the pinching gesture). Pinch gestures have been chosen as being intuitive, ergonomic, and natural to the user for switching between different types of interaction modes, as shown by Bowman (2001) [6].

Finally, the potentiometer can be setup directly on the breadboard as illustrated in Figure 4. The potentiometer is connected to pin P3 as this pin allows for analogue reads. As a result, a signal between 0 and 1023 can be read from P3, which is determined by the extent that the user has turned the potentiometer dial. This input device will allow for the user to tailor the sensitivity of their interaction with the system when moving the glove. For convenience, the external battery pack should also be attached to the glove so the glove can be freely maneuvered as a single unit.

In all cases, (insulating) tape and blue tack should be used to fix the glove components in place such that maneuvering the glove does not cause reliability issues with circuit connections. Alternatively, an edge connector can assist with securing circuit connections, especially with the Micro:Bit. An edge connector was not used in this project as the form factor of the edge connector available was undesirably large, which reduced the ability of the user to manipulate the glove.

Micro:Bit Coding: The Micro:Bit code required is given with this submission. The code on the relay and agent Micro:Bits is identical, allowing for concise and manageable implementation of the Micro:Bit logic with effective event handling. This was especially useful in the face of bidirectional communication concerning multiple input and output devices. As such, the relay is distinguished by a relay ID.

The relay Micro:Bit logic is simple; upon receiving a message from the radio, forward the message over serial, and vice versa. However, the relay should also check such messages to determine if they are intended for the relay itself. This was implemented to allow for a quality-of-life feature to be implemented within the system; there is an initial handshake protocol between the various components to indicate to the user if the system has been set up successfully.

The agent Micro:Bit logic is more involved and can be divided into two components: handling communication, and handling input and output (IO) devices.

The agent receives and send messages via radio. This wireless communication is beneficial and necessary for the system; the glove must be able to act as a freely maneuverable IO component. Having a wired connection with the glove would impair this requirement. To this end, a simple but robust messaging protocol was developed which addresses concerns with radio communication (i.e., unexpected, and noisy messages may be received, or messages may be lost entirely).

The agent Micro:Bit must also manage several input and output devices on the glove as the microprocessor for the overall IO device. The Micro:Bit must recognize events when its onboard IO components are triggered (i.e., appropriate messages are sent to the computer whenever the 'A' or 'B' buttons, or the capacitive logo, are pressed). Also, the Micro:Bit must constantly (i.e., forever loop) check the status of the finger switches and send appropriate messages; whenever one of the fingers connect with the thumb, a finger identifier and accelerometer data is sent to the computer. Similarly, whenever the potentiometer is turned sufficiently, the Micro:Bit must send the updated value to the computer, which is translated to an interaction sensitivity.

Crucially, the agent Micro:Bit has two important behaviors in its implementation.

First, a tolerance is assigned to the potentiometer to determine how much the potentiometer must be turned before triggering a sensitivity change to be made. The potentiometer is a noisy device, which is exasperated by its placement on the glove, which is moved around. Thus, changes to the potentiometer are handled in intervals to prevent noise from flooding the system with repeated messages creating minimal changes to sensitivity.

Second, whenever a finger (i.e., index, middle, or ring) is initially connected to the thumb, the current state of the accelerometer is used as a reference point for accelerometer data being sent whilst the finger-thumb switch is engaged. This creates a crucial interaction behavior; the tilt of the device affecting the 3D environment is in reference to the position/orientation of the Micro:Bit when the interaction was triggered, and not relative to the canonical ‘flat’ position of the device. This provided necessary ergonomic benefits that are illustrated in the accompanying demonstration video.

PyAutoGUI Script Coding: The PyAutoGUI script concerns how messages from the glove are interpreted as interactions within the 3D environments on the display.

Initially, a bespoke approach was planned which used *p5.serial* to interact with this project’s 3D website directly. However, the developed glove would then only be able to interface with a single website and would not operate as a general 3D hand gesture device that can allow for more meaningful interactions with 3D environments as the web transitions to more ‘Metaverse-like’ websites. It was realized that such a transition would have to support backwards compatibility with mouse interactions, but that these mouse interactions would be made more intuitive through the 3D glove movements. As such, PyAutoGUI has been used to translate the 3D glove data into mouse manipulations that interact with 3D websites; the net benefit is that use of the glove is more intuitive than simply using the mouse for these kinds of websites. It is recognized that future work may cut out the need for the mouse entirely, as is available in websites that have VR capability.

The PyAutoGUI script logic is simple; messages from the glove are translated into keyboard and mouse interactions. The ‘A’ and ‘B’ buttons on the agent Micro:Bit are translated to the left- and right-arrow keys respectively. In this project’s 3D website, this switches between different 3D scenes. The capacitive logo is translated to the up-arrow key, which resets the current 3D scene in this project’s 3D website. Then, the index, middle, and ring finger messages are converted into left-click-drag, scroll, and right-click-drag mouse movements respectively. The degree of movement (i.e., how fast the user can manipulate the 3D environment) is determined by a sensitivity, which is altered using the potentiometer messages from the glove. The potentiometer values are mapped to a reasonable range of sensitivities.

