Visualization Research Center of the University of Stuttgart (VISUS)

Bachelorarbeit

Augmented Reality Feedback Visualization for Guitars in Music Education

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Abstract

This paper presents an application that helps users to learn play the guitar. To be able to give feedback, the physical guitar is equipped with markers and we track every note that is played. Subsequently, visualizations can show the user if and at what point they made a mistake while playing. A learner can see the visualizations either on a screen or through AR glasses. Additionally, overview graphs of whole songs can be displayed that indicate in bars, pie charts or other geometries how often the respective notes were played correctly or incorrectly. Likewise, multiple visualizations can be displayed simultaneously to compare the different times the same song was played by a user. Our implementation can be used with the Microsoft HoloLens or with monitor and webcam. Our results with monitor and webcam showed good working and understandable results. For our evaluation we used case studies. If our program can improve learning to play the guitar has to be shown in representative user studies. Due to the SARS-CoV-2 pandemic we had only a short time to use the Microsoft HoloLens. For this reason we could only show that our visualizations would work but we found no solution to read the .JSON files that we used as input. Therefore we were not able to evaluate our application with the Microsoft HoloLens.

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1 Introduction

Many people would like to learn how to play the guitar; however, a personal music teacher might not always be affordable. Therefore, more and more apps and programs have appeared on the market that enable people to learn how to play the guitar on their own. A lot of work has been put into the development of visually appealing and entertaining programs and devices. Therefore including virtual reality (VR) and augmented reality (AR) into music education can have great potential **??**. Yet, for learners without experience with musical instruments, reading music, understanding all the symbols, and playing chords at the same time can pose a challenge.

The users do not have to switch attention Figure 1.1 between the sheet music and the instrument anymore and can concentrate completely on the finger positions on the guitar instead. Yet showing learners the correct finger positions is only part of the work that guitar teachers do—they also point out the greatest difficulties and show the learners how to smoothly switch positions; they tell them what needs improvement and praise them when they get better. To come as close to the proficiency of a guitar teacher as possible, the goal of this work is to give helpful and understandable feedback to users. In the past this has been done only as instant feedback by indicating if the currently played note was right or wrong. For this purpose, different visualizations that show summaries of whole songs were created.

Furthermore, the option to replay the song is implemented. All notes are displayed in the order they were played by the guitarist. This allows you to use the program long after you actually played the song, and you can also easily track your progress.

The application was created in unity together with the AR software development kit (SDK) Vuforia [1]. Vuforia enables creating new markers that will be tracked automatically after printing and attaching them on the physical guitar. It is usable with webcam and monitor or with the Microsoft HoloLens. The application needs ground truth (how a song is played correctly) and recorded songs as input and then displays all kinds of mistakes in different graphs. By using augmented reality, more visualization options are available than in 2D space. This allows us to place the visualizations so that they are not covered by the guitarist's fingers and to show more information simultaneously. If no augmented reality device is available, this program can still be tested and used as all functions are also working with webcam and monitor.

Some possible types of errors that can be made when playing the guitar are wrong note(pitch), wrong timing, wrong volume, holding the guitar wrong and to play with a falsely tuned guitar. Achieving valuable improvements in correcting the positions of the guitar would require precise tracking and distance calculating between arm and instrument. As this would be to much additional

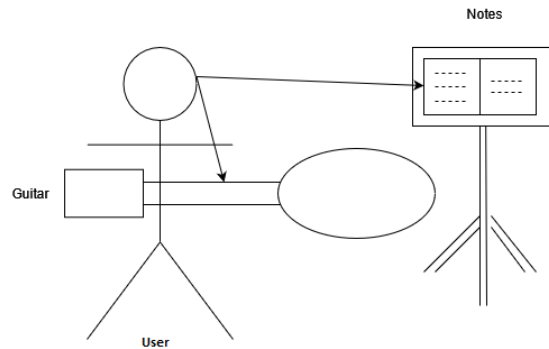---

[1]

Figure 1.1: Permanent switch in attention between notes and fretboard when learning to play the guitar

work it was not included into this application. Furthermore, equipment to tune your guitar already exists. Therefore, the focus of this Unity project concentrates mainly on wrong note(pitch), wrong timing and wrong volume.

The error visualizations are either overlays on the physical guitar or somewhere parallel in space. The types of visualizations are bars, cubes and spheres and other geometric objects that variate in color and distance to the ground and also pie charts. The color variations are between green and red while green is indicating better or more correct played notes than red. The same goes for different height where higher indicates more or better.

It is also possible to show multiple graphs at the same time to compare different times that the same song had been played. Holding the guitar in a position so that the fretboard is visible is common for beginners. More advanced players on the other hand hold the guitar away from themselves. Therefore we can also show our visualizations on a mirrored fretboard that is positioned opposite to the physical fretboard..

Most of my work was done with the mirrored monitor instead of the Microsoft HoloLens because the HoloLens was not available for me due to the restrictions following the SARS-CoV-2 pandemic. Therefore, many things are better optimized for this option. Furthermore, the field of view and the projectable field of the Microsoft HoloLens 1 turned out to be very small, so that tracking the guitar and watching the projections at the same time is nearly impossible. Consequently, the application cannot be practically used with the Microsoft HoloLens . However, the Microsoft HoloLens second generation already has a much greater field of view. All things considered, the Microsoft HoloLens was probably merely the wrong device to test the application on. Future work would be to test the program for several in a user study.

2 Background & Related Work

In the background section, the different parts of a guitar are explained as well as how it is tuned, what notes and chords are and what the Microsoft HoloLens is. In the related work section, already existing apps to learn an instrument with augmented reality are introduced.

2.1 Background

Guitar Parts   To understand where the parts of the guitar are when we are talking about frets, strings, nuts and bridge we show all basic parts in Figure 2.1. Different guitars can have more or less frets and strings that's why I used variables to make my work usable with every guitar. Also the distance from nuts to bridge is used to calculate the correct position of all notes.

Tuning   The standard tuning for guitars is [E, A, D, G, B, E] which indicates the start notes on the position of the nuts where the first note E is the thickest deepest string commonly in pictures on top of guitar followed by A.

Every note is a semitone higher than the previous of the same string this results in this order of notes shown in Figure 2.2.

Important to notice here as it will be referenced later is that some exactly similar notes occur multiple times on the fretboard but never 2 times on same string.
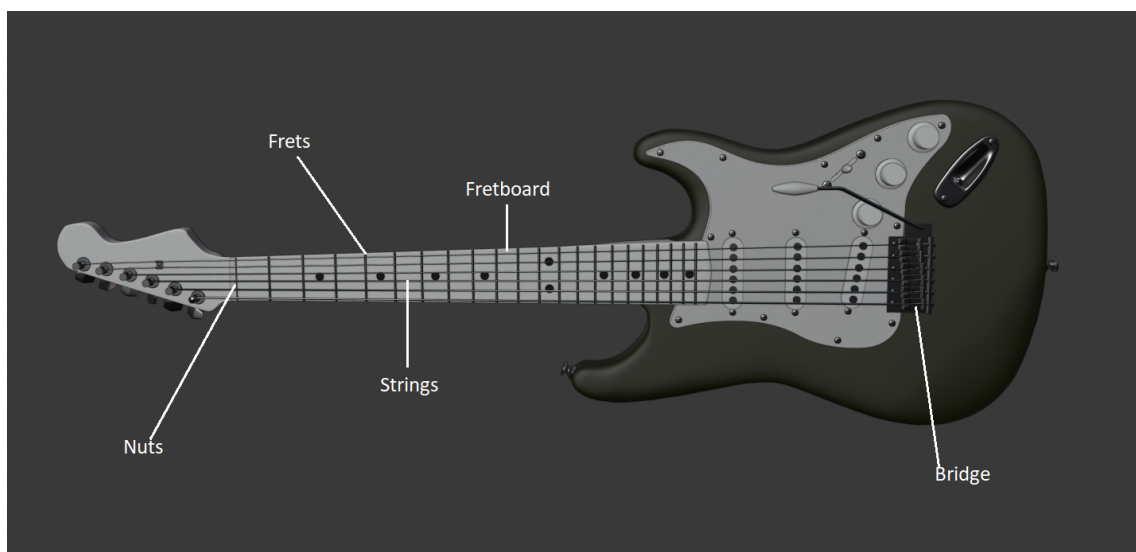

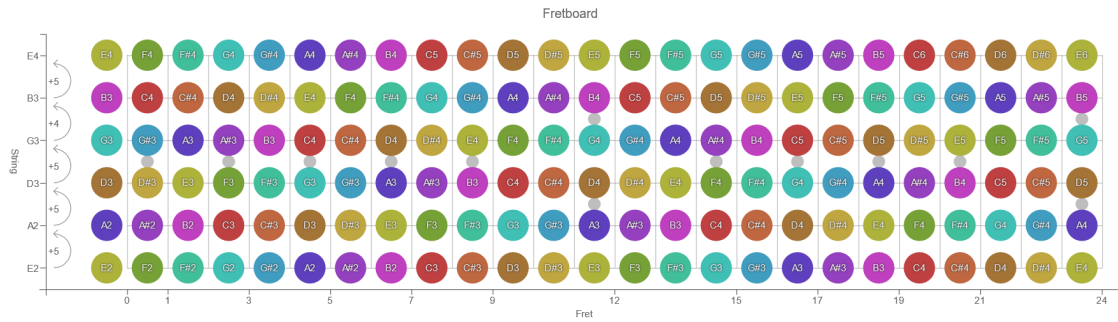**Figure 2.1:** All important names of the guitar for this project.

