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ORIGINAL PAPER

Sonophenology

A multimodal tangible interface for the sonification of phenological data at multiple time-scales

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Abstract The study of periodic biological processes, such as when plants flower and birds arrive in the spring is known as Phenology. In recent years this field has gained interest from the scientific community because of the applicability of this data to the study of climate change and other ecological processes. In this paper we propose the use of tangible interfaces for interactive sonification with a specific example of a multimodal tangible interface consisting of a physical paper map and tracking of fiducial markers combined with a novel drawing interface. The designed interface enables one or more users to specify point queries with the map interface and to specify time queries with the drawing interface. This allows the user to explore both time and space while receiving immediate sonic feedback of their actions. This system can be used to study and explore the effects of climate change, both as tool to be used by scientists, and as a way to educate and involve members of the general public in a dynamic way in this research.

Keywords Sonification · Tangible interfaces · Geo-spatial data · Phenology

1 Introduction

The ancient science of phenology is the study of the annual timing of biological processes such as when a particular species of tree first flowers in the year, when birds return from their migrations, or when frogs first emerge after winter. The word phenology comes from the two Greek words for "to show or appear" (phaino) and "reasoning, or rational thought" (logos).

Phenological data has been collected and used since the dawn of agriculture and civilization in humans. From the timing of the flooding of the Nile [1] to the best times to harvest maize, people have collected this data and have used it to determine timing strategies for planting as well as to keep track of medium to long term climatic changes. In the example of farming, not only the timing of biological processes but also the dependence of timing on specific geographic locations are of prime importance.

A new type of interface metaphor in the field of Human-Computer Interactions (HCI) is that of tangible interfaces. In these interfaces, users not only interact with the screen and keyboard as usual, but also interact with physical objects in the real world. Types of devices commonly used for tangible computing include cameras, sensors, motors, actuators and displays. These interfaces help to merge the real and virtual worlds into a single, unified user interface [2].

We describe a system that sonifies phenological data and allows users to explore these datasets using a tangible interface. The system we propose could be used with both historical phenological data and also with the large quantities of crowdsourced phenological data that is just now becoming available. There are several aspects of the field of phenology that make it a particularly interesting candidate for control through a tangible interface and sonification. One of these is that phenology studies changes over time and music can be thought of as sounds organized in time [15], the interrelation and mappings between data and time in the problem domain and the music domain.

Ideally a system for exploring phenology data should allow the specification of both spatial and time range queries in addition to simple point queries (e.g. render the data from Tokyo and Osaka between 1985–1990). We describe a mul-

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timodal tangible interface with fiducial markers on a map that are used to specify point queries and a tangible drawing interface to specify time queries. Of particular interest is the relative timing of different events such as the flowering that happens earlier in the South than the North. Synchronicity and relative timing are clearly conveyed in our sonification.

This paper extends the work presented [18] by Ness, et al. by making the display to be more multi-modal, with both a map-based fiducial interface as well as a drawable resistive sensitive interface. Multi-modal interfaces have a number of advantages over unimodal interfaces, including a flexible use of input modes to best suit the task at hand, allowing diverse user groups with different abilities to use an interface, and having the flexibility to adapt to the continuously changing conditions of mobile use [19]. In our particular case one important advantage of using a multimodal interface is that our device is designed to be used in a teaching setting or as a public art installation, and by having a combination of the fiducial based interface with the graphite interface, participants can be more engaged with the topic of climate change.

2 Related work

A related paper is "The Climate Symphony", [21] in which a system is described that is a combination of sonification and a narrative structure. In this artistic presentation, 200,000 years of ice core data is sonified by taking eight sets of time series data of the relative concentrations of a number of ions and reducing them to three dimensions using Principal Component Analysis. These time series data were sonified with simple sine waves which were then amplitude modulated by the amount of the ice sheet's coverage. This design exploits the natural ability of humans to hear periodic structure in audio signals, and demonstrates that this type of data is amenable to sonification. Another important contribution of this paper that is of direct relevance to our work is that it attempts to create a system that will engage members of the general public by providing an interesting and pleasant way to explore climate data.

