

1 **HaptiEditor: Haptics Integrated Virtual Terrain Editing Tool**

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7
8 The contemporary landscape of virtual world design is characterized by the ubiquity of diverse tools and terrain design engines,
9 which have significantly reduced the barriers to entry in this domain. Despite this progress, the predominant input modalities of
10 mice and keyboards fail to provide users with haptic feedback during the processes of designing, testing, and experiencing virtual
11 environments. Addressing this limitation, we introduce HaptiEditor, a virtual terrain editing tool that integrates haptic feedback
12 through the utilization of force-feedback capabilities offered by the Haply 2Diy device, implemented within the Unity game engine
13 framework. Our primary objective is to enhance both the design process and the evaluative capacity of designers, as well as to enrich
14 the immersive engagement of users or players navigating these virtual worlds.

15
16 Additional Key Words and Phrases: Haptics, Tool Design, Unity, Haply, ForceFeedback, Haptic Texture Rendering

17
18 **1 INTRODUCTION**

19
20 Haptics interfaces are already often used for enhancing the sculpting experience, in multiple fields, notably, medical
21 braces. However, there hasn't been any significant implementation of force-feedback interfaces in the case of terrain
22 editing and terrain painting. HaptiEditor is a project intending to explore this application of the haptics, in the hope of
23 seeing whether or not it is promising to invest more effort into this idea.

24
25 HaptiEditor is a Unity application which has for objective to edit maps and terrain by painting textures and objects
26 on different scales. By using the Haply 2DIY we hope to create an interesting approach to terrain creation and edition
27 through haptic feedback. The goal is to allow real time editing of a virtual space, and simultaneously feel the effect of
28 the changes right away.

29
30 The development period span over a period 3 months during the Winter session of 2024, in the course entitled
31 CanHap501. CanHap501 is a program which covers multiple Canadian universities in the hope of introducing graduate
32 MSc students to haptic interfaces. This course teaches us how to conceptualize, prototype, develop and do user evaluation
33 with multimodal human-computer interfaces and haptic experiences. This project is being developed in a team of three,
34 each of us in different location (i.e. Montreal, Okanagan and Vancouver) with the management issues it entails. For
35 instance, we had to deal with timezone issues as Okanagan and Vancouver are on a different timezone than Montreal.
36 Or, the version of the hardware given to each student could be different depending on the node they are coming from.

37
38 Since the development timeline of this project is very short we decided to go with a rapid prototyping approach as
39 learned in parallel during this course. Moreover, since we didn't really have enough time to create a fully fledged terrain
40 editor software, we agreed to use Unity to simplify a lot of the designing and implementation to get to experiment with
41 the haptic side of the project quicker. Especially since Unity, as a game engine, already implements some solid systems
42 for collision, forces and texturing.

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53 During the development of HaptiEditor, a system to zooming in and out has been implemented. Using a system of
 54 sampling existing textures form the surface's material in order to create haptic feedback and Unity's collision system,
 55 HaptiEditor is able to provide different haptic feedback depending on the scale of the end effector scale in the scene.
 56 This allows a haptic continuum to enable the user to feel the terrain they are editing at any scale they would potentially
 57 need.

58 The present report is a statement of the advancements and findings made during the development of HaptiEditor.
 59 It will go over the different avenues tried in order to create HaptiEditor, what was prototyped and how it shaped
 60 the current software. Then we will examine the results gathered through semi-formal user testing and the overall
 61 appreciation the porject received. The results of the user testing and our implementation will thouroughly be discussed
 62 in the Discussions section. There will be an appendix going over the details of the code judged the most important for
 63 our software to work.

64 2 RELATED WORK

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86 3 APPROACH

87 This project attempts to deliver on a haptics focused terrain editing experience first and foremost. The overarching
 88 approach was to first establish a reliable coupling via a virtual proxy to Unity's physics system, and then create a proof
 89 of concept terrain editing tool which is driven by the aforementioned virtual proxy.

