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Building whimsical instruments using Digital Waveguide Mesh with a implementation of DWM framework in MaxMSP

Introduction

With the hardware world obeying Moore's law and the continuous halving of computer memory cost, sample based computer instruments still dominates musical performance. Offering non-substantial competitiveness in emulating real instruments over sample based method, physical modeling instruments' distinct advantage is in their ability to simulate surreal instrument that would be otherwise hard to construct in in the real world. This paper would explore such potential of physical modeling by implementing a whimsical surreal instrument using the Digital Waveguide Mesh (DWM) technique in the MaxMSP environment. A framework of MaxMSP objects are also created in this project to facilitate the building of DWM.

Background

Digital Waveguide (DWG) and it's relative the DWM are terms coined by Julius. O. Smith at CCRMA. (Smith, 2016) They offer a computationally efficient way of modeling physical vibrations in a system by simulating strings with digital delay lines. While there's much to talk about for Digital Waveguide techniques, only a brief summary of some relevant topics is presented here to facilitate the discussion in the rest of the paper.

It has been known that left and right going traveling waves are solutions to the 1-D wave equation (d'Alembert, 1747). This phenomenon can be visualized by imagining a pebble thrown into a still lake: the ripples goes out in all directions, but the shape of the wave doesn't change. In other words, a progression in time for a traveling wave can be seen as a shift in space. Coincidentally, shift-register arrays or digital delay lines happen to be one of the most readily available and efficient computational architecture, and therefore using digital delay lines to model string became a natural choice. This fact was exploited unintentionally by the research pair Karplus-Strong in their early string synthesis algorithm. (Karplus-Strong, 1983)

The digital waveguide use two delay lines traveling in different directions to simulate both the right going and left going traveling wave, with their length simulating the physical length of the string. To excite the simulated string, a signal can be sent into both delay lines at the same point, and to understand the instantaneous wave variable at a certain point along the string, the signal can be tapped by summing at a fixed position the values in both of the delay lines. Figure 1 shows a block diagram of a typical DWG string, with both ends rigidly terminated.

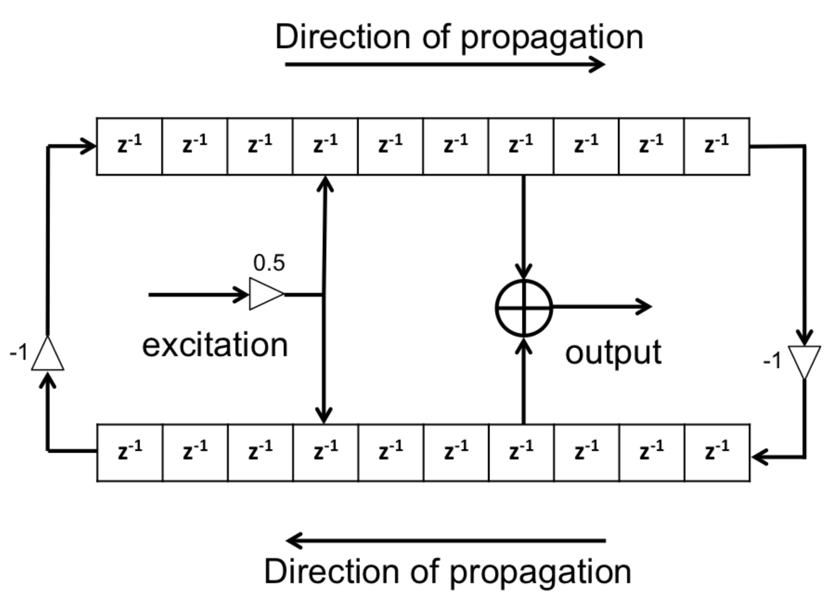

fig.1 DWG implementation of ideally terminated string.

To extend such a simple structure to be able to create more complex physical objects, multiple such strings can be connected via Scattering Junction. The underlying idea is that at a wave impedance mismatch, some of the wave would be reflected back into the original medium, while some would propagate into the new medium. The index of reflection and propagation is dictated by the relationship between the wave impedance of the different medium connecting. In the DWM model, a scattering junction handles the distribution of the waves by looking at the wave impedance of each connected waveguide, and then calculating the outgoing waves for each waveguide accordingly.