Also related is the paper "Sonification of Daily Weather Records" [8], in which the authors describe a system that sonifies the weather data from Lincoln, Nebraska. In this paper, the authors choose three different parameters to sonify, temperature, rainfall and snowfall. For the temperature, they take daily high and low temperature measurements and convert these to MIDI notes. Because of the sizable difference between the high and low notes, this produces a sonification with two independent melodic lines, which humans are able to independently track as separate streams, as previous research by Bregman has shown [3]. The maximum number of streams that are perceivable by a human depends on a number of different factors, including frequency, timbre and localization, but is quite low, with three streams mentioned as being sometimes difficult to resolve [3].

Another related area of work is the use of sonification as well as other modalities for the exploration of geoscientific data [10]. For example a multi-sensory system that combines 3D graphics, haptics and sound for highway location planning has been presented [11]. The use of sonification for georeferenced data is particularly important in the case of users with visual impairements [26].

In the majority of existing system for sonifying scientific data the result of the sonification process is a monolithic audio signal and the amount of influence users have in the sonification process is minimal or non-existent. In contrast in our system we have tried to make the sonification process an interactive, exploratory experience. Our design has been informed by several different research topics: phenology [16], tangible interfaces [12], and interactive sonification [25]. In the following section we describe these different topics and show how they relate to our work. The resulting system which we call Sonophenology integrates these different influences in a coherent whole.

3 Background and motivation

3.1 Phenology

Recently, phenological data has been used in a number of research projects in climate change [13, 17, 20, 24]. In these studies, a general conclusion has been reached that changes in local and global temperature affect the timings of phenological processes, and that these processes are precise measures of climate change. Currently these results are typically compared using either statistical measures, such as the ANOVA (Analysis of Variance) tests such as in Doi [5] or using visual representations of this data such as graphs that show histograms of the timing of various events across years.

3.2 Tangible interfaces

A fiducial marker detector uses a camera system and a set of fixed tags that contain a variety of different iconographies that typically look like a grid of dots. The colour, geometry and topology [4] of the placement of these dots are designed to be uniquely identifiable [6]. There are many advantages to the use of fiducial tracking systems, including a direct-manipulation modality, multiple dimensions per fiducial marker and the ability to quickly and cheaply print new markers using an ordinary printer. An excellent collaborative benefit of this system is that markers can be positioned by a separate person, or by teams of people.

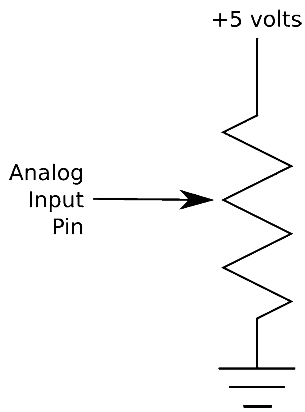

Fig. 1 A circuit diagram of the graphite resistive sensor. The *resistor symbol* in the *circuit* represents the area of graphite that is drawn on the piece of paper

Another type of tangible interfaces that has gained some popularity among artists are drawable interfaces that exploit the fact that graphite is a partially conductive material. Graphite is a common medium used by artists, both in the form of raw charcoal and compressed into pencils. Because graphite is an imperfect conductor of electricity, a circuit containing a longer path of graphite will have more resistance than a shorter one. The resulting circuit is about as simple as can be imagined, consisting only of a variable resistor, which is the graphite strip, an Analog to Digital (A/D) converter, a power source, and the wires that connect these items. This circuit is shown in Fig. 1. In this type of drawable interface, an electrode is attached to a section of graphite drawn on paper, which is then attached to an Analog/Digital converter. To complete the circuit, another electrode is placed on a piece of graphite, and the resistance of the circuit is converted into digital form. These graphite based interfaces are quite new and most of the applications of this have been primarily focused on artistic expression and exploration. One of the most well documented of these is Drawdio,[1] a system in which users can create musical instruments using graphite drawn on paper, or indeed any partially conductive surface. We look forward to more scientific explorations of such resistive based interfaces in the future.

