Inventing a Versatile Platform for Instrument Augmentation and Electroacoustic Composition

Erik Stifjell
UiT The Arctic University of Norway Academy of Music/
University of Bergen Faculty of Fine Art, Music and Design
Tromsø/Bergen, Norway
erik.stifjell@uit.no

ABSTRACT

The FLAPIBox (FLexible instrument Augmentation that is Programmable, Integrated in a Box) is an innovative, flexible, cross-instrumental augmentation device that is adaptable to a wide range of instruments, utilizing diverse loudspeaker and microphone technologies without necessitating permanent modifications to the instruments themselves. The aim of the development is to design a system to seamlessly integrate electronic sound with acoustic instruments and the first compositions utilizing it has already been written. The FLAPIBox combines concepts form both augmented (hyper-) instruments and self-resonating vibrotactile feedback instruments (SRIs) to enhance musical expression and performance.

This paper reports recent evolution and presents the latest version of the FLAPIBox. After three years of development, several iterations and meticulous bench tests of various components, the latest version appears both stable and well-worked. The paper also discusses the critical considerations that have shaped the physical and technical design of the FLAPIBox and proposes directions for future development.

1. INTRODUCTION

The development of the FLAPIBox draws on the author's experience as a composer searching for alternative ways to implement electronic sounds in compositions which has been an important focus for the last 15 years. The main motivation is to develop a universal platform for integrating loudspeaker and microphone technology into a wide range of acoustic instruments. Simplification of the technical setup when performing electroacoustic music has been another important goal. Moro et. al already pointed out similar benefits when *"using a self-contained embedded platform in the creation of DMIs[1] (...)"* [1].

A preceding paper presenting the FLAPIBox [2], contained a review of related works, with a main focus on SRIs and augmented instruments. The findings showed a predominance of augmented instruments projects focusing on sensor data mapping for further processing in a DAW[2] or similar. What these often had in common was that they were initiated by instrumentalists within the impro scene, who use PA systems as part of their musical expression. They were also often intended to fit only one specific instrument. SRIs were mostly semi-integrated solutions, i.e. with built-in microphones and speakers and with the ability of connecting external effects or a computer. The conclusion indicated that the FLAPIBox stands as a significant contribution to the domain of augmented instruments, being a versatile option with cross-instrumental capabilities.

A stage setup with the instrumentalist(s) in the center and loudspeaker-boxes on each side of the stage, often hanging from the ceiling, detaches the sonic gestures made by the performers. Flores describes it as a *"disembodiment of the audio source"* [3], when the loudspeaker is not a part of the instrument. This makes it difficult for the audience to understand the connection between the sonic gestures performed on stage, and the sound coming out. This is sometimes also a problem for the instrumentalists as well, having loudspeakers placed in front of them and not hearing clearly how the instrument sounds through them [4]. Is there any way to counteract the disembodiment and to unify the acoustic and electronic sound world within the instrument itself? "Søvnen – for bass flute and electronics" and "MHRD / LDVK – for brass trio and electronics" are both compositions that try to answer this question.

2. INSTRUMENT DESIGN

The design of the FLAPIBox has similarities with most SRIs [5]: microphone – preamplifier – (computer) - amplifier - loudspeaker. This design is most clearly illustrated by Armitage et. al [6]. The FLAPIBox design has been slightly altered for each new prototype, leaving the 2024-design as the most simplified yet. An online repository[3] contains all files needed to build the FLAPIBox together with infrastructural software and an open library of interchangeable software modules.

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[1] Digital Musical Instrument

[2] Digital Audio Workstation

[3] https://github.com/erikstifjell/FLAPIBox

2.1 Earlier prototypes

In the preceding paper published [2], two early prototypes of the FLAPIBox were presented. Although the focus was to test different components and neither prototype was integrated (boxed), both prototypes proved the concept of a flexible, cross-instrumental augmentation platform for embedding electronic sound into acoustic instruments.

