Striso, a Compact Expressive Instrument Based on a New Isomorphic Note Layout

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ABSTRACT

The Striso is a new expressive music instrument with an acoustic feel, which is designed to be intuitive to play and playable everywhere. The sound of every note can be precisely controlled using the direction and pressure sensitive buttons, combined with instrument motion like tilting or shaking. It works standalone, with an internal speaker and battery, and is meant as a self contained instrument with its own distinct sound, but can also be connected to a computer to control other synthesizers.

The notes are arranged in an easy and systematic way, according to the new DCompose note layout that is also presented in this paper. The DCompose note layout is designed to be compact, ergonomic, easy to learn, and closely bound to the harmonic properties of the notes.

Keywords

new instrument, isomorphic, 3D note control, accelerometer, DIY, open source, perceived pitch height, tuning invariant

1. INTRODUCTION

I have been playing instruments since I was young, and while the reason to switch from piano to accordion was mainly to play something more portable, another aspect caught my fascination: because the buttons on the bass side are arranged like the circle of fifths (or more general spiral of fifths, a basis in the theory of harmonic properties), it was easier to feel what happened in the music. My right hand, which still played the piano keyboard, needed my brain much more to get its job done. Ever since then I have been fascinated by instruments which have their notes arranged based on their harmonic properties, instead of only their pitch height.

When I started building musical instruments, I started thinking about ways to create new instruments with their notes arranged following the circle of fifths. This resulted in the DCompose note layout, a 2D button layout where both the circle of fifths and pitch height play an important role. This turns out to be an isomorphic layout, which means that each type of interval or chord you play has the same shape. I will elaborate on this further in section 3.

After several acoustical instrument designs which were difficult to build, a friend explained how to work with microcontrollers, and so the plan for making an electronic instrument was born. The goal still was to make a real instrument, with its own sound and the expressiveness of an acoustic instrument, not an interface for mimicking other instruments. This resulted in the Striso (see figure 1), an instrument with the benefits of an electronic instrument, yet an acoustic sound and feel. In section 4 you can find the details of the Striso.

Figure 1: The Striso, with for the right hand the DCompose note layout and for the left hand a reduced size note layout for accompaniment.

The bass side uses the intriguing auditory illusion of pitch circularity to play music which tricks your ears. You will see what that means after reading section 5.

In making these ideas reality there is a lot of technology involved, and thanks to a big DIY community and FabLabs the possibilities for creating complicated technology on a small scale have greatly improved. Section 6 focuses on the technology and construction of the electronics, the hardware, and the software for the synthesizer and its parameter mapping.

But first, in the next section, there is a bit about the history of other work in the fields of note layouts and musical expression.

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2. PRIOR WORK

2.1 Note layouts

In the past centuries many people have attempted to create alternative note layouts which are based on harmonic properties of notes, in contrast with the note layouts based on the physical properties of instruments.

Using harmonic properties to build a note layout quickly leads to isomorphic note layouts. On an isomorphic note layout the notes are located in such a way that each musical interval always has the same shape. So for example a minor third always has the same direction and distance. This makes the layout transpose invariant: every interval, chord, scale or melody has the same geometrical shape and fingering when it played in a different key. This means that the musician needs to learn scales and chords only once, and also that music theory becomes much more intuitive and attractive to experiment with.

Another property that helps a lot in this aspect, is tuning invariance, which means that in different tunings the shape and fingering of intervals and chord is the same [10]. Even when using only the default tuning of western music, the 12-et tuning[1], this facilitates better understanding of music theory, such as the difference between d♯ and e♭, which different in other tunings than 12-et. It also makes it a small step for musicians to explore different tunings, such as the meantone or 31-et tunings that have been popular until the 18th century [14].

For many instruments the note layout is closely tied to the physical shape, like guitar and violin. For others it is most practical for the construction to stick to a linear layout, like piano and harp. Instruments where the position of the buttons is more or less free, like on organs and accordions, attracted experiments, and the development of electronic interfaces and synthesizers made experimenting a lot easier.

The first and most used isochromatic note layout dates back from 1850, when the first chromatic button accordion was made [5]. This layout however is not tuning invariant, and as such less useful for learning music theory. In 1872, Bosanquet created his generalized keyboard [2], while searching for an alternative to the piano keyboard that works for different tunings, and as such is the first tuning invariant keyboard. In 1896 a very compact note layout was patented by Wicki [17], and later reinvented by Hayden, with which a series of concertinas was made. It was mainly focussed on 12-et instruments, but is tuning invariant.