3.3 Sonification

Sonification can be described as the use of audio to convey information. In other words, scientific data is represented not as a visualization, like a graph, but instead as a collection of sounds that are played at different times.

The manner in which a given set of data is mapped to audio is a challenging problem, there are an infinite number of ways to transform data into a sonification [7]. Many aspects of any sound can be modified: we can perceive changes in amplitude, pitch, timbre, directional, and temporal information. Any of these auditory aspects, or audio parameters, can be modified by a data set. The best choice when selecting audio varies, depending on the content of a given set of data. The direction, or polarity, of the datasets that are being compared can also affect the perception of a sonification. For example, temperature is often described aurally as a tone with changing pitch [22]. The scale of the relationship between a one-dimensional data set and the audio parameter modified by that data must also be considered. If we consider the temperature to pitch example, we must consider how quickly will the pitch increase, and whether the relationship will be linear or non-linear [23], that is to say, one wants to preserve the ratios, not the differences in frequency. The presence of interesting trends, for example discontinuities, can often be clearly identified in sonifications of data. The aesthetics of sonification are also an important consideration. The goal is to create a collection of sounds that represents a dataset accurately, logically and clearly and is also pleasing to listen to.

4 System description

4.1 Overview

Our system consists of a number of separate sub-components that interact together to provide a tangible interface for the exploration of geo-spatial phenological data. The overall organization of this system can be seen in Fig. 2.

The phenological data sources that we obtained for this paper are quite diverse, and contain various types of information that could be used for sonification. In this application, we constrained our analysis to include only the species name, the latitude and longitude of the observation and the date when this observation was taken. Other data that we are not using for this paper include the type of observation, for example whether the observations of the first bloom or when they were in full bloom. Many of the observations also include comments from the observers. These additional sources of data could be used in the future to enhance the sonification and visualization in our interface. Our GIS-enabled database system can be extended to accommodate these additional data sources.

The second section of our system is the fiducial tracking interface. This uses a consumer grade webcam and tracks pre-printed fiducial markers on a surface. We also use fiducial markers to determine the position and orientation of the physical map underneath the fiducial markers. We then create a mapping from the set of coordinates of the fiducial markers to the physical latitude and longitude on the map. When the user places fiducial markers on the map, this system then takes the latitude and longitude of these points and queries the database to obtain corresponding phenological data points.

[1] http://drawdio.com/.

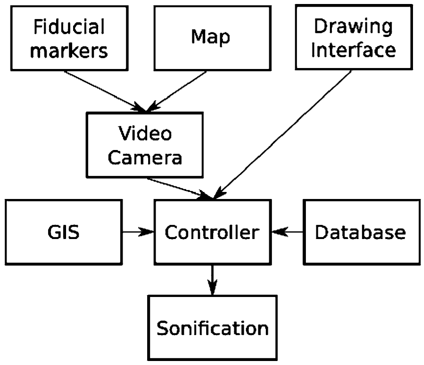

Fig. 2 A flowchart of the system organization of our system. This system has at its core a Controller module that communicates with the phenology and GIS databases as well as the video camera and sonification engine. It generates sonifications by tracking the positions of fiducials on a printed paper map

The third part of our system is a drawing based interface that uses the conductivity of graphite to allow users to select a specific date range. In our system we use two different regions of graphite that has been applied to a heavy stock type of paper, one region for the beginning date and one region for the end date. The conductivity information is digitized by the Make Controller single board system and are sent to the controller program using the Open Sound Control (OSC) protocol.

The final step in this system then involves taking these phenological data points, which include latitude, longitude, species and observation date, and sonifying them.

4.2 Phenology—Japan lilac

In order to describe the system we focus on a set of observations of the flowering of the common purple lilac *Syringa vulgaris* in Japan [9]. Observations on the flowering of this species were collected from 1996 until 2009. Because of the large difference in latitudes between the south and north of Japan, flowers bloom earlier in regions in the south of Japan before they do in the north of Japan. These types of geographical differences are one source in the variation of flowering times. Another difference that may be possible to observe is the effects of climate change on the flowering times of these lilacs, however to truly see effects of climate change, one must of course examine temperature records over longer time spans, on time spans of centuries to millenia. If average temperatures increase over a period of years, one would expect that the phenological processes that respond to temperature would tend to move to earlier times in the year.