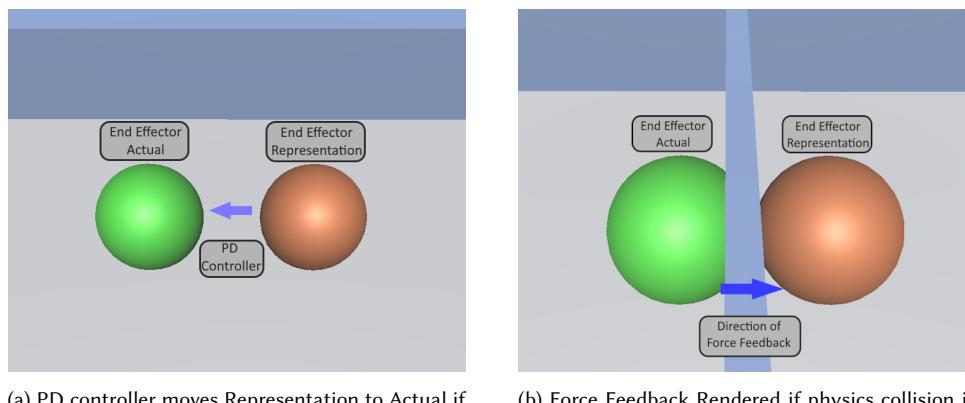
90 The three fundamental questions we had were as follows:

- 105 (1) How would we design a generic virtual coupling between Unity's physics engine and the Haply's force feedback
 106 mechanisms?
 107 (2) How would we detect and render textures in realtime?
 108 (3) How would we design the tool itself, with the main mode of interaction being through the Haply?
 109

110
 111 **3.1 How would we design a generic virtual coupling between Unity's physics engine and the Haply's force
 112 feedback mechanisms?**

113 We initially employed the Unity template obtained from the Haply GitLab repository as the foundation for our
 114 implementation. However, upon closer examination, it became evident that the forces applied were hardcoded, prompting
 115 us to adopt a PD controller model [3] facilitated by a virtual proxy (*See 1*), as elaborated below.

116 In our implementation, we utilized Unity game objects, specifically employing one designated as the "**End Effector
 117 Actual**" to track the ideal positional data of the Haply, and another marked as the "**End Effector Representation**"
 118 equipped with a built-in sphere collider. This was to allow it to interact with Unity's physics engine. Subsequently, we
 119 established a PD controller relationship between these two entities. The underlying operational logic mandated the
 120 "**End Effector Representation**" to consistently attempt to minimize the euclidean distance between itself and the "**End
 121 Effector Actual**". This behavior was governed primarily by the proportional component of the PD controller, supple-
 122 mented by the derivative component to offer additional smoothing (*See 1a*). In instances where the "**Representation**"
 123 detected any physical collisions, it directed the Haply to exert a force in the direction of the "**Representation**" from
 124 the "**Actual**" (*See 1b*). This would happen in parallel to the distance minimization attempts of the "**Representation**".
 125 Consequently, this establishment facilitated an adaptable virtual coupling mechanism, subject to the influence of Unity's
 126 physics engine via the intermediary proxy.
 127



146 (a) PD controller moves Representation to Actual if
 147 there is no obstruction
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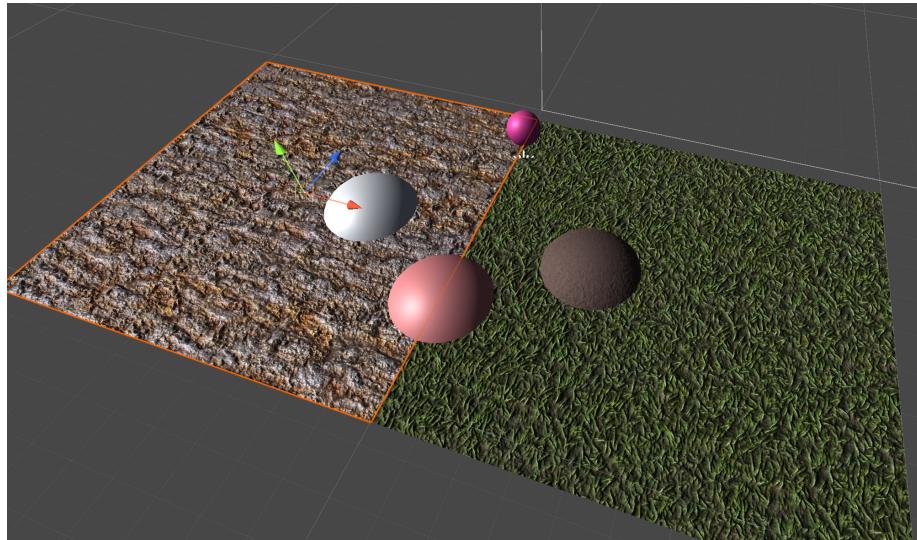
146 (b) Force Feedback Rendered if physics collision is
 147 detected