Website Coding: Finally, a 3D website was developed to showcase the abilities of the 3D glove. Whilst not strictly necessary - accessible 3D websites already exist on the web - a bespoke 3D website allowed for the different use cases of the 3D glove to be demonstrated. The website code for this project is provided in the submission. The code is summarized as using the *Three.js* library to load open-source 3D scenes which show different use cases for the glove in different 3D environments [7].

Challenges & Key Points

The main challenge of this project was in the misinterpretation of what the accelerometer data on the Micro:Bit conveyed. The documentation for the Micro:Bit accelerometer was misleading; it describes the accelerometer as providing the acceleration exhibited in the directions along the three axes [5]. As such, it was understood that movement of the glove in a 2D plane could be extrapolated. Instead, the accelerometer data, to the best of my knowledge, more accurately provides tilt information along the three axes. This limited the gestures that were available to be implemented with the glove.

Initially, to maneuver around a 3D object, I wanted the user to be able to pinch and move the glove in the x- and y- directions, which is a more intuitive interaction for this type of 3D object manipulation than the current implementation, which uses the tilt of the device instead. This concept is more aptly illustrated within the demonstration video. Despite this, the 3D glove interactions are still intuitive to the user, especially considering that many different navigations of 3D environments are possible. For example, using the tilt of the device is very intuitive for 'fly controls' in 3D environments, where the camera is analogous to an airplane, whose nose is pointed via tilting the glove.

Given additional time, I could have explored use of the proximity sensor to read the 2D plane movements of the glove that was initially desired. However, this would have been an ad hoc solution which neglects the point of the project; the 3D glove was intended to be a singular, simple device that allows for more intuitive interactions with 3D environments. Furthermore, the whole project may have been accomplishable via computer vision with the user's camera feed. Initially, such a system was considered. However, I have found this to be unreliable in past experiences, and such a system would not have allowed me to showcase what I have learnt in this module as aptly as the current system. However, systems that combine such ideas have also been explored with success [1]. Furthermore, I initially wanted to explore two handed navigation of 3D environments, where both Micro:Bits would occupy a glove on each hand and communicate with an Arduino Uno using an FM radio module. I didn't have the necessary components to approach this, so I opted for single hand interactions. However, the use of two-handed glove interactions has been explored in the literature with success [6].

There is a range of focusses available for future work with this project idea. One such area of interest is in the idea that the 3D website could be supplemented with augmented reality; by adding the 3D scenes within an overlay of the user's camera feed, the user can be made to feel as though they are directly manipulating virtual 3D objects when viewing their display. For example, the user view could be such that it looks as though they are pinching the edge of a 3D object and rotating it in real-time when such objects are fully virtual. Another obvious extension of this idea lies within virtual reality. The 3D glove concept can be used for more intuitive user interactions in VR environments in place of current hand-held VR controllers on the market. This is a large area of research currently within the literature [2]. This project could just as easily have explored use of the 3D glove within a VR world; however, I specifically wanted to explore the use of such devices in fields that would have to transition towards VR/'Meta-verse'-like interactions. The web is one of such fields that was chosen for investigation.

References

1. Kumar, P. & Verma, J. & Prasad, Shitala. (2012). Hand data glove: A wearable real-time device for human-computer interaction. International Journal of Advanced Science and Technology. 43. 15-26.
2. Jan, A. (2019). The Evolution of Gloves as Input Devices. Retrieved 10 May 2022, from https://medium.com/@b00062378/the-evolution-of-gloves-as-input-devices-84efe6ff72bb; Sturman, D. J., & Zeltzer, D. (1994). A survey of glove-based input. *IEEE Computer graphics and Applications*, *14*(1), 30-39.
3. Gallo, L. (2010). A Glove-Based Interface for 3D Medical Image Visualization. In: Tsihrintzis, G.A., Damiani, E., Virvou, M., Howlett, R.J., Jain, L.C. (eds) Intelligent Interactive Multimedia Systems and Services. Smart Innovation, Systems and Technologies, vol 6. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-14619-0_21
4. 3D Website Examples: https://spline.design/?ref=lapaninja, https://www.fromscout.com/, https://www.stord.com/?ref=lapaninja
5. MakeCode Acceleration: https://makecode.microbit.org/reference/input/acceleration
6. Bowman, D., Wingrave, C., Campbell, J., & Ly, V. (2001). Using pinch gloves (tm) for both natural and abstract interaction techniques in virtual environments.
7. Open-Source 3D Objects Used In 3D Website: https://sketchfab.com/3d-models/free-1972-datsun-240k-gt-b2303a552b444e5b8637fdf5169b41cb, https://sketchfab.com/3d-models/earthquakes-2000-to-2019-894ad84ceb8b444a91fbc05f20530bcd#download