4.3 Tangible interface

While it would be possible to develop a simple desktop or web-based interface to explore a sonification of this data, a much more intuitive and engaging interface could be a tangible interface, where users interact with a physical interface. We have chosen a fiducial based tag tracking system previously used in the reacTable [14]. A picture of this system is shown in Fig. 3, with the resistive interface shown in Fig. 4. A detailed picture of the map is shown in Fig. 5.

Fig. 3 Shown above is a picture of the fiducial tracking interface. Above the computer monitor is a small consumer grade video camera, which is pointed downwards in order to view the fiducial markers which are placed on a printed paper map

This interface is inexpensive and easy to deploy, requiring only a consumer-grade webcam, physical printed map and printed fiducial tags, and could be easily deployed within a classroom setting. With such a system in a classroom, a teacher could teach students not just about phenology, climate change and maps, but also about new systems for physical interaction with computers. By moving markers across the map, the students experience a direct correlation with the location of the marker on the map and the associated phenological data. Because of its physicality and interactivity, this is a system that even young children could use to interactively engage in climate study, something that otherwise might be too abstract.

In the previously described version of this interface [18], we used the rotation of the fiducial markers to specify a date range to be sonified. We found that this interface was

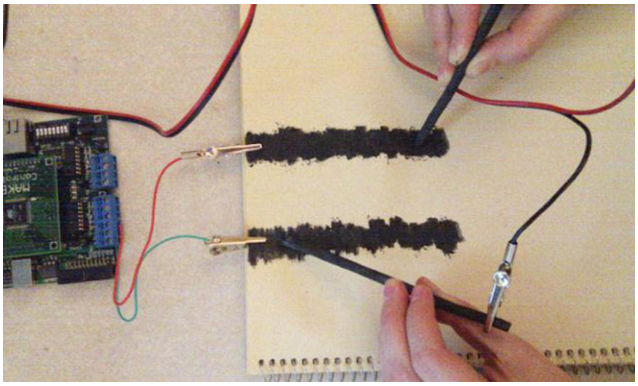

Fig. 4 Our tangible drawing interface is shown in this figure. On the sheet of paper two regions of graphite have been drawn. These are hooked up to the analog input ports on the Make Controller shown here. Hooked to the positive voltage terminal are two artists charcoals which complete the resistive sensing circuit

quite non-intuitive for most users. In our current work, we have replaced this method for selecting date ranges with a drawing interface based on the conductivity of graphite pencils. In this interface, a piece of paper is used, and using graphite pencils, two regions are drawn on this piece of paper. We then take these two circuits and connect them to a device capable of converting this analog signal into a digital signal, in our case we use the popular Make Controller, which is a small, general purpose controller device. The Make Controller has the added advantage that it natively outputs data using the Open Sound Control (OSC) protocol. We map one of these regions to the beginning date to be sonified and the other region to the end date to be sonified. We have found the entire interface works best with two or more users, one to select the date range, and one or more to select the range of dates to be sonified. We have found this type of multi-user interface works well when applied in educational contexts, and encourages groups of students to work together to explore and interact with this data.

4.4 Sonifications

There are a number of advantages to sonifying these phenological data over using statistical tools and visual graphs. One advantage is that by using different timbres to represent the different sections of the map that we are sonifying, we take advantage of the fact that humans can distinguish different melodic streams that are rendered in parallel by different timbres. This could potentially allow a user to follow many different lines of data at once. This technique becomes even more powerful because of the distributed geographical and temporal nature of the phenological data, where flowers in the south bloom earlier than flowers in the north. These different melodic lines start and swell at different times, and the combination of different timbres with different start times of