149 Fig. 1. Virtual Coupling between Representation and Actual End Effector

150
 151 Notably, while the direction vector was three-dimensional, only the X and Z components of this vector were translated
 152 to the Haply to render force feedback. The selected axes were simply an artifact our design decision for editing on a
 153 terrain lying in the X-Z plane.
 154

157 3.2 How would we detect and render textures in realtime?

158 Tangentially influenced by the research conducted by Li et al. (2010) [2], we opted to leverage the inherent image
 159 data embedded within the texture for the application of small directional jitters. The procedural approach to texture
 160 rendering works by sampling a three by three pixel window beneath the end effector representation. Subsequently,
 161 grayscale conversion is applied to this sampled data, facilitating the extraction of pixel brightness values. The brightest
 162 pixels then exert the most pronounced forces in a direction towards the end effector, effectively pushing away from itself.
 163 This mechanism imparts the perceptual impression of being coerced towards regions of lower luminosity. Critically,
 164 this force modulation exclusively manifests during end effector movement, thereby avoiding any undesirable tremors
 165 during static user positioning. By recalculating this tug force on a per-frame basis, an appreciable frequency modulation
 166 is introduced to the end effector, directly mirroring the texture's visual attributes (*See 2*).
 167



168 Fig. 2. Two different textures providing different jittery sensations
 169

170 Although our initial approach involved the utilization of heightmap data instead of the texture's pixel values, we
 171 found the latter approach yielded satisfactory outcomes during informal tests, prompting its adoption as the preferred
 172 methodology.
 173

174 3.3 How would we design the tool itself, with the main mode of interaction being through the Haply?

175 Game engines typically offer a range of tools for terrain editing, which are primarily oriented towards editing within
 176 the editor environment rather than functioning during runtime. Consequently, it became necessary for us to reconstruct
 177 the fundamental components of a terrain editing tool within Unity, essentially embedding them as "game mechanics".
 178 This endeavor chiefly involved leveraging Unity's Terrain game object [4]. A straightforward user interface facilitates
 179 the selection among textures, objects, and an eraser tool, further categorized into sub-menus delineating texture types
 180 (e.g., grass, sand) and object variants (e.g., trees, rocks) (refer to Figure 3). The user can then designate their preferred
 181 object or texture through mouse interaction. Upon selection, the chosen item acts akin to a virtual paintbrush, allowing
 182 object placement or texture painting at the location of the end effector. Activation of the painting action is achieved
 183

either through the stylus button integrated with Gen3 DIY devices or, alternatively, by utilizing the spacebar in cases where the stylus button is unavailable.