Figure 2.2: Standard tuning for guitars the same note has the same color.

Chords and Scales   When playing the guitar either one single note is played at the same time or multiple which is then called chord. Chords have a root note and the other notes played simultaneously should sound good together therefore they have to be from the same scale. Scales also have root notes. Starting with the root note different scales include different notes. Major scales has the sequence whole, whole, half, whole, whole, whole, half. Half or whole indicate if after including the previous note the next semitone higher note will also be included (half) or the note one whole note higher(whole). The most known scale is C-Major and it contains the notes C, D, E, F, G, A and B which would be all the white notes on a piano. But there are many more different scales.

The Microsoft HoloLens   The Microsoft HoloLens 1 is ä pair of mixed reality smart glasses developed and manufactured by Microsoft, The pre-production version of HoloLens, the Development Edition, shipped on the 30th of March 2016, and is targeted to developers in the United States and Canada for a list price of dollar 3,000-[KPG17].

Microsoft recommends Unity engine and Vuforia to create 3D apps for Holo Lens [KPG17] .

The Microsoft HoloLens has the commands gaze, gesture and voice. Gaze commands are used to focus objects or apps. Every focused app can be selected by using an air tap with fingers. This is accomplished by putting the index finger on the thumb while the hand is visible for the camera. The tap can be held for a drag simulation to move an element. Another option to select focused is to use voice commands what is only possible for certain commands and actions. If voice commands are possible the HoloLens will show the text that has to be said.

The main functions of the Microsoft HoloLens are head pose estimation, real environment reconstruction, virtual environment processing, user perception, and user control [LDZS18].

2.2 Related Work

The products gTar [1] and Fretlight [2] are lighting positions directly on a physical fretboard to indicate which note to play next. [KWS+14] compared the Fretlight learning method and the normal way of learning an pentatonic scale. They could show a small improvement in some aspects with the

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[1] https://www.kickstarter.com/projects/incident/gtar-the-first-guitar-that-anybody-can-play?lang=de
[2] https://fretlight.com/

Fretlight method. This shows that gTar and Fretlight are some valuable learning tools. As both of them cost money many works tried to achieve the same without the need of buying nothing else than a guitar. For this purpose Ar or projectors are used which will be further described in the next paragraph followed by the same method for other instruments.

AR learning with Guitar   To achieve this [Lia05] used a marker on the guitar and a webcam as input, recognizing and evaluating whether the chord is being played correctly by using the webcam's microphone and having a projector that indicates the position that the user's fingers need to be in to play a chord on screen. [SSL16] And [LGJK11] created an Augmented Reality application called guitAR that let's a mobile projector projects light dots on the fretboard that indicates where to place your fingers to play the next note/chord. This approach has big visualisation problems because you have to estimate most times where to position your finger exactly because your fingers are in the way of the projectors light path. [SSL16] did the same where the mobile projector is a smartphone and new songs can simply be searched and downloaded. [MS06] This very similar to my project and also similar but more advanced work to guitAR tracks your guitar with markers and a camera and then shows an overlaying hand model on the monitor where you can see how to position your fingers correctly and if they are correct. The paper made an live demonstration and got as feedback that this system is useful but hard to use because they also wanted to be able to see the feedback of more positions than only from the front of the guitar. Because of this work we decided not to also try out showing hand models as error visualization as it would result in pretty much the same work and result but just from an 3dimensional view and therefore probably a bit easier to use and understand.

AR Learning Approaches for other Instruments   There are also many other AR based music learning works for other instruments. Hereby the user is sitting in front of the instrument wearing an AR device [CAAS19; CFAW13; DGHL17; FPYT16; GCZL20; HA17; HZY+11; TKM18; YAKN11; ZHP19]. The AR device then highlights directly on the instrument the positions of the note that has to be played. This can be also done with an mobile projector instead of an Ar device as in [RVLC14]. The differences between the works are mostly in type of music input, tracking of the instrument and how detection of the played notes work. Many of this works come with different game-style visualizations to keep the user motivated. Thereby [CAAS19] has group piano learning where other group members can be challenge for a duel. [YAKN11] designed their system with a game-like user interface and tasks with levels. And [FPYT16] used an animated character as feedback for better motivation.

3 Design

The visualization options for the Guitar are endless, especially when you can use the 3D space for that matter. So the main goal is to find only the useful off all the possibility's.

Our design is categorized in the basic part were the construction and physical design techniques are explained. They are followed by a special type of visualizations that do not make use of the 3rd dimension and are therefore called flat. After showing the 2D designs we introduce the 3D visualizations. Furthermore we present different possible transformations like rotating, mirroring, scaling and shifting. Afterward our design ideas for multiple visualizations at the same time are shown. Lastly we present some feedback visualizations that show scales and replay a song.

3.1 Basic Design

As physical guitar the fender stratocaster 3000 is used. A physical guitar equipped with markers to make it track-able for Vuforia is the only needed physical object. The visualizations can then be seen by using the Microsoft HoloLens Figure 3.1b.

An other option is to view the visualizations on a monitor that shows the video from a recording camera with the calculated visualizations above the guitar 3.1b.

As input we converted recorded MIDI files into .JSON files. For the different types of guitars that are possible the exact position of the notes on the fretboard must be calculated. This is done by the adjustable input of how many strings and frets the guitar has and the length from bridge to nut. The calculations are based on chosen start notes to also support not standard tuning and guitars with more or less than 6 strings. The positions of the next fret can be calculated by successively dividing the scale length minus the offset to the previous fret by around 17.817. To also calculate the right position of notes on the same fret the distance of the strings that are the furthest from each other at nuts and bridge Figure 2.1 is needed. The positions of all notes are then be calculated by interpolation.

3.2 2D Visualizations

The simplest way to create visualizations is flat ones directly on the fretboard Figure 3.2. This visualizations are using only two dimensions what makes them having less usable space than 3D ones. The advantage of this type is that no note can be concealed by any other note from most views. Out of all imaginable flat visualizations we implemented three - lying bars, pie charts and 2D flying notes.
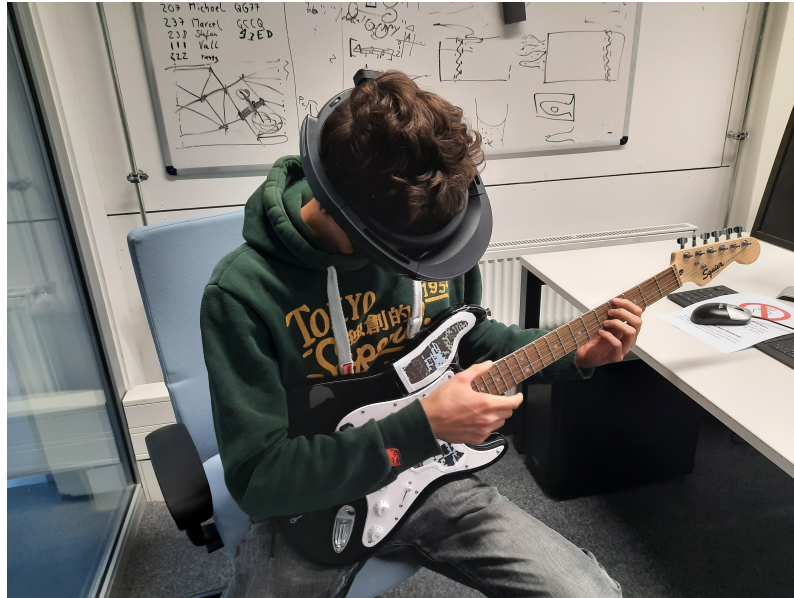
(a) Setup for the Microsoft HoloLens

(b) Mirrored monitor setup.