A great attempt to launch a new instrument using the Wicki layout has been done with the Thummer, which ceased development due to funding issues [13]. This created some follow-up in the DIY scene[2].

Also multi-touch apps for tablets incorporating Wicki and other hexagonal layouts have been created[3].

For teaching music and for beginning musicians a nice property that can be found in the Wicki layout is that the area with learned notes can be gradually increased: the pentatonic scale is one connected and compact area, which can be extended to the diatonic scale, and finally to all other notes [12].

The developments around the Wicki layout lay a firm basis for the DCompose layout.

2.2 Musical expression

Several ways of adding expression to digital button or key based instruments have been developed, starting with key velocity sensing which is now very common on keyboards. Later continuous pressure sensing, also called aftertouch, has been implemented on keyboards and new button based controllers.

More recently research has been done on 3D note control, by adding direction sensitivity per button in addition to pressure sensitivity, such as in the Eigenharp [1] or Seaboard [7]. Or even by blurring the borders of buttons to a continuous field, such as the Haken Continuum [4], Madrona Soundplane [6] or Linnstrument [8].

Additionally there are many ways of adding expression to the whole instrument instead of per button, like pedals, breath controllers, strip controllers and motion sensors. Nice examples are thumb controllers plus motion sensors in the Thummer[4], and strip controllers plus breath controller in the Eigenharp, in addition to its 3D button sensitivity.

3. DCOMPOSE, A NEW NOTE LAYOUT

The name DCompose has several origins. It refers to the mathematical term decompose, the layout is an orthogonal decomposition of the pitch height and the circle of fifths. There is the D, the D is the central note in the circle of fifths, and as such the central note on the layout. At last there is the musical meaning of compose.

The goal of the DCompose note layout is a note arrangement which is compact, ergonomic, easy to learn, and closely bound to the harmonic properties of the notes.

For the construction of the layout, the circle of fifths is put on the horizontal axis, while the pitch height is on the vertical axis. Every note can now be placed on the field based on these two properties, see figure 2.

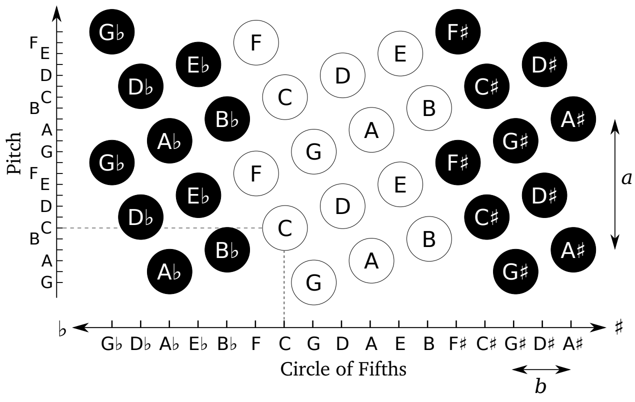

Figure 2: In the DCompose note layout notes are positioned based on their pitch and their position in the circle of fifths. To create an even spacing the vertical octave spacing a is 2.268 times the horizontal second spacing b. For the Striso $b = 18$mm.

The result is the DCompose layout. It is both compact and ergonomic to play with four fingers, which keeps the thumb available for other controls, stabilizing the instrument or helping with difficult passages. It is based on the first two harmonics, the octave and the fifth, and these are both located close to each other. The different octaves are placed vertically aligned above each other, while the circle of fifths is in the horizontal direction. This makes it easy to play in any single key, and also to deliberately play notes that are out of key, which are located just a bit further away. It is also tuning invariant, which helps in understanding music theory and encourages players to explore other tunings, such as Pythagorean, meantone or 31-et.

[1] 12 equal temperament tuning: the octave is divided in 12 equal steps, which is the most used tuning in western music.

[2] see `http://www.altkeyboards.com`

[3] iMusix for iOS, and Hexiano for Android

[4] Thummer demo video at `http://youtu.be/lWK1d9fzlVQ`

Since it is an isomorphic layout it has all the related properties, e.g. chords always have the same shape, and transposing is a matter of moving your hand. Some chord shapes are shown in figure 3.