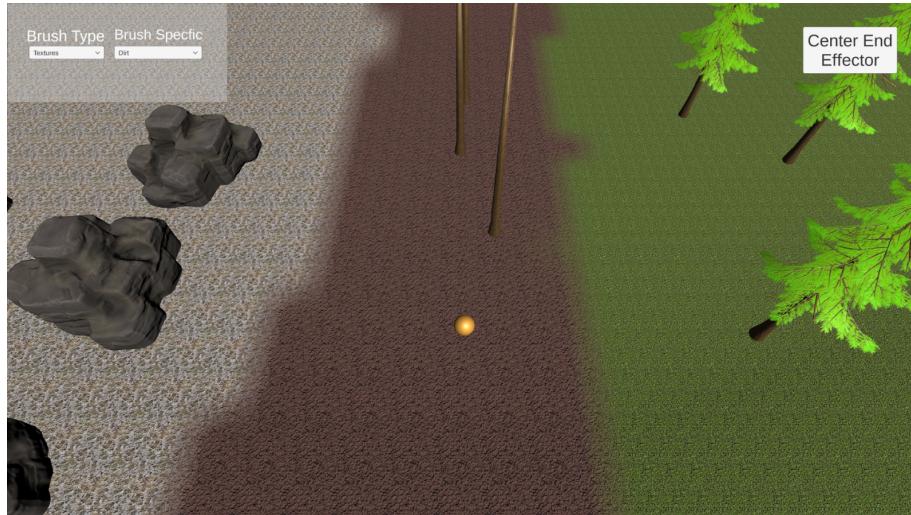


Fig. 3. The final terrain painting interface

The central utility of this approach lies in its capacity to provide users with tactile feedback commensurate with their interactions with the terrain. Objects impart a proper rigid collider based resistance as a consequence of the virtual coupling (see Subsection 3.1), while textures undergo modulation in their visual characteristics and behavior in accordance with texture rendering principles (see Subsection 3.2).

4 PROTOTYPING

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5 EVALUATION AND RESULTS

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6 DISCUSSIONS

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326 7 ACKNOWLEDGMENTS

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332 ACKNOWLEDGMENTS

333 To bob.

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335 REFERENCES

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342 A INDIVIDUAL CONTRIBUTIONS

343 A.1 Rishav's Contributions

344 For the final iteration, we wanted to build an executable that anyone with a haply 2diy board can plug and play.
 345 Expecting everyone to install Unity would be quite an ask, so we needed to build a live board configurator.

346 The live board configurator would need to modify the following parameters:

- 347 • Board Presets
- 348 • Gen2 or Gen3 (for arm distance offset)
- 349 • Encoder rotation direction
- 350 • Actuator rotation direction
- 351 • Arm offsets for base position
- 352 • Encoder resolution
- 353 • Flipped Stylus Button (Some Gen3 boards have flipped sensor data for the stylus port)

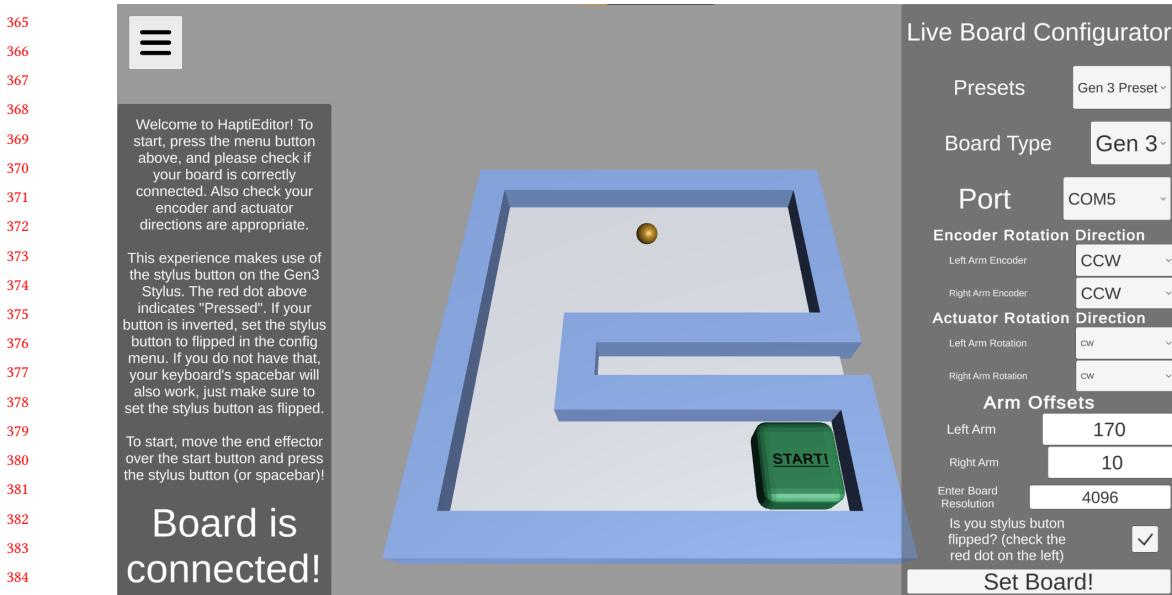


Fig. 4. HaptiEditor configuration menu

Actually passing the appropriate data and reloading the board was significantly more difficult. In a nutshell, I had to do the following:

- Cancel the worker thread simulation task gracefully
- Flush all forces
- Delete the existing instance of the board (along with the encoder, actuator and sensor parameters)
- Create a new board instance with the new parameters
- Attempt a connection to the new specified port based on the user's selection from current active ports
- Launch a new worker thread.
- Potentially connect to a Button Handler if the scene had one present.

This required a significant amount of refactoring of the core hAPI, but in the end I was successfully able to load and reload new user specified board configurations. The main chunk of this was happening in the `EndEffectorManager.cs` as follows:

```

404 1 public void ReloadBoard(DeviceConfig customConfig, string targetPort)
405 2 {
406 3     // Destroying existing setup
407 4     haplyBoard.DestroyBoard(); // added function to close port and destroy this board
408 5     CancelSimulation();
409 6     SetForces(0f, 0f);
410 7     Destroy(pantograph.gameObject.GetComponent<Device>());
411 8     // New Setup
412 9     device = pantograph.gameObject.AddComponent<Device>();
413 10    device.Init(); // re-establishes basic connections with pantograph and board
414 11    LoadBoard(customConfig, targetPort);
415 12    // Checking for button handler
416 13    ButtonHandler buttonHandler = gameObject.GetComponent<ButtonHandler>();

```

```

417 14     if (buttonHandler == null) return;
418 15     buttonHandler.SetButtonState(customConfig.FlippedStylusButton);
419 16 }
420 17
421 18 private void LoadBoard(DeviceConfig customConfig = null, string targetPort = null)
422 19 {
423 20     device.LoadConfig(customConfig); // loads new config if custom config is not null
424 21     haplyBoard.Initialize(targetPort); // attempts connection with new port
425 22     device.DeviceSetParameters();
426 23     // ...
427 24     simulationLoopTask = new Task( SimulationLoop );
428 25     simulationLoopTask.Start();
429 26 }

```

After this, I decided to improve the visual experience of the project. Users will be expected to understand that they have to configure their board, and that their board might be set up different to our dev setups, so the menu scene should ideally be different from the actual terrain editing scene. Additionally, the stylus button (or space bar) is critical to the experience, so the users should be aware of how to do that as well.

To let the user learn this separately, I worked on a simple menu scene with a bit of flair, and added scene transitions. Users will now be expected to first configure their board, be able to move over a physical button in the world, and then click on the stylus button to enter the terrain painter tool.

I fished out a basic scene manager and transition handler from an older project, and after some tweaking, blender modelling and building an executable for Windows, I produced the menu scene in [Figure 4](#).

A.2 Sean's Contributions

This iteration, I finalized work on the texture pipeline and integrated it with Pierre's work from iteration 2 on texture and object painting on the terrain object. Pierre wrote some logic to get world position into a corresponding position on the surface of the terrain object, removing the need for our expensive physics ray-cast. The rest of the process involved the following changes:

- Detecting which terrain texture was currently painted onto the surface of the terrain underneath the end effector. This required fetching the blend ratios of each material at the EE location and determining which was present:

```
452 1 float[,] swatch = terrain.terrainData.GetAlphamaps((int)pixelUV.x, (int)pixelUV.y, 1,1);
```

- Once I have the ID of the texture to sample, we fetch color from its normal texture, giving us both a direction and intensity of force we immediately apply to our end effector. This greatly simplified the sampling code:

```
453 1 Color normalPixel = prot.normalMap.GetPixel((int)normalUV.x, (int)normalUV.y);
454 2
455 3 forces.x += normalPixel.r - 0.5f
456 4 forces.y += normalPixel.g - 0.5f;
457 5
458 6 forces *= intensity;
459 7 previousPosition = eeTransform.position;
```

- I introduced a variable `swatchscale` to allow us to control the ratio of world movement relative to movement on the normal map, controlling the linear density of our texture. Normal sampling also greatly improved the accuracy of forces, as we're no longer estimating heightmaps from surface color but now have geometry-accurate normal maps.