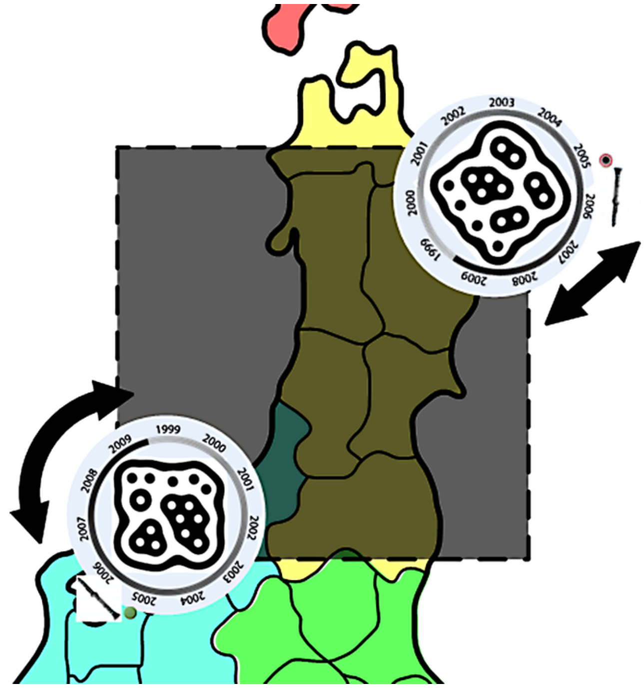

Fig. 5 Moving a fiducial will sonify data that is represented by map locations under that particular fiducial marker. These fiducial markers and the map itself are printed out on heavy stock paper in an ordinary printer

these timbres make it even simpler for users to follow the progression of phenological events.

Our primary sonification metaphor is that of a step sequencer, which uses a fixed two-dimensional grid consisting of quantized steps, with the horizontal axis representing time and different steps on the vertical axis being different instruments, or different pitches of one instrument. In our system, the vertical, or pitch axis, corresponds to different years, and the horizontal, or time axis, corresponds to the timing of the phenological event in days since the start of the year. This system allows us to easily hear and compare changes in the timings of different events over years by listening to the organization of pitches. If a phenological event occurs on the same date each year, one would hear a chord of all the notes at the same time. If on the other hand, the date of a phenological event becomes earlier each year, one would hear a descending arpeggio of notes. A graphical view of three observation locations over a time period of 10 years is shown in Fig. 6.

The comparison of phenomena over various years is an essential part of this system, as one a primary motivation of this project is to provide a way for people to not just see but also hear and explore the effects of climate change. These different modalities of experience might prove effective in educating people about phenology and climate change.

Another mapping that we are exploring is to instead represent each phenological observation as a distinct sonic