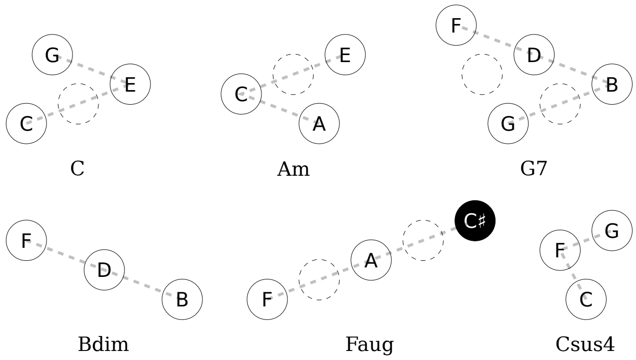

Figure 3: The shape of a chord is alway the same in an isomorphic layout. Here some common chords are shown for the DCompose layout, put the shape of a chord somewhere on figure 2 to get the chord for another note.

The buttons can be coloured for visual guidance. Since the piano layout is so well known, the easiest way to get people familiar is to use the same colouring, white for the C major scale, black for the rest. For tactile orientation the D's, which are the central notes, can be marked with a texture.

To get a nicely filled surface the spacings of the second and the fourth should be equal. To get this the vertical spacing of the octave should be 2.268 times the horizontal spacing of the second (see figure 2). After testing with different hand sizes, a practical value for the horizontal spacing of the second of 18 mm is found, giving an octave spacing of 40.82 mm. For a button array of three octaves with 17 buttons per octave this gives a buttonboard of 16 x 16 cm, which can be used on a very portable instrument. Combined with transpose buttons to shift octaves and key this gives enough range for a most music (for one hand), but also a bigger board with more octaves or more notes per octave can be used.

3.1 Comparison to existing note layouts

The DCompose layout is very close to the Wicki layout. The difference is that the Wicki layout doesn't have the simple relationship between pitch height and location on the note layout [10]. Other properties are shared with the DCompose layout, so existing learning material can be used or easily changed, and Wicki players can easily switch.

Another layout which is closely related it the Bosanquet generalized keyboard. This layout also has the pitch height and the circle of fifths on the axes, only the scaling is different and pitch height is horizontal and the circle of fifths is vertical. Compared to the DCompose layout the octaves are put further apart and the circle of fifths is made narrower. This makes it closer to the piano layout, even the same fingering can be used, which is a benefit for piano players. However, it is less compact, and hence less practical for use on a compact portable instrument.

The note layout of the Array mbira [16] also follows the same pattern of the pitch height vertical and the circle of fifths horizontal, only this time scaled so the octaves are closer to each other and the circle of fifths wider. Here octaves are close enough to each other to be played with a single finger, which gives interesting playing possibilities, but since the major seconds are not adjacent it is less intuitive to play.

All in all the DCompose layout is a compact isomorphic layout where harmonic notes are located close to each other. It can be learned quickly as it is isomorphic, all chords have the same shape and transposing is as easy as moving your hand. Also major, minor, and other scales are easy to remember and have straightforward fingering. The pitch axis is clear, which is not the case on some other isomorphic layouts. Because of its compactness even a small hand can easily span three octaves, and even though less harmonic intervals are further away – where you expect them – they are still comfortable to reach.

4. STRISO, THE INSTRUMENT

The name Striso contains iso, from the isomorphic layout, also tri is found, for the 3D expression control in each button. The first syllable also refers to 'string', as an inspiration for the variety of sounds and expression it can make.

The Striso is built around the DCompose note layout, which fulfills an important part of the goal of being intuitive to play. Furthermore the goals were set to make an instrument which

- is distinct and recognisable both in sound and appearance,
- allows both hands to play, melody and accompaniment,
- is freely movable, to add expression using instrument motion,
- is small enough to easily take with you,
- has space for a reasonable speaker.

The result of this fits in a box of 20x20x20 cm, with the sides angled for comfortable playing (see figure 1). On the right side is a three octave DCompose buttonboard for the right hand. The right hand can move freely around the buttonboard, so its focus can be on playing notes, although the palm or thumb can also be used to stabilize or shake the instrument. The left hand holds the instrument using a thumb strap, as is used on certain concertinas. This way it has direct contact with the instrument and its movement. To reduce strain for the left hand there is an attachment for a neck strap on the top. For the left hand there is a special reduced size button board for playing accompaniment, which is described in more detail in the next section.