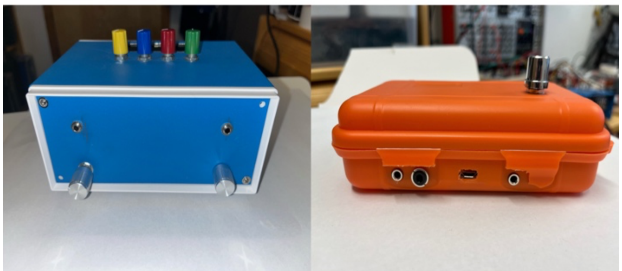

Figure 1. Integrated prototypes #1 and #2

Later, two integrated prototypes were made (Figure 1), #1 (blue) and #2 (orange). Prototype #1 was based around a Raspberry Pi 4 SBC[4] and a XH-M190 (TPA3116 chip) 2x100W amplifier, running RNBO (Max)[5]. The remaining components (preamplifier, step-up converter etc.) were the same as the breadboard prototype described in the preceding paper [2]. Prototype #1 had an LCD screen for visual feedback and digital encoders (multicolored) for controlling the Raspberry Pi, utilizing the computer's exclusively digital GPIO pins. An additional python script running in the background was needed for communication between encoders, LCD screen and the RNBO-patch. The two potentiometers on the front controlled the preamplifier's gain and amplifiers volume.

Prototype #2 was based around a Bela Mini[6] and a Kemo #M033N 18W mono amplifier. Since the Bela Mini provides 59dB gain for the input, a preamplifier was not needed. Two mini-jack input were fitted to handle both dynamic/piezo and electret microphones. One mini-jack output was fitted for connecting a loudspeaker. Two Micro-USBs for 5v power were also fitted, one for powering and programming the Bela Mini, and the other for powering the amplifier via a step-up converter (5-10v). A 10k analog potentiometer was added for output volume control. At a later stage analogue potentiometers and push buttons were tested.

These two quite different prototypes provided knowledge on which components worked best, what limitations and opportunities they provided, how the technical setup could be simplified and, not least, how to maintain an open-source approach. For Prototype #1 the latter was not possible, due to the choice of using RNBO as the software option, a costly, platform dependent solution. Prototype #2's computer was a Bela Mini and Pure Data[7] as the software option. These choices provided both an open-source, platform independent option, and a much more simplified technical setup.

[4] Single Board Computer
[5] https://rnbo.cycling74.com
[6] https://bela.io/
[7] https://puredata.info

The Kemo #M033N amplifier used in prototype #2, proved to be a little complicated to integrate with other components. It was only 18 watts, mono, which in some cases could result in too low output volume in addition to the limitations of only having one channel. In prototype #1, XH-M190 had more accessible connections, making it easy to integrate. The amplifier also had two channels of 100 watts each, which opened the possibility of using both input channels on the Bela Mini and connecting two loudspeakers.

The conclusion was to continue further development of the FLAPIBox with Bela Mini and the XH-M190 amplifier.

2.2 FLAPIBox 2024

Figure 2. FLAPIBox 2024-version

The housing is made of 3D printed PLA and measures 164 x 117,5 x 77mm. The top panel is fitted with an OLED screen, 6 potentiometers, 2 push-buttons, one rocker-switch and 2 LED-lights (Figure 2). The left side has two mini jack inputs for microphones, two micro-USB and one USB-A input. The back side has one micro-USB input, and the right side has two mini jack outputs for loudspeakers.

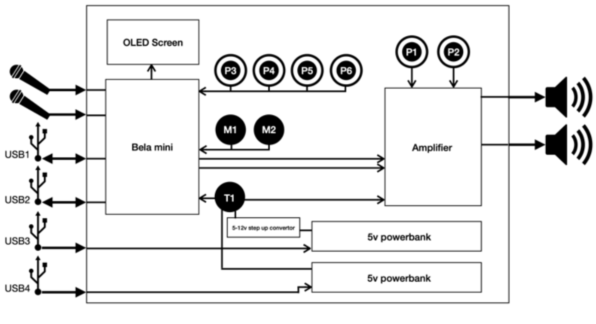

Figure 3. System diagram of the FLAPIBox

The hardware design of the FLAPIBox 2024 version (Figure 3.) is based around the Bela Mini system and an XH-M190 2x100W power amplifier and unlike the previous prototypes, this version is battery operated. Two 5v power banks supply the FLAPIBox with power: one for the Bela Mini and one for the amplifier via a 5-12v step up converter, increasing the voltage to within required range. A double throw toggle switch (T1) turns on the Bela and amplifier. Two micro-USB plugs (USB3, 4) charges each of the power banks.

Two mini-jack inputs are fitted for connecting microphones. These are connected to Bela's Audio In [adc~1-2][8]. The signal patch runs further from Bela's Audio Out [dac~1-2] to the two channels on the XH-M190 amplifier, which output volumes are controlled by two 50k potentiometers (P1-2). Two mini-jack outputs are fitted for attaching loudspeakers.