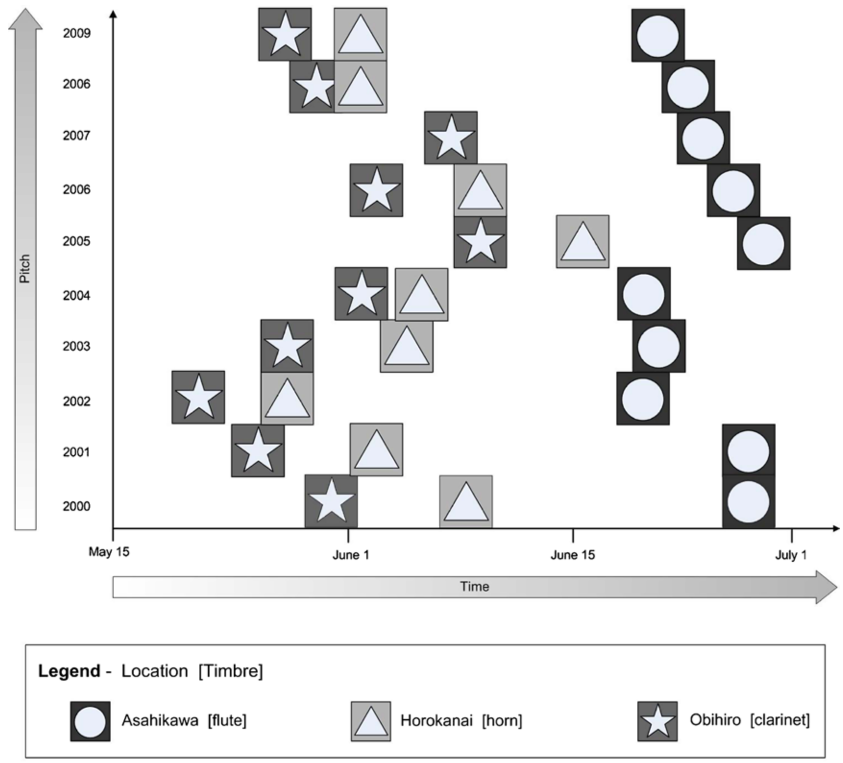

Fig. 6 A graphical representation of 10 years of flowering data for the common lilac in three locations in Japan. The three different locations are depicted by different shapes, *a circle*, *a triangle* and *a star*. From this diagram, one can see that there are certain years (2002–2004) in which flowering occurred earlier than in other years

event. This type of sonification produces a radically different soundscape which is more textural and ambient. One can imagine what this sonification sounds like by thinking of the timing of blooming of plants in the spring. One will often see one or two different plants of a species flower, then as time goes on more plants will flower in almost an exponential fashion until all the plants of the species have flowered. If one were to sonify each of these events as an impulse sound, then the sonification of this data would sound something like the popping of popcorn. What is interesting in this method is that it allows us to perceive the "stochastic" nature of the natural process, where each event is not significant unto itself, but the aggregate events outline a process that can be reflected in an auditory soundscape that reveals subtle differences in the rate of change of a physical system. Our ears are very sensitive to subtle differences in stochastic signals like colored (or filtered) noise changing its spectral characteristics over time.

5 Conclusions

In this paper we have presented a system that takes geospatial phenology data and allows users to interact with it using a tangible interaction metaphor. The dataset of the flowering dates of Japanese lilacs was a useful dataset to explore with this system as it contained data points of flowering dates that occurred at different times and in different locations from the northernmost to the southernmost areas in Japan.

We have explored this dataset with our system. We have observed a number of interesting properties of the data and of the system. One interesting observation about this data is that in certain years the flowering of trees occurs earlier, and in some years they occur later. This is clearly heard in the sonification of this dataset because in these years, the note that is played for the different instruments is the same, and is repeated earlier in the cycle than those notes from other years. Another observation is that for the data points that occur earlier in later years, a descending arpeggio is indeed heard.

With the inclusion of the tangible interaction interface, this system is quite approachable for members of the general public, and in the few number of interactions that these individuals have had with our system, they find it both interesting and easy to use. We are currently considering doing user studies with this system, with the goal of building a system to help educate students and the public about climate change with an engaging interface.

In the current version of the interface, the length of the musical phrase that is played is of constant length. If the amount of data points that have been chosen by the user is low, then the sound will have a broken up character, with notes interspersed with silence. We are currently designing and implementing an interface that will allow the user to change the amount of time that the musical phrase plays for, and if the quality of the sound is too broken up, this time can be shortened, which makes the musical phrase more connected. The length of time that individual notes play will also be adjustable by the user and by automatic scaling algorithms in the software.

We also plan to deploy and test this interface in a variety of settings, including in a school setting with students of various ages, and we are interested in how easy the different age groups would find the different multi-modal parts of the interface. We anticipate that younger children will find the graphite interface engaging because of its tactile nature, and that older students would find the fiducial map interface more interesting because of it's correlations with augmented reality, a concept that is becoming popularized with such devices as the Nintendo 3DS. We also wish to create a public art installation, either in an art gallery or in a more educational setting, and observe how members of the public use this interface, and if this interface is indeed more engaging than a traditional mouse and keyboard system.

This system can also be used for other phenology datasets, and as websites such as the National Phenology Network and Nature's Calendar start releasing their crowd-sourced data, we anticipate that there will be a huge amount of phenological data that would be interesting to sonify. In addition, this system could also be used with other geo-spatial datasets, for example, one could develop an interface to allow scientists to sonify the amount and type of ground cover as determined by satellite images.

We have made a website[2] that presents visualizations and sonifications of the data used in this paper, along with videos showing the system in action.

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[2] http://sonophenology.sness.net.