The Striso is designed to work standalone, using the internal speaker it can be used for small performances or campfire music. Using the headphone plug you can practise everywhere in silence, or connect an amplifier on stage. For recording, composition, or controlling other synthesizers, it can be connected to a computer.

The goal of this project is to create a real instrument, with its own distinct and versatile sound. As such there is only one main operating mode, which is versatile enough to create different sounds by playing in different ways. This means that there should be many expression possibilities. The next part will elaborate on this subject.

4.1 Musical expression and sound

To put as much control as possible in every note the buttons have 3D note control: continuous pressure and direction sensing on each button. This way for each note the volume, pitch bend and some timbre related parameter can be controlled independently.

Additionally a motion sensor (accelerometer) lets instrument motion like tilting or shaking be used to add more expression and sound effects.

The buttons are shaped in a way that the position where a finger is placed on a button has little influence, only the pressure and the direction of pressure matter. This way precise finger placement is less important.

The top of the buttons has a linear shape, which helps with feeling the orientation of the button, and also of the note layout, when playing without looking. This shape give precise control over the note, and also makes it possible to pluck the buttons, like plucking a string (see figure 4).

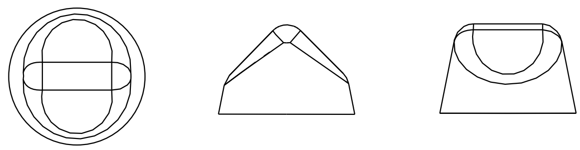

Figure 4: The shape of the buttons, top view and side views. The buttons are sensitive in all three directions. The directionality of the top helps with feeling orientation and makes plucking like a string possible.

The sound of the Striso is inspired by a string, where you can both have natural decay, when plucking or hammering, or a sustained note, with other actuation like bowing or resonating with an amplifier.

The Striso is supposed to sound like an acoustic instrument, and as such it is important that there is a clear match between the sound and the look and feel, and that each action has a believable influence on the sound. Still it must be possible to touch or even cross the border of a believable acoustic instrument.

5. SPECIFICITIES OF THE BASS SIDE

The left side, or bass side, is mainly meant for accompaniment, and as such different aspects are important.

For accompaniment, it is more important which chord is played than in which octave or which inversion. This can be combined with the intriguing auditory illusion of pitch circularity, which makes it possible to change the perceived pitch height independent of the pitch class of the note that is played [15][3]. This is also used on the bass side of accordions, where all bass notes have the same perceived pitch height, and all bass chords have a slightly higher perceived pitch height.

Using pitch circularity, only one octave of notes is necessary, as the notes never get higher anyway. This is convenient when it isn't important that the note is played in a specific octave, as it is when playing chords. Think of a guitar, the player often only knows the chord, and not exactly which notes or which inversion.

A new implementation of pitch circularity is introduced here, called 'perceived pitch height modulation', which makes it possible to change the perceived pitch height of every note while playing. As the buttons are direction sensitive, one axis can be mapped to perceived pitch height, which introduces the possibility of playing any note at any pitch height. In the next part the details are explained.

This creates many creative possibilities, for example imagine playing a C major scale upwards, while ending on the same C without any jumps. Or even end an octave lower, play perceived pitch height glissandos, or change the inversion of a chord smoothly. To help your imagination, listen to some of the audio samples[5].

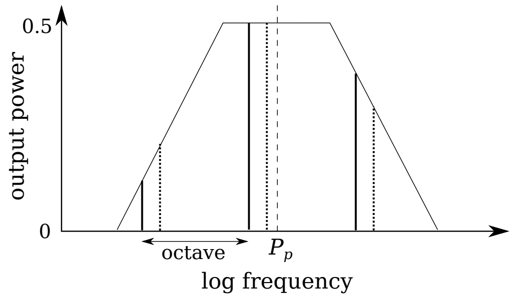

Figure 5: The method for generating notes with an arbitrary perceived pitch height. Three notes in succeeding octaves are played, while their output power is based on the distance to the requested perceived pitch height P_p as in this graph. In the graph this is shown for two notes, C with a solid line and D with a dotted line.