Figure 3.1: From an outstanding perspective the setups with HoloLens and mirrored monitor.
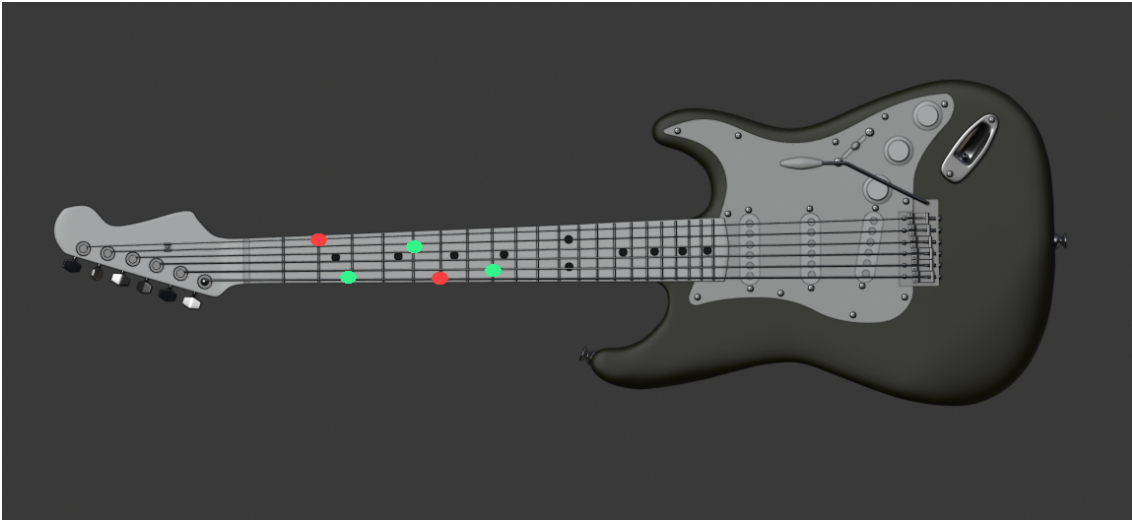
Figure 3.2: Simplest visualization option directly on the fretboard

3.2.1 Lying Bars

The lying bars Figure 3.3a have to be very short as the distance between frets decreases as they come closer to the bridge of the guitar. They are made of two bars one green and one red that always add up to the same length.

3.2.2 Pie Charts

The pie charts Figure 3.3b are even more restricted in size as the lying bars because they have to be smaller than the distance to the next note on the same fret. They are also separated in two colors where one transition is always towards the nuts for each note to make them easier to read.

3.2.3 2D Flying Notes

The *2D flying notes* Figure 3.3c are the only visualization where the root of the notes is not on the fretboard. It can show only one color and is therefore less accurate perceptible than variations in distance would be [Mun14].

3.3 3D Visualizations

Flat visualizations are very similar to the related work part for guitar learning Section 2.2 or physical methods using projectors. They are having the problem of the fingers lying over the visualizations when playing.
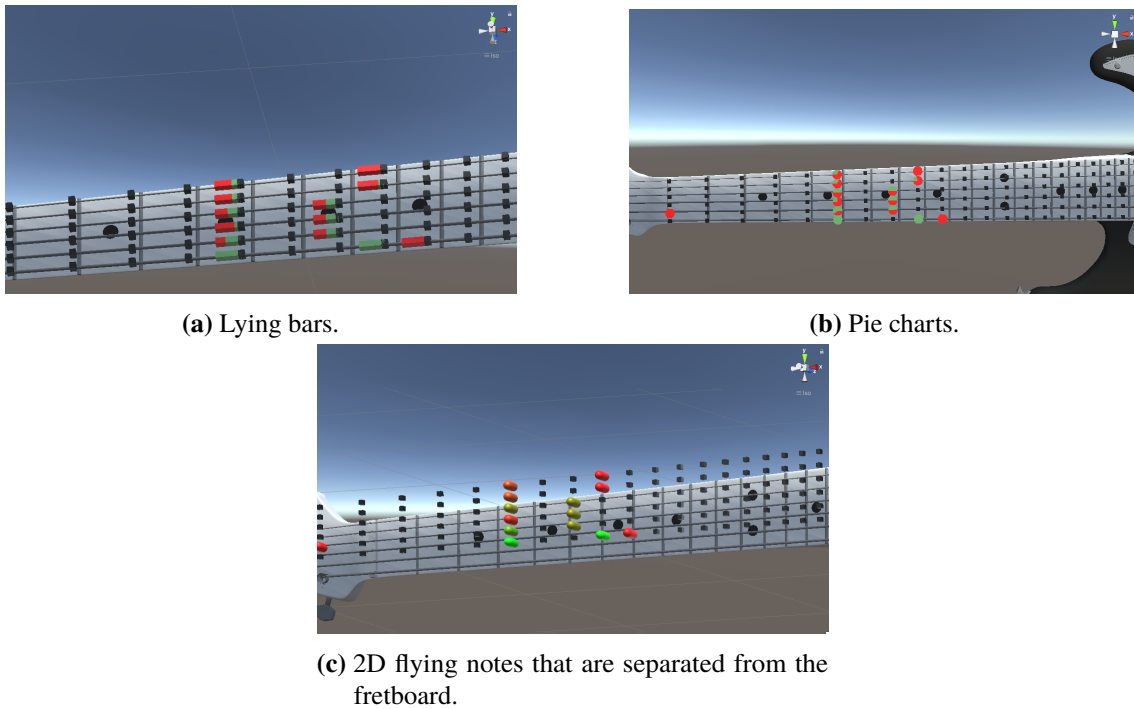
(a) Lying bars.

(b) Pie charts.

(c) 2D flying notes that are separated from the fretboard.

Figure 3.3: 2D Visualizations for the same notes showing in all pictures how often the note has been played right or wrong.

(a) Parallel visualization

(b) Visualization option above fretboard
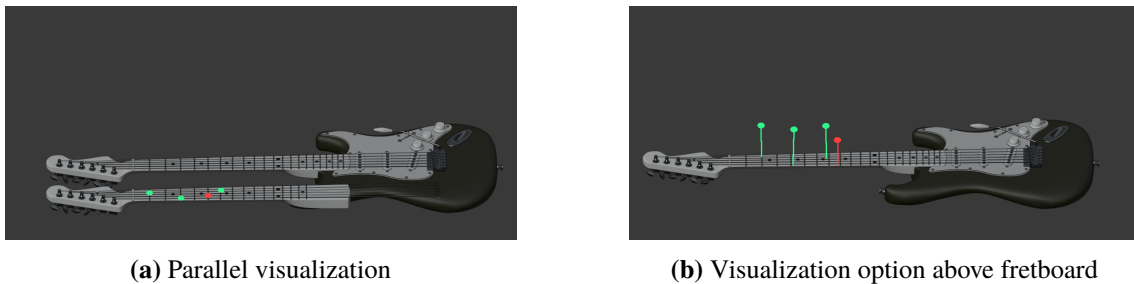
Figure 3.4: Visualization options that do not get covered by fingers

To address this problem there are two options: either having the visualizations also using the z-axis to be above the fingers as shown in Figure 3.4b or not on the physical fretboard but parallel on a virtual one Figure 3.4a. parallel fretboard will be mentioned in chapter transformations Section 3.4. As 3D visualizations we implemented 3D Bar Charts with two or three different color and 3D flying note with and without indicators to where they belong.

3.3.1 Bar Chart with Two Colors

This visualization contains two separated bars in green and red Figure 3.5a. It is designed to visualize the amount of wrong or right played notes either from their attribute pitch or timing.

3.3.2 Bar Chart with Three Colors

The bar charts with three colors Figure 3.5b is the advanced form of the bar charts with two color showing three segments instead.

The main reasons for this visualization are either to show the improvement in blue or to show two different types of errors at the same time. Showing different types of errors is useful when missing the wrong timing while playing to indicate if the note was played to early or to late. As improvement visualization it can be used to compare two different times the same song was played to show in blue the increase of the green bar.

3.3.3 Flying Ellipsoid

The *flying ellipsoids* visualization Figure 3.5c shows the same information in it's height and color. Red means this note is always played wrong while green stands for always right. When the ellipsoid is red it is directly on the fretboard and it at the highest height when green.

3.3.4 Ellipsoid with Connection to Root

This visualization is an extension for the *flying ellipsoids* Section 3.3.3. It has also a thin black bar connecting the root note with the *flying ellipsoid* Figure 3.5d. This makes it easier to estimate how high the ellipsoid is flying.

3.4 Transformations

By shifting, rotating and scaling the user can bring the visualization perfectly in his field of view. It is accomplished by using the user interface (UI). Furthermore can it be easier to understand and compare graphs when viewing them from multiple perspectives. For the mirrored monitor setup rotating and shifting per UI gives the possibility achieve this. With the Microsoft HoloLens this can be also done by head movement.