Using these two fundamental structures, the bidirectional delay line and scattering juncture, a mesh that approximate any physical object can be built, with the mesh points represented by the scattering junctures. A typical rectilinear DWM is shown in figure 2.

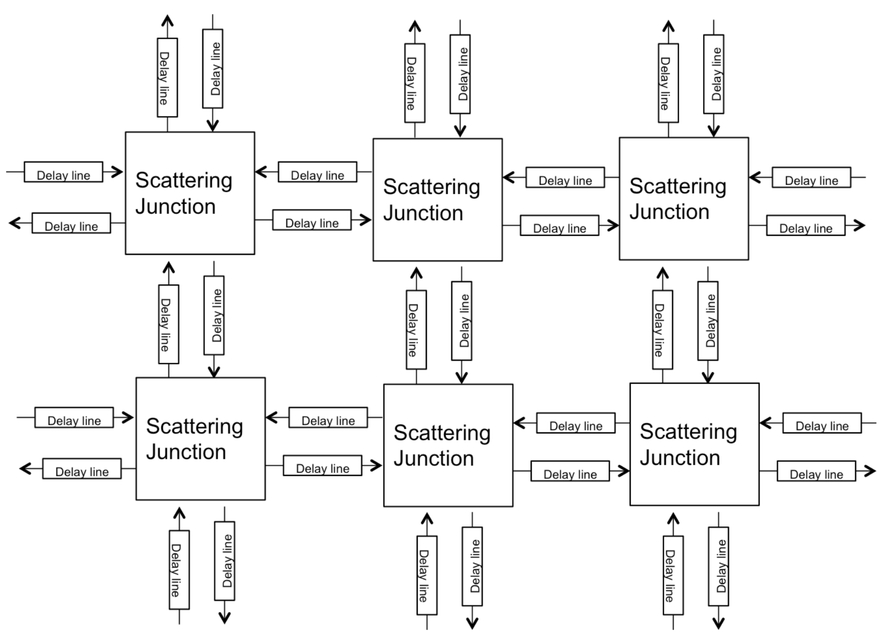

fig.2 DWM of a membrane using delay lines and scattering junction

Method: Max Framework

With the ease of interactivity being a priority, MaxMSP is chosen as the platform for implementing the above discussed structures. As opposed to building the bidirectional delay line and scattering junction as they are described, a hybrid scattering junction that contains only the out going delay lines is implemented. Far left of figure 3 shows a 4-port representation of the implemented SJ. With this configuration, each 1way going delay line can be paired with another outgoing delay line from another such hybrid junction, and when the mesh is built by connecting all the desired scattering junctions, the rest of the delay line can be terminated by a rigid termination, shown in the middle of figure 3. A simple mesh can be constructed out of these two basic element, and it is shown at the right side of figure 3.