4 10k potentiometers (P3-6), [adc~3-6] and two momentary push buttons (M2-3), [Pd: 15-16] control the Bela mini. An OLED-screen [12-C1 SCL, SDA] provides visual feedback. The Bela USB host port is connected to USB1 for the ability of connecting peripherals. USB2 is connected to Bela's Micro-USB for accessing the IDE on a computer.

This controller setup provides both static and dynamic settings: Analog potentiometers for common parameters such as input gain, delay times etc. Momentary switches control dynamic parameters such as switching through presets. In addition, the onboard USB host port is available for further extensions. This hardware design uses 4 analogue (8 in total) and 2 digital pins (16 in total), which makes later iterations of the FLAPIBox further expandable.

2.3 Peripherals

The FLAPIBox offers an integrated solution, where microphones and loudspeakers are mounted on the instrument itself, unlike many other augmented instrument designs. Because of the FLAPIBox' input and output flexibility, such peripherals are widely available, both off-the-shelf and with slight modification, such as prototyping holders and housings. At present, only dynamic microphones and loudspeakers are intended to be connected, in addition to generic midi controllers. In future iterations, sensor inputs will be considered. The Bela mini has an option of providing 3.3v for electret microphones. A switchable circuit has already been tested but was not necessary for further development.

2.3.1 Microphones

The two microphone inputs on the left side of the FLAPIBox can handle most instrument microphones and piezo pick-ups. The following off-the-shelf solutions have been tested and found suitable: Helpinstill[9] for both upright and grand piano, PiezoBarrel[10] for trumpet, trombone, and euphonium (also work with woodwind instruments).

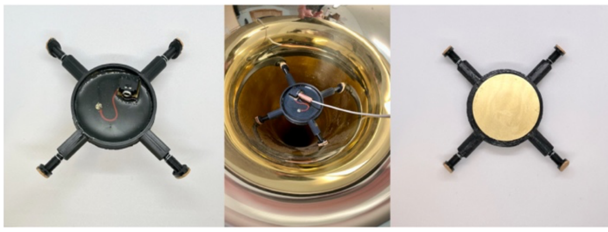

Figure 4. BrassBellMic.

The BrassBellMic (Figure 4) was developed as a prototype for suspending a 50mm piezo element in the center of a euphonium bell. The piezo element is glued to the bottom of a 3D-printed tray filled with epoxy to secure a mini jack output and electrical connection points. Four cylindrical tubes with feet fasten the construction to the inside of the bell with the help of springs. A layer of cork is glued to the feet for friction against the brass. The aim of this construction is to avoid feedback, as the piezo element only picks up mechanical vibrations in the instrument, and not unwanted sound outside the instrument [7]. However, some sounds from valves being pressed were picked up. With some design improvement it is believed that this solution has potential for providing an acceptable sound signal for further sound processing. Because of the large size of the piezo element, this configuration cannot be used with smaller bells like trumpet or trombone. Smaller piezo elements have not been tested yet.

2.3.2 Loudspeakers

Two main types of loudspeakers are suitable for embedding in acoustic instrument: Normal loudspeakers and sound exciters[11]. Normal loudspeakers are the preference for wind instruments. Mid-range car speakers such as PRO PSM-8, MAD PM1-64 and MAD M2-34 from GAS have been found suitable as hand-held, un-modified loudspeakers for brass instruments. For woodwind, where both hands are needed for playing, more extensive prototyping might be necessary [3] [8]. For resonance box instruments[12] and percussion instruments, sound exciters are preferred. Off-the-shelf exciters like Monacor AR-50 and Dayton DAEX32Q-4/8 usually require little or no modification to work with the instrument, i.e. non-permanent installation with clamps, adhesives or tension rods [9].

[8] [ ] refer to connections in the Bela mini's pin diagram
[9] https://helpinstill.com
[10] https://piezobarrel.com

[11] Also bass shakers and tactile transducers.
[12] Piano, stringed instruments

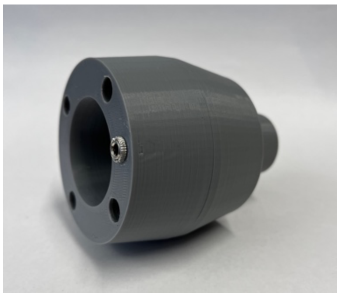

Figure 5. FluteFootSpeaker

The FluteFootSpeaker (Figure 5) was developed in connection with the composition of “Søvnen – for bass flute and electronics” and is a 3D-printed housing in three parts that holds an AuraSound NS2-326-8AT Full-Range Woofer. 3D-print files and building instructions can be found at an online repository.[13] The FluteFootSpeaker is based on a Euphonium mouthpiece speaker, designed by Geir Davidsen, but has been modified to fit the foot of a bass flute. The speaker plays into the instrument, and due to its characteristic, the speaker element can set the body of the flute in motion, thus creating the illusion that the sound is coming from the flute itself. Since the construction closes the foot, the lowest pitch (C_3 or B_2, depending on model) cannot be used when the FluteFootSpeaker is attached, which must be considered when composing for this setup.