5.1 Perceived pitch height modulation

The perceived pitch height modulation is implemented in a relatively simple way, which in principle can be applied on any sound. If instead of playing one note, the same note is played in three succeeding octaves, the perceived pitch height is similar to the middle note played alone. By changing the relative volume of the three notes this perceived pitch height can go up or down, while still playing the same note. The three notes that are chosen are the note closest to the requested perceived pitch height P_p and the note one octave higher and lower. The output power A_n of each note is calculated with the formula

$$A_n = \begin{cases} 0.5, & \text{if } \Delta P \leq 0.5 \\ 0.5 \cdot (1.5 - \Delta P), & \text{if } 0.5 < \Delta P <= 1.5 \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

where

$\Delta P = |P_n - P_p|$

P_n is note pitch

P_p is requested perceived pitch height

and pitch is expressed in octaves:

pitch $= \log_2$(frequency)

This way the total output power of the three notes always is 1. This is illustrated in figure 5. Now the perceived pitch height can be changed independent of the note that is played. In practice the perceived pitch height is different per person, and is also influenced by the audio equipment [3]. For this instrument this is no concern, as the musician can adjust the requested perceived pitch height by ear.

Using perceived pitch height modulation also has implications for the button layout, as is explained in the next part.

5.2 Button layout of the bass side

Using perceived pitch height modulation only buttons for one octave are needed, where the perceived pitch height is controlled by the direction sensitive buttons. Because there is not really an increasing pitch height in the notes,

[5]Audio samples can be found at `http://www.toverlamp.org/nime/perceived_pitch`

a straight Wicki layout is used. While one octave would be enough, it is important to keep the isomorphic properties, so three rows of buttons are available, where the top row is a copy of the bottom row.

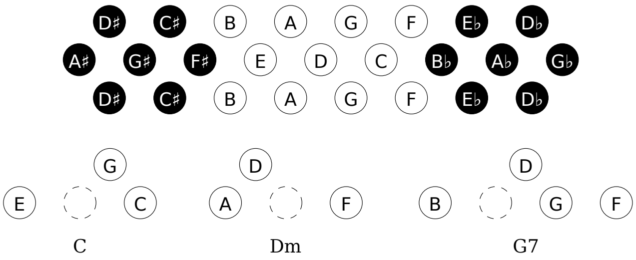

Figure 6: The mirrored Wicki note layout as it is used on the bass side, and some common chord shapes. Thanks to the perceived pitch height modulation it doesn't matter which chord inversion is played, so the inversion with the easiest fingering is chosen.

The layout is mirrored, so on both sides the same direction for sharp and flat are used: pinky direction for sharp and thumb direction for flat. The layout and the shapes of some chords are shown in figure 6.

On the Striso the left hand has restricted movement freedom, so the buttons are smaller and spaced closer than on the right side. The spacing is equal to the bass side of an accordion. For accordion players the spacing should feel familiar, just as the order based on the circle of fifths. Only there are way fewer buttons and way more possibilities.

6. TECHNOLOGY

The design of such an instrument is one thing, the technology to really create a well functioning device is another. The setup of a production line is even yet another thing. However, in these times of rapid prototyping and customized manufacturing, they all tend to get closer to each other.

The first working prototype has been made with little more than an Arduino, a transparency sheet, aluminium tape, some pressure sensitive foil and a piece of silicone tube. While it did work and was more or less playable, the sensitivity was far from constant. A couple of prototypes later the aluminium tape was replaced by gold plated contacts, and the Arduino with one of the fastest microcontrollers available, and the silicone tube by molded silicone.

This section will explain more about the technology used to create the prototypes.

6.1 Electronics

The core of each pressure and direction sensitive button is formed by three pressure sensitive pads. Using three pads the pressure and direction of the pressure can be measured. Since there are many buttons the sensors need to be cheap and small. Luckily Velostat or Linqstat, the black antistatic foil in which electronic components often are shipped, has a pressure dependent resistance, and is used for pressure sensors by the DIY community [11]. The pads are placed between a flexible circuit board on one side, and a rigid circuit board on the other side (figure 7). The easiest way to connect all the pads is using a matrix without any additional components per pad. The downside of this method is that there is crosstalk possible between pads when multiple pads are pressed. Since it is a big benefit that no additional components are needed, the matrix is designed such that the impact of crosstalk is low. This is done by connecting each octave to a single analog input, while all buttons with the same pitch class are sharing a digital output. This way the only crosstalk that is possible is between the same notes in different octaves, which isn't much of a problem in music.