3.4.1 Mirrored Fretboard and Notes

One transformation option is to mirror the virtual visualization of fretboard and notes Figure 3.6. This is very useful when seeing the guitar from behind. This has the reason that hereby the visualization of each note still aligns with the corresponding note on the physical fretboard.

(a) Two colored bars.

(b) Three colored bars.

(c) Flying ellipsoids.

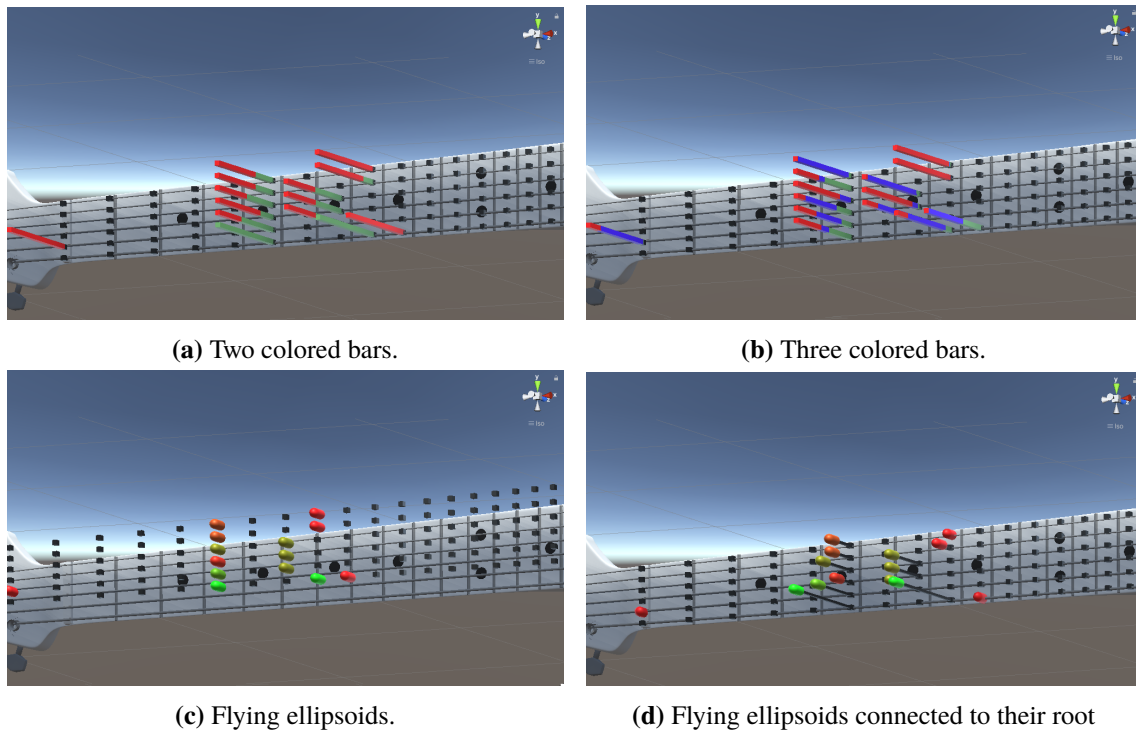(d) Flying ellipsoids connected to their root

Figure 3.5: Comparison of different types of 3D visualization methods green indicating right played notes, red false and yellow means the same amount of notes was played right as wrong.
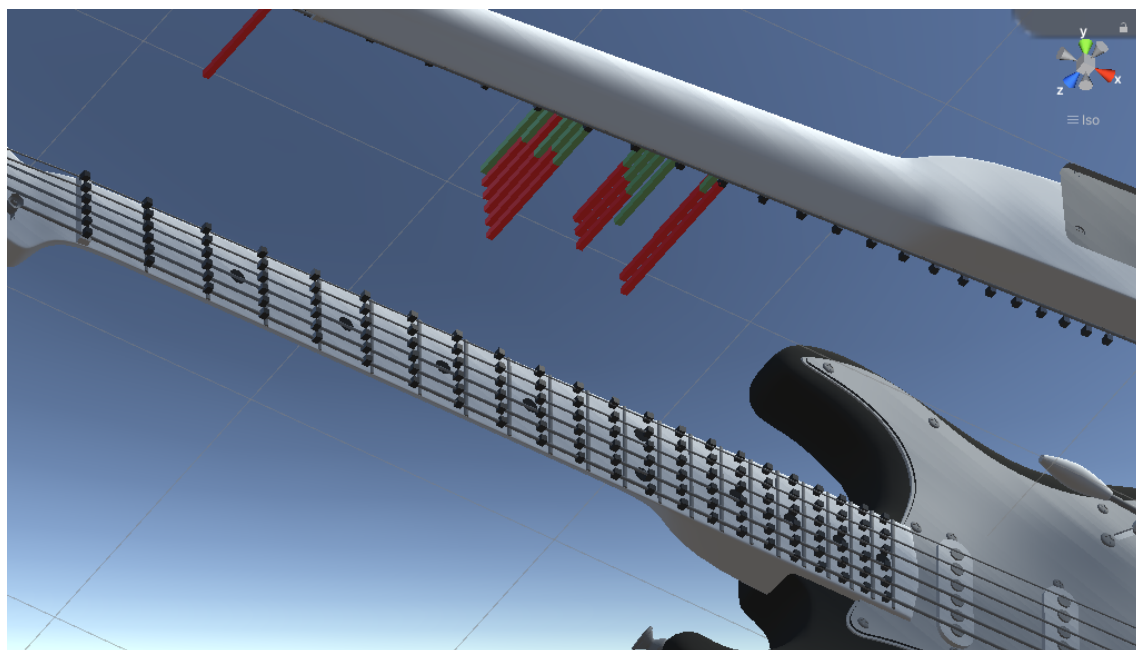

Figure 3.6: Mirrored notes visualizations on the opposite of where the physical guitar would be

3.5 Multiple Visualizations

Another option is to multiply the notes to show visualizations of your recordings for the same song. Useful stacking order for the multiple visualizations are: next to each other Figure 3.7b were no note can be in front of another, on top of each other Figure 3.7a what makes comparing of the same note easier in some cases but hard to find an angle from where to see everything or as staircases Figure 3.7c next and on top of each other what has the same advantage than next to each other but from the normal perspective when holding the guitar the farthest visualization is nearer but relating the same notes to each other is even harder. Other visualizations are way harder to compare because the same notes wouldn't be in the same axis any more. Every 2D or 3D visualization can be shown with this multiple visualizations. To show this we also used the connected ellipsoids in .

3.6 Other Feedback Visualizations

Additionally to the visualizations described in the previous sections that are all error visualizations we also implemented other types of feedback visualizations. With the Show Scales Figure 3.8 user can choose a root note and select between major, minor and pentatonic scale. In this visualization the same note has the same color and it can be activated simultaneously to other visualizations to compare how many notes played in a song are also in the scale. We also implemented to possibility to replay a song Figure 3.9 which will indicate with a green bar when the note was played at the time.
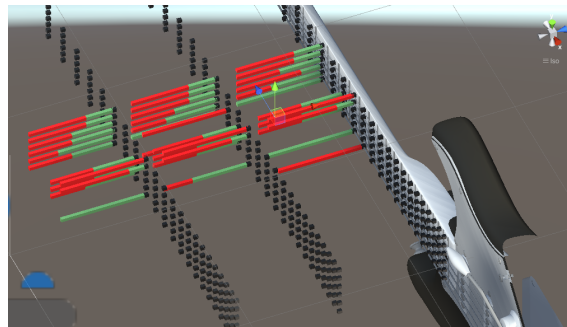
(a) Three different recordings stacked above of each other.
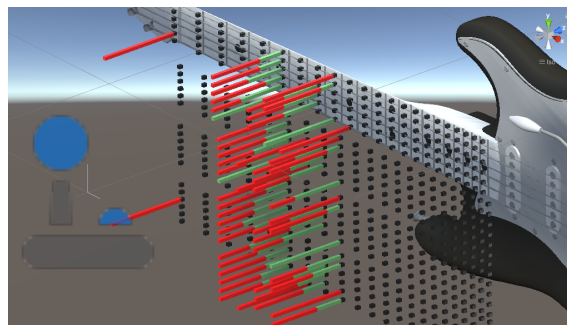
(b) Four different recordings stacked next to each other.
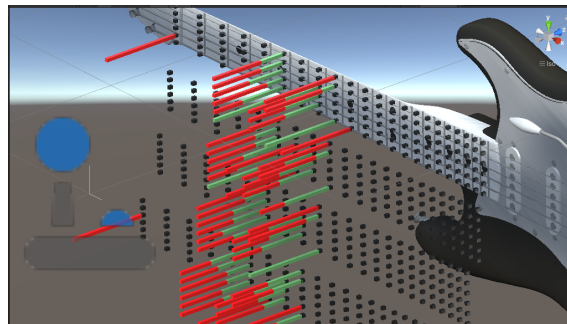
(c) Four different recordings stacked in staircases.
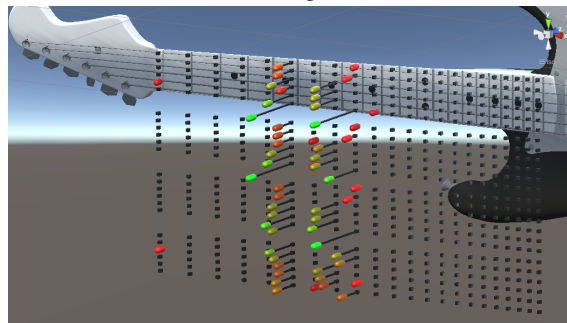
(d) Four different recordings stacked next to each other visualized with connected ellipsoids