3. SOFTWARE

Throughout the development period, a modular approach to both hardware and software has been important with the aim of being able to easily reuse and replace modules. At the early stage, RNBO (Max) was used for developing the software. However, RNBO is neither free nor platform independent, thus making it impossible to maintain an open-source approach. When Bela was explored, Pure Data became the obvious choice of programming language due to its close relation to Max, though the Bela system is programmable in multiple languages.

The FLAPIBox’ software consists of an infrastructure consisting of a pd-object[14] that initializes the hardware connected to the GPIO-pins. The object also holds commands for communicating with the OLED-screen. In addition, a C++ program, running in the background, is needed for setting up the screen. For the latest FLAPIBox version, the example found at the Bela website is suitable, but a customized program will be made at a later stage.

Furthermore, the FLAPIBox software contains a library of different modules for generating and processing sound. The development of these modules is connected to composing music pieces and even though they are intended to fit a piece-specific task, the modules are always designed with reusability in mind. All software developed for the FLAPIBox will be made available in the project repository continuously.

[13] https://github.com/erikstifjell/sovnen
[14] flapiinfra.pd

4. DISCUSSION

The development of the FLAPIBox has through four earlier prototypes, led to a version that appears technically stable and is a good starting point for further exploration of the dialogue between acoustic and electronic sound in compositions. The choice of Bela Mini computer and XH-M190 amplifier has led to a simplified technical setup, and at the same time opened up more expansion possibilities, which fits well with the intention of developing the FLAPIBox: A flexible, cross-intrumental instrument augmentation platform that is programmable and *“provides a good, alternative way to diffuse acoustic and electronic sound”* [2] The FLAPIBox is comparable to other hybrid projects between SRIs and augmented instruments such as The HyPer(sonal) Piano Project [10], HypeSax [3], WYPYM [11] or WindBack [8]. Although these projects have microphones and loudspeakers integrated, they depend on an external computer and are instrument specific, making the FLAPIBox one project among few that has cross-intrumental properties.

The 2024-version of the FLAPIBox has shown that it is possible to develop a fully integrated unit that can run on batteries. Technically, there are some limitations that need to be addressed. Sensor data mapping has not yet been considered. However, there are available both analogue and digital GPIO-pins making it easy to add sensor connectors on the current design. Another issue is whether the analog potentiometers [adc~ 3-6] should be replaced with digital encoders. Analog potentiometers’ value is fixed to the position of the potentiometer, making it challenging to use the potentiometers for controlling different parameters in the software. One advantage of using digital encoders is that the value is not determined by the position of the encoder, but is stored within the program, making it easy for the encoders to control several parameters. One disadvantage is that a digital encoder requires 2 GPIO-pins each. For the current version of the FLAPIBox 4 encoders will need half of the 16 digital pins available. It will however, free up 4 analog pins, leaving all 8 available for sensors.

4.1 “Søvnen – for bass flute and electronics”

The main reason for developing the FLAPIBox has always been related to the author's own music. The aim for composing “Søvnen” was to investigate whether it was possible to establish a dialogue between the bass flute and sine waves inside the instrument and simultaneously create an ambiguity about what or who produces the sound. To achieve this, the FluteFootSpeaker was developed.

The material for the composition comes from a recording of the folk tune “Når søvnen falder mit øie på”, performed by Malin Alander. The recording has been time stretched approximately 1000% before converted into midi notes. The result made the starting point for a selection of pitches that form the composition. This selection has been divided between the bass flute and the sine waves.

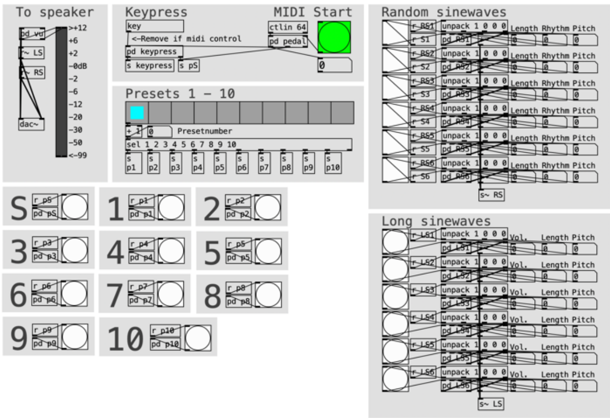

Figure 6. Pure Data patch for "Søvnen", Laptop version.