- Selected texturally distinct normal maps for our materials for a clearer distinction between painted materials.

- Added back space-bar support for painting, so a user has an alternative to the stylus button.

I then tuned the scaling code Rishav worked on in iteration 2 and added it to our scene. The following changed:

- I added a scale factor for the movement range of the end effector, so it expanded as the scene zoomed out, covering the new area.
- I then tuned the ratios for movement range, end effector size and camera zooming so that they scaled in tandem.
- I changed the painter code so that the painted objects had their appropriate colliders, allowing the large end effector to skate over rocks as we'd intended it to, rather than getting stuck like before.

Lastly, I tuned the texture sampling code again so that it would play nice with the zooming feature we'd introduced. I chose a `swatchscale` such that at high zoom levels, individual surface features like pebbles were quite large and discernible, but with a wider camera, surface features became higher frequency noise and force feedback from geometry became the primary force on the end effector. Textures representations were different depending on the painted texture on the terrain and could be rendered in tandem with terrain objects placed during use. We learned that these pipelines could all coexist in a cohesive way and were pleased to see our parallel approach to developing them paid off.

A.3 Pierre's Contributions

As stated in our blog posts for iteration 2, the goal for the third was to merge every concepts and prototypes into one single, preferably enjoyable, experience. In this iteration we ended up working together way more and in closer collaboration by helping each others a lot more. This can be easily explained because we didn't prototype on a different aspect of the experience and were actually making something unique together. This is why sometimes the lines of contributions of what I did and what a team member did will blur into what we did this feature together.

While we knew that we would merge all of our progress into the Terrain scene because the end goal is to use Unity's Terrain game object has our editor, the `TerrainScript.cs` from iteration 2 wasn't usable as is. Firstly, we need to fix the lack optimizations. Secondly, the user should have a way to change the brush type and their specifics without using Unity editor menus (it is necessary if the user interacts with our software through an executable instead of the Unity Project). Thirdly, Lastly, it is unlikely the code we used for texture sampling for haptic feedback would work on the Terrain game object, because it has the particularity to not have a `MeshRenderer` (a component that allows a game object to render a mesh). Finally, there needs to be a way paint using the stylus button instead of the mouse.

During this iteration Rishav did an amazing work at going over the code that has been made and telling us what should be avoided in the future. Following those practices we started a refactoring on `TerrainScript.cs`. During this time, I found a way to optimize the management of the `TreeInstances` what were giving us issues during the second iteration, basically, deleted `TreeInstances` would never really be deleted but replaced with empty version of themselves.

This is problematic because with the core logic of the problem they would be given another collider the next time the software is running even though there is nothing to delete.

```

1  private void OnApplicationQuit()
2  {
3      //test
4      List<TreeInstance> trees = new List<TreeInstance>(terrain.terrainData.treeInstances);
5      List<TreeInstance> trees_cleaned = new List<TreeInstance>();
6      TreeInstance empty_tree = new TreeInstance();
7      for (int i = 0; i < trees.Count; i++)
8      {
9
10 }
```

```

521 9         if (!trees[i].Equals(empty_tree))
522 10            trees_cleaned.Add(trees[i]);
523 11        }
524 12      terrain.terrainData.SetTreeInstances(trees_cleaned.ToArray(), true);
525 13    }

```

Using this code when the application is closed we remove all of the TreeInstances that we could consider empty. The way it works is by going through all the objects in the Terrain TreeInstances and comparing it with an empty object. If they are different we add them to the new list that will contain all the non-empty TreeInstance.

Then using the ObjectPlacer.cs as a reference I created two co-routines one for painting object on the terrain and the other for painting texture. We implemented an enumerator containing all the brushes types (i.e. Texture, Object and Object Eraser) and depending on this brush type one of the co-routine or the object deletion will be enabled.

From then on Rishav worked with me on a basic UI so we can change the brush types and what texture/object is being painted.

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