Figure 3.7: Comparison of different methods to show multiple recordings for the same song at the same time with the 3D bar chart type in pictures a-c and connected ellipsoids in picture d. All different types of visualizations can be shown with this multiple visualizations.
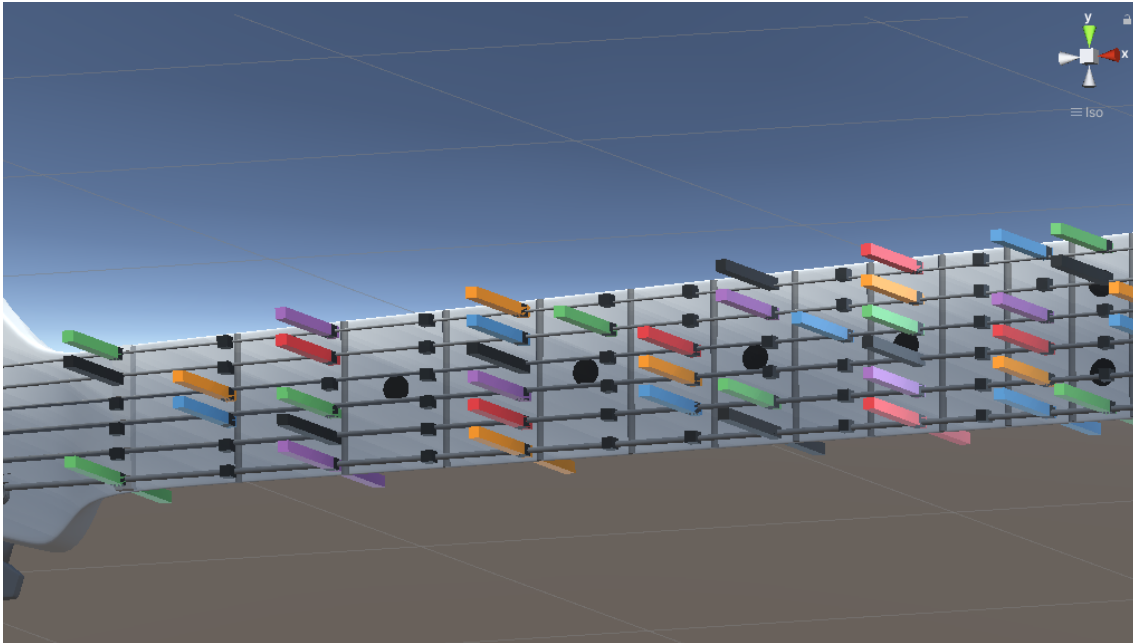
Figure 3.8: Guitar showing B major scale in mirrored monitor View.

Figure 3.9: Fretboard while replaying the 6 standard tuning notes E2-E4.

4 Implementation

We implemented our project for the monitor with webcam and the Microsoft HoloLens approach which is described in Basics Section 4.1. Thereby we encountered some challenges that could be solved. They are described after the Basics in Challenges.

4.1 Basics

The guitar which was used while developing the application is the Fender Squier Stratocaster with 21 frets. It is a widely used guitar and can be assigned to the lower pric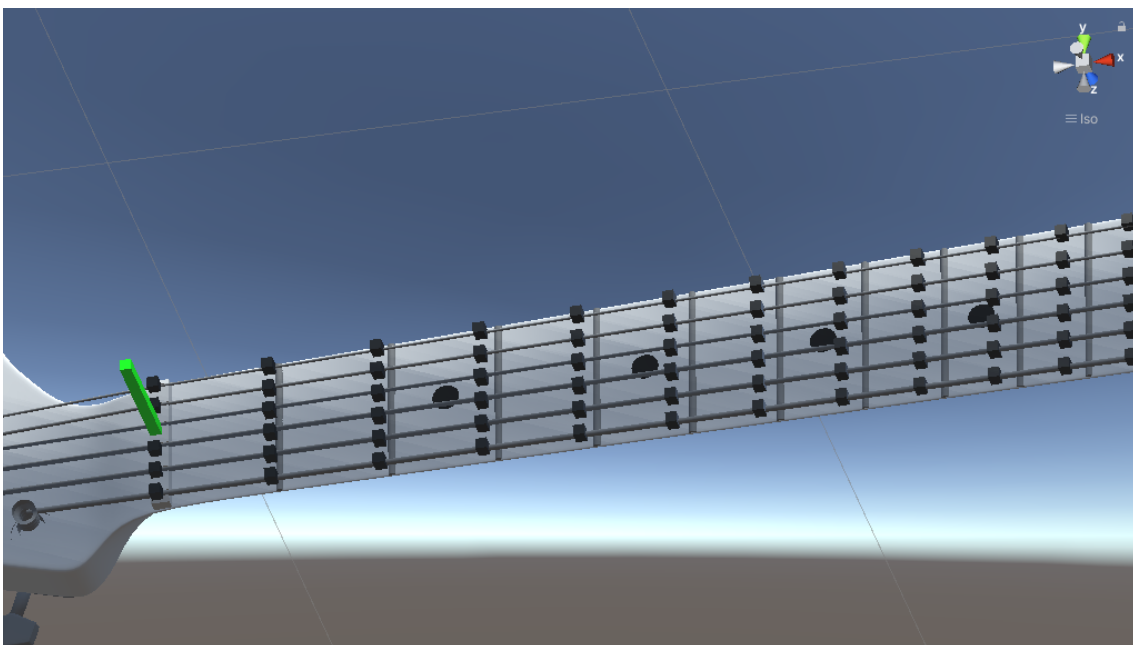e range To have a virtual guitar that is similar to the physical we downloaded an free red 3D model from Behance [1]. The 3D model was then painted in the right colors and some parts were deleted with blender. I have worked with the free and open source 3D creation suite Blender [2] before therefore we used it to edit the models.

As a development platform, we used Unity because one of my supervisors and I were already familiar with it. Unity is an often used and free platform that also supports multi platforms and uses the scripting languages C# and JavaScript. For this project we chose C# as it this more widespread than JavaScript.

The marker tracking for the guitar is done with Vuforia [3]. We choose Vuforia as Ït was demonstrated that by augmenting Microsoft HoloLens with Vuforia's RGB target recognition for inside out tracking, significantly greater hologram stability could be achieved than without-[FJDV18]. While additionally Microsoft recommends Unity engine and Vuforia to create 3D apps for Microsoft HoloLens [KPG17]. Vuforia consists of an online database where the markers get uploaded and an package for unity where we used version 9.8.8.

To achieve creating the markers using random pictures and converting them into 8 bit format is sufficient. The pictures are then formatted with gimp [4] and uploaded to the Vuforia target database. Then they can be printed and mounted on the guitar. The Vuforia camera asset that comes with adding Vuforia to unity is then tracking targets with the image attached automatically. To deploy the project on the Microsoft HoloLens we used Visual Studio 2019 [5].

The visualizations are instances of the same object for each note. This object can be freely adjusted and extended to easily implement further options.

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[1] modelhttps://www.behance.net/gallery/50753419/Fender-Stratocaster-FREE-3D-model-download

[2] https://www.blender.org/

[3] https://developer.Vuforia.com/

[4] https://www.gimp.org/

[5] https://visualstudio.microsoft.com/de/vs/

4.2 Challenges

The challenges that occurred while implementing are the SARS-CoV-2 pandemic in Germany, problems to get the song inputs and working with the Microsoft HoloLens.

The Input   There are different possibilities to get input from the user: Firstly, the MIDI files could be transferred via USB; secondly, pre-saved files with full recordings could be used (It is not important how they were recorded; they just have to be converted into the right format); or thirdly, the notes could be calculated from sound or video as done in **??**.