The software is written in Pure Data and consist of different modules (Figure 6) that make up the electronic part of the piece. The first version was developed on a laptop computer[15] and has later been converted for the FLAPIBox. The main purpose of the software is to play sinewaves of different length and pitches. A control module handles either keypresses from a button or a MIDI pedal (or computer keyboard). Furthermore, the module controls 11 chronological presets consisting of up to 6 layers of long sinewaves and/or up to 6 layers of randomized pulses of short sinewaves. Parameters such as duration, pitches, delay times and density are stored within each preset.

The result is a tranquil piece with slightly static harmonies, due to the root pedal mostly being present. Abrupt rhythmical structures following the harmonic series, circling ambiguously around its partials and neighboring semitones. Sometimes chords appear, sometimes complex rhythmical structures. All sounds are projected from the inside of the bass flute, yet the performer is not always playing. A successful dialogue between the flute and the sinevawes, man and machine.

4.2 "MHRD /LDVK – for brass trio and electronics"

Trumpet, Trombone and Euphonium with PiezoBarrel mouthpieces and hand-held loudspeakers connected to a FLAPIBox each, three in total, make up the technical setup for this work-in-progress composition. Each of the FLAPIBoxes play back sound files consisting of layers of sine wave glissandi. More layers are added by playing the brass instruments. The sound picked up by the PiezoBarrels are slightly processed, adding more layers with different textures. The piece is a further study of the dialogue between instrument and electronic, but with more voices, creating a more complex polyphony. It is also a further study of the possibilities the FLAPIBox offers.

5. FUTURE WORK

Although the technical setup of the FLAPIBox is reliable it is worth investigating whether it will be beneficial to replace the analog potentiometers with digital encoders. It is also desirable to consider both digital and analog inputs for connecting foot pedals such as volume control and on/off switches. Since these are routed to a GPIO-pins, they will also be programmable for various sensor inputs.

Furthermore, peripherals suitable for woodwind instruments should be explored. There are several versions of loudspeakers positioned in the bell of saxophones or bass clarinets: Lupone [8], Panariello/Percivati [11] suggesting an inward projecting loudspeaker, while Flores [3] suggests an outward projecting loudspeaker. For brass instruments, van Eck presents the idea of a loudspeaker in place of a mute [8, p124] that can be a good starting point for developing a speaker mute. This can also be envisioned as one unit combined with the BrassBellMic, similar to future developments of Un-Mute [3], but without the built-in amplifier. IntraMic[16] for clarinets and saxophones and Barcus Berry 6100 Electret Flute Microphone are also worth testing with the FLAPIBox.

Going forward, the focus should be on the software side. With a reliable, technical platform, it is believable that others might contribute to developing software. For the author's part, Further development is driven by the creative process of composing new pieces. Two compositions are already planned for the current version of the FLAPIBox: A piece for acoustic piano, exploring the Helpinstill pick-up system and up to two sound shakers and a piece for euphonium with PiezoBarrel and two remote euphoniums with mouthpiece speakers. Furthermore, exploration of the feedback possibilities with the FLAPIBox and brass instruments would be interesting.

6. CONCLUSIONS

The 2024-version of the FLAPIBox provides a flexible platform for augmenting acoustic instruments. It shows cross-instrumental capabilities and can administer a wide range of peripherals. The knowledge gained from the development has led to compositions utilizing the FLAPIBox and both customized and off-the-shelf peripherals. This paper demonstrates novel approaches to both instrument augmentation and diffusing electronic and acoustic sound components in music.

Acknowledgments

The author would like to thank Geir Davidsen for contributions regarding the development of the FluteFootSpeaker, Malin Alander for sharing her version of the folk tune "Når søvnen falder mit øie på" and her beautiful recording of the song, which is the starting point for "Søvnen – for bass flute and electronics". Also, many thanks to Lars Asbjørnsen for commissioning the same piece, for good conversations and contributions to the composition process, and for the wonderful performances of the piece.

[15] When performing the laptop version, a stand-alone XH-M190 amplifier is connected to the computer and FluteFootSpeaker.

[16] https://www.horn-fx.com/intramic-article

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