The pads are sampled by microcontroller, which then sends those signals to the internal synthesizer or to a computer. The first prototype used an AVR microcontroller, which is the basis for the Arduino platform. However it became apparent quickly that something more powerful was needed, with more digital outputs and a faster ADC. One of the most powerful microcontrollers around is the STM32F4, a 168 MHz ARM processor with three very fast ADCs and up to 140 input/output pins. Also a floating point unit is included, which gives it enough power to run a synthesizer. A prototype board for this microcontroller is available under the name STM32F4-DISCOVERY, and includes an accelerometer and audio codec, which makes it a perfect choice for prototyping new instruments.

The firmware is developed using ChibiOS[6], an open source real-time operating system which provides a hardware abstraction layer and fast multithreading.

6.2 Synthesizer and mapping

The synthesizer is written in the functional audio programming language Faust[7], which combines a functional and a flow based language, and is specifically designed for real-time signal processing and synthesis. There are libraries with common functions included, and there are good examples available [9].

The Faust compiler generates C++ code, which can be compiled to a large variety of targets, including plugins for popular software or standalone programs controlled by open sound control (OSC). In order to run the synthesizer on the microcontroller in the Striso a new target is developed for embedded use. The source code including an example for the STM32F4-DISCOVERY board will be available on the website of the author[8].

In order to quickly try new ideas and fine-tune the parameter mapping the synthesizer is run on the computer, while a small program converts the messages from the Striso to OSC messages controlling the Faust synthesizer.

[6] `http://www.chibios.org/`
[7] `http://faust.grame.fr/`
[8] `http://www.toverlamp.org/nime/`

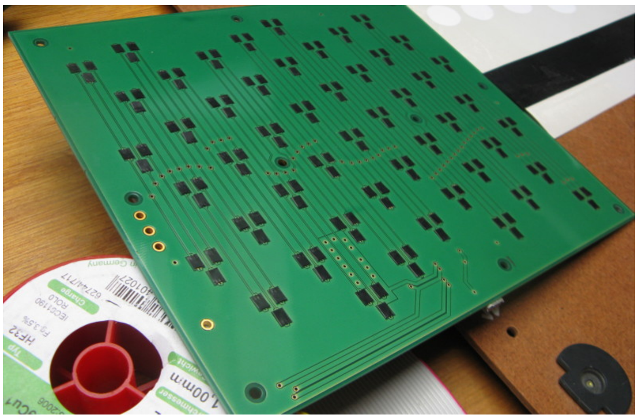

Figure 7: Circuit board with all the pressure sensitive pads.

7. EXPERIENCES AND FUTURE WORK

With the DCompose note layout a compact isomorphic layout is created, based on the circle of fifths and pitch, which is easy to learn and helps understanding music theory.

With the Striso an expressive instrument is made with 3D sensitive buttons and motion sensing. It uses the DCompose note layout, and has a built-in speaker, battery and synthesizer, and a special bass side which features perceived pitch height modulation, which is also introduced in this paper.

In the current state the Striso is a prototype, and has been tested informally by several people. The general response is very positive, and the layout is quickly understood, especially since the black and white colouring is added. For some people not having the minor seconds close to each other feels strange, but adaptation is generally quick when noticing that when the index finger is on a certain note, the pinky is very close to a minor second higher or lower. Also using the left hand for accompaniment doesn't always feel natural, especially using a different layout. Hence ideas for adding a stronger connection between both hands are being researched.

Additional experience with the DCompose layout is obtained with a modified accordion (figure 8), which is being used with great pleasure by the author.

The note layout is very easy to play in any key, especially when playing blind and guidance by the colours is not needed. The layout makes it easy to jam in a certain key, but also attracts experimenting with out of key notes and other scales such as blues or gypsy scales, since the relation with other notes can be felt well. Fingering is generally smooth and goes almost automatically for melodies, for polyphonous pieces more thinking ahead is needed to play smoothly. For me as an accordion player the separation between the two hands feels natural, though the bass side gives much more freedom than the bass side of an accordion.

The goal of making in acoustic like instruments have already proven successful, more than one was surprised to find out it is electronic.

Since people have different taste and musical ideas the intent is to make parts available for custom instruments, if there is enough interest. The software and firmware will be open source.

Progress of the development of the Striso can be followed on the website[9].

Figure 8: The accordion of the author modified to the DCompose layout. It has four octaves with 21 buttons per octave.

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