The last option would've been to time consuming therefore we only tested the first two. For the first option getting the MIDI data in Unity needs a converter therefore we used Minis: MIDI Input for New Input System [6]. Minis only works with Unity's new input system, which in turn made other things like keyboard input far more complicated in comparison to the old input system. One of the problems for example was that with the old input system you could simply listen for any key pressed on the keyboard and then find out which key it was. With the new input system, every action needs to have linked keys that trigger the action because they want to separate physical keys with actions to make it easier to switch between different input devices. So there is no way to recalculate what triggered the action. which is probably intended and would need a long workaround if it is Therefore you have to create a new action for every key u want to map to a different action and bind it to the key.

After testing Minis: MIDI Input for New Input System we were able to get the note name, velocity and pitch but the guitar's fretboard has the same notes with the same pitch on different strings Figure 2.2. So we could not identify the unique position of each note with this approach. The data send from the guitar still contained this information because the program usable with the MIDI pickup could identify the strings. We contacted the developer of Minis: MIDI Input for New Input System but he responded that he could not help us because the MIDI format he converts to unity does not contain the information.

So we decided to use the other method with saved files instead therefore we used the JSON format. This worked very well and debugging was also very easy with this approach.

SARS-CoV-2 pandemic in Germany   Due to the restrictions following the SARS-CoV-2 pandemic in Germany, I was not allowed to enter the University of Stuttgart for five of the six months that I have worked on this project. Since I was neither allowed to take the HoloLens home, I did most of my work with the mirrored monitor instead. When I was finally allowed to go to university, I had to change many things again to make the project work with the Microsoft HoloLens.

Microsoft HoloLens   Since I was not able to test my application directly with the HoloLens , I started the project using the mirrored monitor display. I was originally assuming that with the Microsoft HoloLens everything would be the same as with the mirrored monitor just without the mirrored view and from 3D instead of 2D perspective. But UI and reading of the input .JSON

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[6]https://github.com/keijiro/Minis

text files did not work. So we implemented the most important UI features with cubes that trigger actions when being focused for more than three seconds with the HoloLens. For the input, I found no other solution that worked for me than to create a new variable for every played note and change the attributes name, pitch, start, end and velocity per script. This was to much work to create visualizations for whole songs as they consist most times of more than 100 notes. For this reason, I only created 2 notes to show a visualization with the guitar on the Microsoft HoloLens.

5 Evaluation

We had little time left at the end time; therefore we could evaluate our visualizations only with case studies.

5.1 Case Studies

We divided the section case studies into one part for the mirrored monitor version and another for the Microsoft HoloLens.

5.1.1 Mirrored Monitor

The results of our case study shows that no visualization is the best in all categories Table 5.1. This indicates that for different purposes different visualizations should be used.

	Same Fret	Different Fret	Clear	Many Clear	Accuracy
2D Visualizations					
Lying Bars	+	-	+	+	3
Pie Charts	o	o	+	+	2
Flying Notes	+	+	+	+	1
3D Visualizations					
Bar Charts 2 Colors	+	+	+	-	3
Bar Charts 3 Colors	o	o	+	-	3
Flying Ellipsoid	+	+	+	+	1
To Root Connected Ellipsoid	+	+	+	+	2
Multiple Visualizations					
Stacked Above	-	-	N/A	N/A	N/A
Stacked Next	+	+	N/A	N/A	N/A
Stacked Staircases	o	o	N/A	N/A	N/A

Table 5.1: The evaluation of all error visualizations. Same fret and different fret evaluates how good the notes are comparable. Then we show clearness of the visualizations when only a few or Many Notes on the fretboard were used. "+"indicates being good in that category, ö"normal and ïndicates bad. The perceptive accuracy ranges from 1 (worst) to 3 (best). The multiple visualizations have N/A for some categories as it depends on which visualizations are shown multiple times.
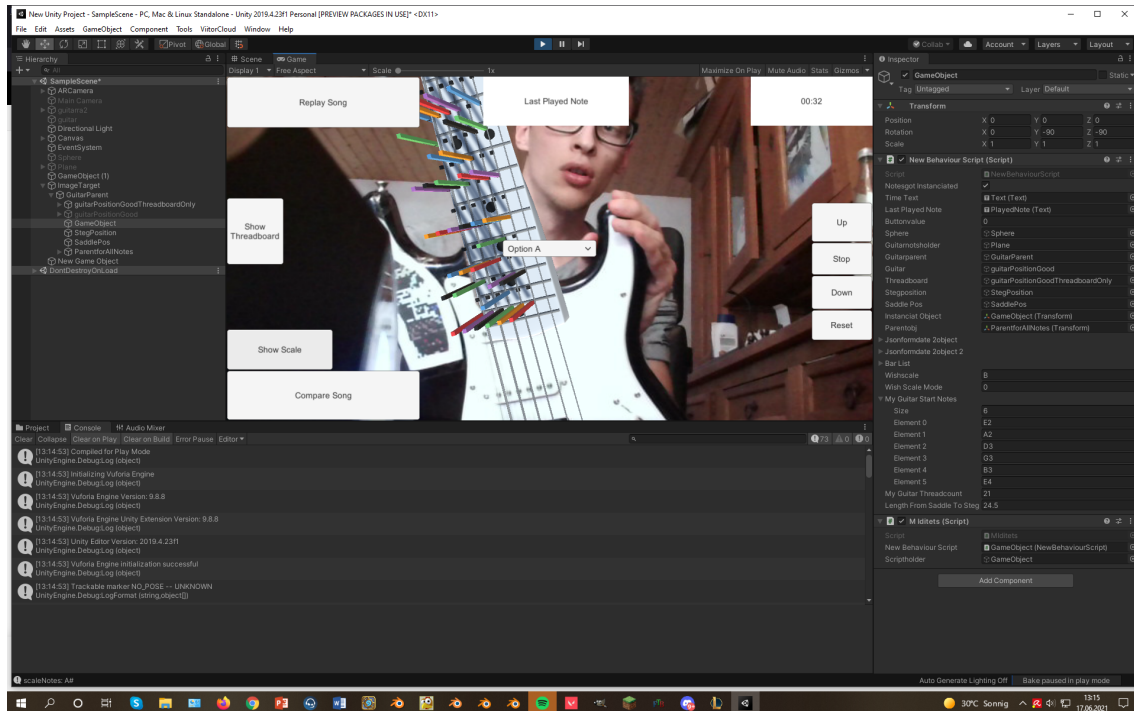
Figure 5.1: Mirrored Monitor with Webcam showing B major scale .

5.1.2 Microsoft HoloLens

We encountered more problems than anticipated while testing the application on the Microsoft HoloLens. The HoloLens has a much smaller projectable field than expected, even smaller than that of my webcam and normal cameras. This is illustrated in figure Figure 5.2. Because of that, the user is very limited in his head movements if he or she still wants the markers on the guitar to be tracked. With the webcam and monitor approach we were able to see the visualization as overlay on the physical guitar and it's markers. As a result we could not see the marker and the visualizations at the same time once the project worked on the HoloLens . The other problem was that the input files were not readable with the Microsoft HoloLens. As we found no fast solution for this problem whilst having only short time left evaluating the visualizations with the Microsoft HoloLens were not possible. To have at least something to show we made screenshots with the Microsoft HoloLens from the view of the created UI which consists of cubes turning red when focused for more than three seconds Figure 5.3. Additionally we made screenshots from the only input that we could use which was coded by hand showing visualizations for two notes Figure 5.4.

5.2 Limitations & Discussion

I don't play guitar myself so I do not know the struggles when learning to play the guitar. Therefore it is hard to test and discuss the findings. We divided this section into limitations for concept, data, design, implementation and evaluation.
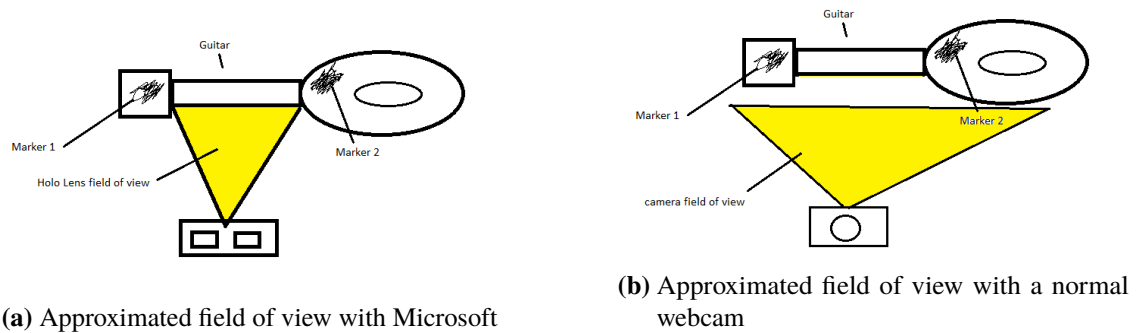
(a) Approximated field of view with Microsoft