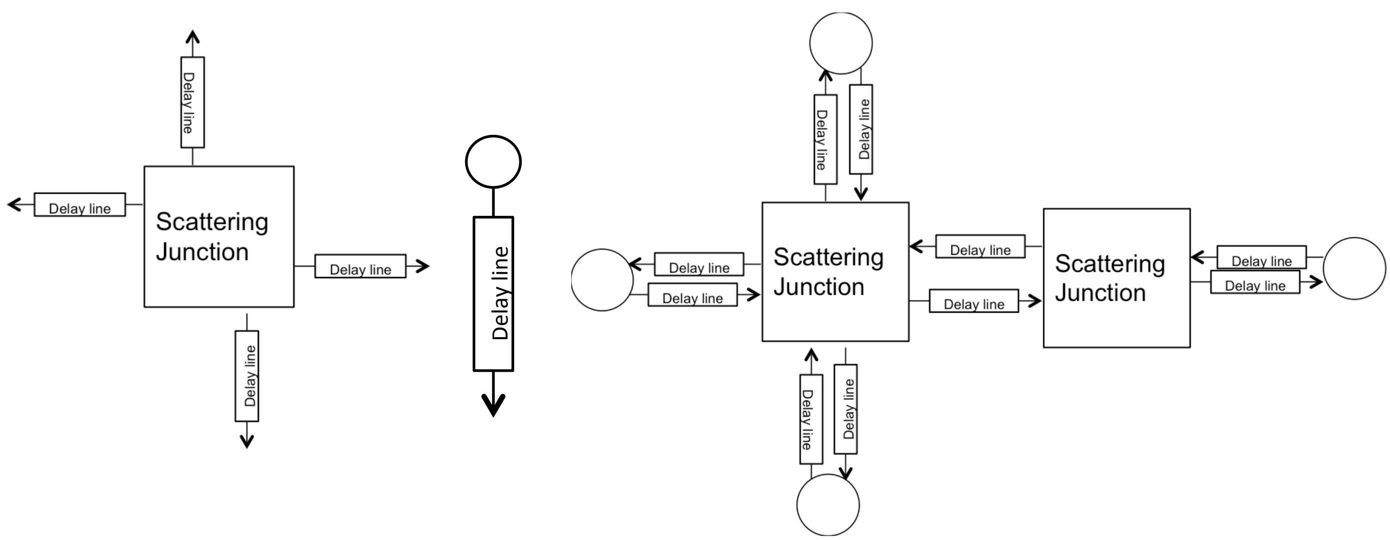

fig.3 Hybrid Scattering Junction, Rigid termination, and a combination.

For each of the hybrid scattering junction, the following parameter needs to be specified: the delay length of each of it's 6 possible outgoing delay lines in ms, and the wave impedance of each of simulated string. If a port is disconnected, then the wave impedance for the string associated with that port is set to 0. For the termination, delay length is required, and also a attenuation and filtering parameter can be specified. The hybrid scattering junction is implemented in sj.maxpat, and the termination is implemented in boundry.maxpat. Although by setting up the system this way, connection and building meshes in Max becomes very easy and intuitive, care needs to be taken to ensure that each bidirectional delay line has agreeing physical dimension: two SJ are associated with each BDL and the length and impedance of the BDL needs to be the same from both junctions to ensure a physically plausible simulation.

Putting it together: The whimsical instrument

It is understood that some of the more nuanced sound from successful acoustical instruments involve the coupling of several separate vibrating body, and the intricate interaction of these coupled bodies provide a rich, time varying attack transient that is sought after in this project. The coupling of two vibrating body is simulated by connecting two meshes of different wave impedance through a scattering junction. The difference in wave impedance at the junction would provide some nuance and asymmetry to the system, causing meaningful evolution to the original sounds of either of the mesh bodies. The two mesh bodies that are being connected are a string and a membrane. The string is modeled by one 2-port scattering junction, and the membrane is modeled by a 6-by-6 rectilinear grid of 36 scattering junctions. The string is set connected to one of the center grids of the membrane, and set to have a much lower wave impedance than the membrane, which preserves more energy in the string than in the membrane, giving more pitch content.

Taking advantage of a physical modeling system, the length and impedance of the string can be adjusted in realtime. Playing around with these parameters can get different pitch and timbre out of the system, which is a distinctive advantage from the sample based system. Another advantage is that where physically the system is excited and tapped can be fully controlled: sul ponticello can be modeled just by sending the excitation signal closer to a termination, as opposed to using different samples or elaborate filters that are typical of sample based virtual instruments. Currently the input and output signal can only be accessed at each grid point, or at the scattering junctions.

Conclusion

In this paper, a whimsical interactive instrument prototype is built in MaxMSP, along with foundational building blocks that facilitates DWM simulation. The sonic output of the system described in this paper is musical in natural and interesting. Because of the novel and surreal construction of the instrument, the resulting sound is familiar yet new. Taking advantage of the interaction between coupled vibrating bodies, a nuanced sound is achieved. Different parameters: string length, wave impedance of the medium, and pick up and excitation locations can be changed in real time in the system presented and this allows for great flexibility and possibility for performance and research alike.

References

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