(b) Approximated field of view with a normal webcam

Figure 5.2: Vision Differences between Webcam and Microsoft HoloLens
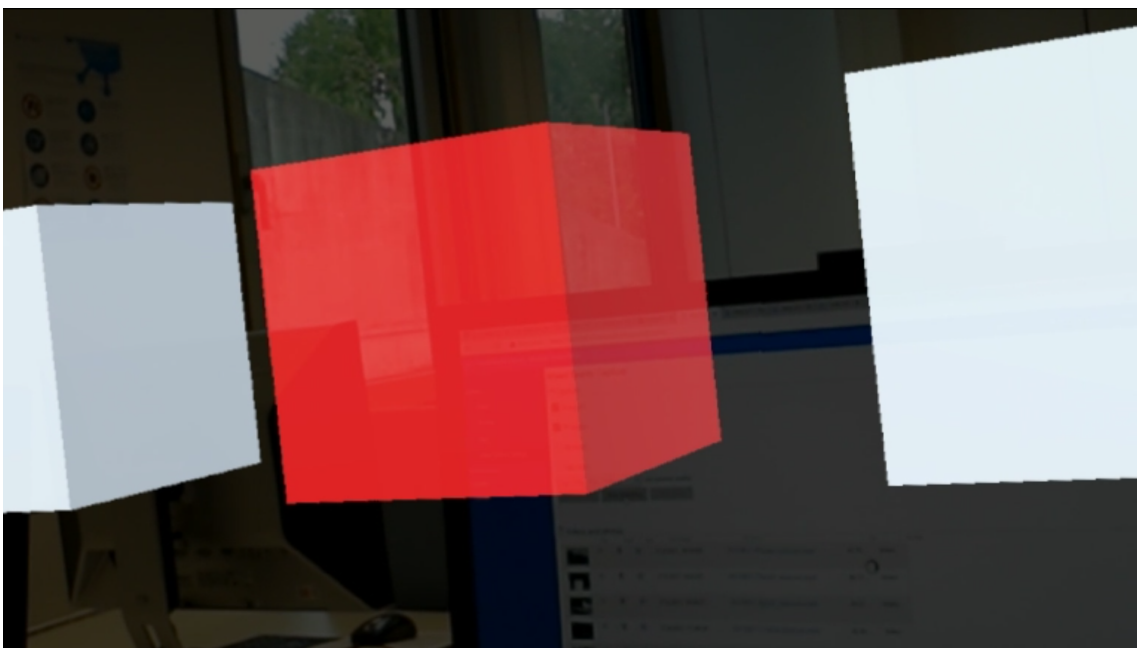

Figure 5.3: UI view with Microsoft HoloLens

Concept   The goal of our work is to show feedback visualizations for guitar learning. One part of that is to be able to show all different types of mistakes that can be made. The possible types of errors we figured out are: playing the wrong note, playing the note not right in timing, playing some notes too loud/not loud enough (wrong strength), having a false tuned guitar and also to hold the instrument wrong while playing.

Our visualizations are able to show all of this except for wrong tuning and wrong holding of the guitar. We decided not to have any visualizations for wrong tuning because many devices and options exist already that fulfil that purpose perfectly. Wrong holding of the guitar would have been to much work to have a satisfying result and was not chosen for this reason.

In case of visualizing errors in strength an one colored bar would contain less useful information as either it would look the same if the same note got played correct the whole time or if it was to strong and not strong enough on equally the same amount. This is because you can not show if the
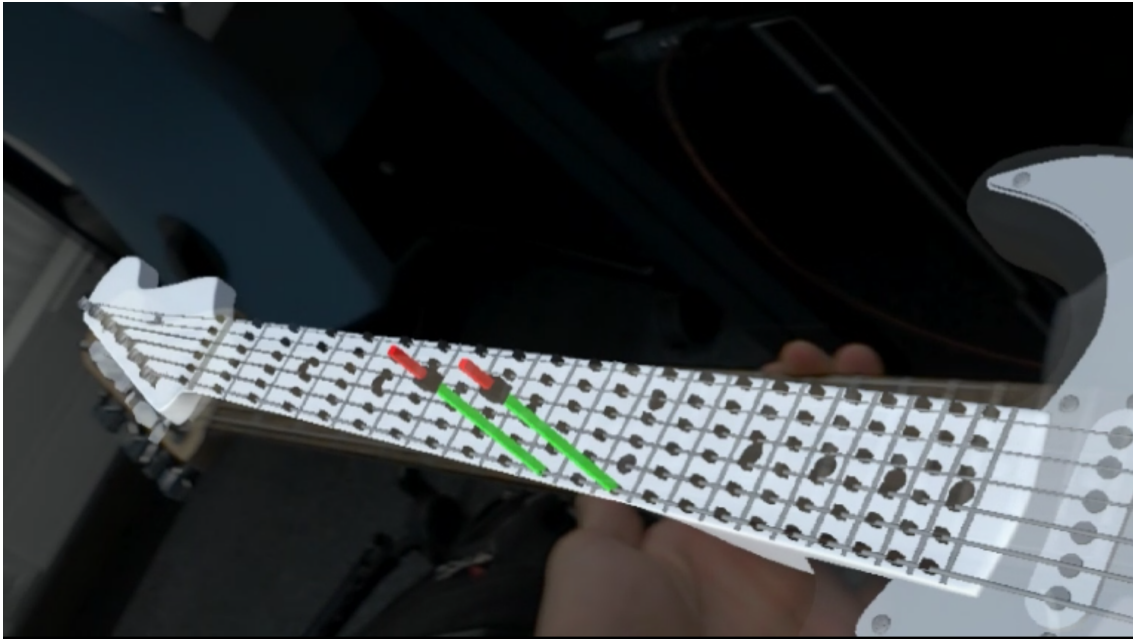
Figure 5.4: Visualization of Two Notes with Microsoft HoloLens.

note was too loud or not loud enough only that it was wrong. So for visualizing this type of errors having bars with three segments in different colors one for too strong, one for the right strength and one indicating how often the note got played not strong enough would make sense. But showing three colors for each note in one bar can be too much to still be understandable or easily comparable when the song contains many different notes and therefore many bars are visible on the fretboard Figure 5.5a. But for songs with just a few notes, this works very well Figure 5.5b.

Data The only data we had were a few recordings of different songs that were played shortly one after another. More interesting would have been showing data from users that really used our work while learning to play the guitar over a longer period of time.

The recorded data is not perfectly comparable to ground truth because we used a self implemented mapping for which note from ground truth was the recorded note. This can cause some problems, for example if the user stopped playing for one second because he has to think about the next finger positions and then keeps playing normally, all following notes would be timed wrongly. Moreover, if the user hit all notes simultaneously all the time, he would have 100 percent correctly played notes because the program only looks for each ground truth note if the same note has been played somewhere near in time in the recordings. As this problem is not trivial perfectly solvable we decided to use only this simple approach as it still shows valuable and nearly perfect statistics. But for future work it should show exact right results as it would really demotivate users and give them wrong assessments to see errors he did not make.

The recorded data also has a lot of notes that do not exist on the guitar and really soft played notes that are not hearable and can be filtered out. Some notes can also be erroneously divided in two times played the same note one after another. This produces errors in the statistics that can not be filtered out.
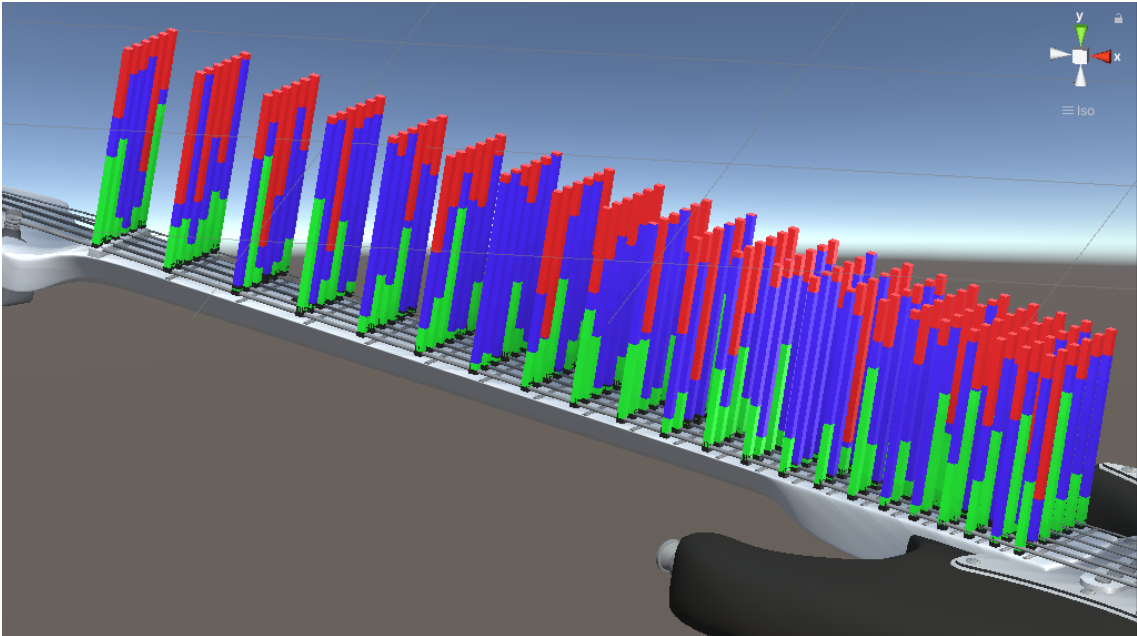
(a) Bars with 3 values on all notes to show how confusing on songs with many notes this can be
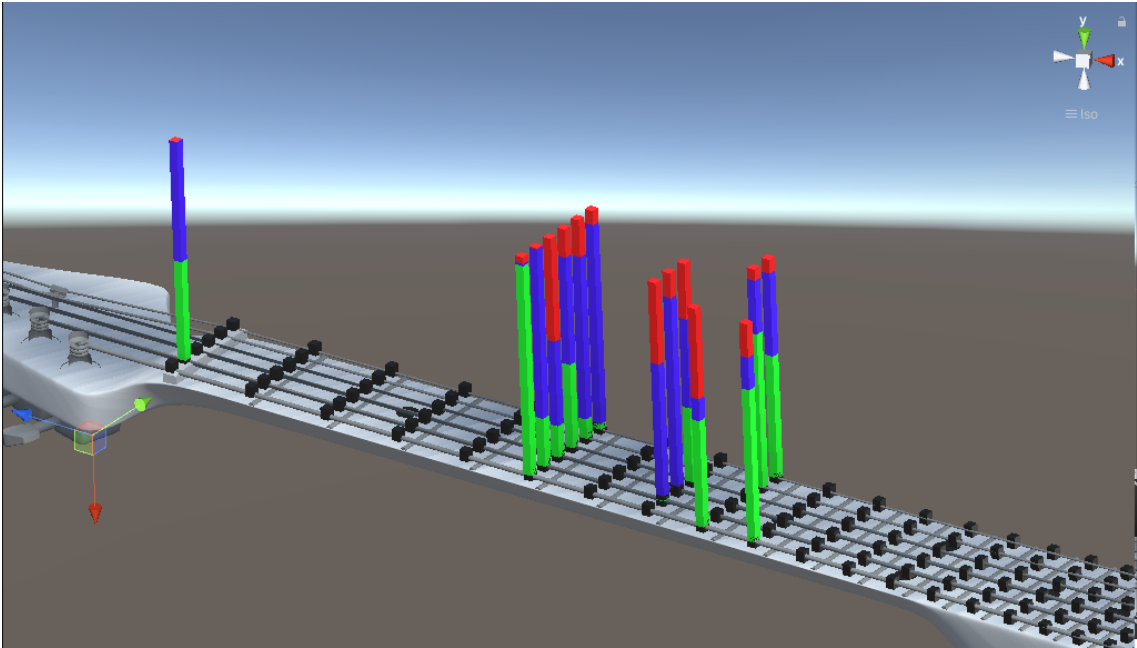
(b) Bars with 3 values for some notes as it would be in simple songs

Figure 5.5: Difference between songs visualizations for many and only some notes

Design   To address the problem of small field of view with the Microsoft HoloLens, one would have to attach markers on both sides in the middle of the fretboard or it would be necessary to hold the guitar the same position while viewing the visualizations. Then again, markers need to be big enough and flat; hence, they cannot be attached directly on the fretboard and would need to be mounted next to it which would in turn be in the way of free finger movement.

Implementation   The tracking of the guitar with markers is very noisy. In order to be tracked, the marker has to be in the field of view of the HoloLens. Otherwise, the signal is jammed.

Especially with the Microsoft HoloLens, this results in either being able to track or to view the visualizations.

Evaluation   We could show some good visualizations for real data with the monitor with webcam approach. Without user studies though, the usefulness of our program can not be rated. Additionally without being able to properly test our application that was originally designed for the Microsoft HoloLens with this device our evaluation is very limited in its expressiveness.

6 Conclusion and Future Work

6.1 Conclusion

Our main task is to show feedback visualizations for guitar learning. Many other works did a small part of this by visualizing correctly or incorrectly played notes directly with various feedback. Some of them also indicating where and how to place the fingers on the fretboard to play the next note. Therefore we specialised on implementing visualizations of summaries from songs. We are able to show visualizations that fulfill this purpose. Hereby we evaluated which visualization has advantages or disadvantages in comparing notes, clearness and accuracy. Our visualizations for multiple songs at the same time are more difficult to compare than if the comparison was done in one graph while showing the difference between the songs. As our input data was very limited we did not find any interesting things when viewing them with our visualizations. The visualizations we have can only show summaries.

Because of the SARS-CoV-2 pandemic we could use the Microsoft HoloLens only in the last month. We were able to see that our visualizations would work if we had found a way to read the input files also with the Microsoft HoloLens. Thereby we found that the field of view of the Microsoft HoloLens is very small. This would make it impossible to track the guitar while viewing the visualizations. That reduces the usability a lot since the guitar must be held perfectly still to keep the note visualization still above the right note on the physical guitar. This means that using our program with the device we planned to use in the beginning does not work very well. Our main idea was to show summaries of songs to not only show what did the user wrong right now but also to show where his weaknesses over a longer period are. This visualizations can be very helpful since they provide the kind of feedback that also music teachers give. Therefore by also implementing automatic finding of important results and using better AR devices our program could be an important help for learning to play the guitar on your own in the future.

6.2 Future Work

Future work can be invested in all aspects. Therefore we divided this part into concept, design, implementation and evaluation of our project.

Concept Including error visualizations for wrong holding and playing with a false tuned guitar that we mentioned in the concept limitations Section 5.2 would be an useful extension. With that included the user could figure out faster if he played the false note and therefore got more errors shown or if he played right with a falsely tuned guitar. Additionally he would not need additional devices to tune the guitar. This would be saving time while making the use of our app more enjoyable.

I had to be corrected multiple times to hold the guitar right whilst making photos for this thesis. As I never used a guitar before this shows that visualizing wrong holding of the instrument would be useful.

Design The design options we have are endless. This leads to the conclusion that the perfect design will never be reached. While we implemented only a few visualizations future work will always be to find better designs. If the problem that results out of the small field of view with the Microsoft HoloLens is not improved by a different implementation it can be also improved with a adjusted design. Therefore it is necessary to find a way to place the visualizations near to the marker. Many other works that also made learning software for instruments made different things to enhance fun while using their program. For this purpose [CAAS19] has group piano learning where other group members can be challenge for a duel. [YAKN11] designed their system with a game-like user interface and tasks with levels. And [FPYT16] used an animated character as feedback for better motivation. Such options can be also included into our project to also enhance the fun when using it.

Implementation The Microsoft HoloLens we used has a very small field of view. This could be improved by using a newer version of Microsoft HoloLens or any other AR device if they have a greater field of view. Mounting an additional webcam on the Microsoft HoloLens and tracking the guitar with would also improve the field of view. But would be possibly bad for the performance.

The marker tracking method with Vuforia can be replaced by 3D model tracking that is also supported by Vuforia. This would require 3d scanning with a special App designed to create 3D models for Vuforia. Therefore the object should have non-reflecting material what was not the case with our guitar as it was metallic black.

To support live feedback a extension for unity has to be developed that can distinguish on which string the note has been played. Otherwise this could be done by calculating the played string with camera or audio. Another option would be to use a different engine than unity.

Evaluation Case studies are very limited evaluation methods. To better evaluate the results of our application it should to be tested in a real scenario over a longer period in representative and well tested and performed user studies.

A further improvement for better evaluation would be to test the project with a newer AR device. This would reduce the restriction of the small field of view that comes with our used Microsoft HoloLens.

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Declaration

I hereby declare that the work presented in this thesis is entirely
my own and that I did not use any other sources and references
than the listed ones. I have marked all direct or indirect statements
from other sources contained therein as quotations. Neither this
work nor significant parts of it were part of another examination
procedure. I have not published this work in whole or in part before.
The electronic copy is consistent with all submitted copies.

Bietigheim 06.09.2021

place, date, signature